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Sustainable Development, Strategy & Substitution: Lessons from a Study of the Process of Eliminating DDT from the Economy

par

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Abstract

How does one product come to substitute for another? What is the process by which one product supplants another in performing a particular function in the economy? These are the questions addressed here. Specifically, this dissertation contends that the way substitution has been conceptualized and investigated to date in the discipline of strategy is incomplete. It is especially inadequate for providing guidance to managers of firms, NGOs and government departments trying to cope with unfortunately increasingly common phenomena of substitution events triggered by environmental and health concerns. Unsatisfied with the literature's preoccupation with objectivist assumptions about information and a focus on the material realm of competing technological artifacts, this research explores the possibility that evaluation and measurement of products' relative performance is subject to historically contingent processes of social construction and negotiation in the realm of ideas. Research efforts have therefore investigated a set of actors wider than that at the level of analysis of industry, opting for analysis at the level of interorganizational domain. Findings of a single exploratory case study aimed at theory building are presented; the fascinating story of dichlorodiphenyltrichloroethane (DDT) is told, focusing on its entry into and exit from the United States economy. Because DDT was substituted for at different times through different processes in different markets, the single case study yields multiple units of analysis.

This dissertation identifies and describes three ideal types of substitution for which both inductively-derived empirical evidence and deductively-derived theoretical support is offered. It concludes that a comprehensive model of substitution includes three distinct processes: artifact-making (or "tool-making") in the material realm, as well as fact-making and rule-making in the realm of ideas, with a common theme of contestation linking all three. So whereas substitution has to date been viewed mostly in terms of struggle in the marketplace, this dissertation concludes that it is better viewed as three parallel, simultaneous, and entangled processes: struggles over "Efficiency", struggles over "Truth", and struggles over "Justice".

Résumé

De quelle façon un produit vient à substituer un autre produit? Quel est le processus par lequel un produit supplante un autre et arrive à jouer un rôle, voire une fonction, dans l'économie? Voici les questions que nous soulevons ici. Plus spécifiquement, la présente thèse propose que la façon que la substitution a été conceptualisée et investiguée jusqu'à maintenant dans la discipline de la stratégie demeure incomplète. Les connaissances actuelles sont particulièrement insuffisantes pour guider les gestionnaires d'entreprises, ceux des ONG, ainsi que ceux des départements gouvernementaux de plus en plus préoccupés par le phénomène regrettable de la substitution liée aux problèmes environnementaux et/ou de santé. L'emphase trop souvent mise dans les écrits de la littérature sur des conceptualisations objectivistes de l'information et sur des objets physiques limite l'utilité de ces écrits. La présente étude de cas a pour but d'explorer l'hypothèse suivante : les évaluations et les mesures de la performance des produits concurrents sont sujets au processus de la construction sociale, et par le fait même ils sont sujectifs et situés historiquement. Pour ce faire, nous avons réalisé une étude de cas exploratoire ayant servi à bâtir la théorie, dont les résultats sont présentés ici. Nous avons investigé un ensemble plus grand d'acteurs que celui suggéré par le concept de « l'industrie »; nous avons documenté et étudié l'ensemble des acteurs du « domaine interorganisationel ». La présente thèse raconte l'histoire fascinante du dichlorodiphenyltrichloroethane (DDT). Elle se concentre plus particulièrement sur la façon que ce produit est entré dans l'économie aux États-Unis et sur la façon que ce produit a par la suite quitté cette économie. Dans différents marchés, le DDT a été substitué par des produits différents et à travers des processus différents. Ces substitutions multiples, mises en lumière par l'étude de cas unique du DDT, nous a donc permis de révéler plusieurs unités d'analyse.

Cette thèse identifie et décrit trois types de substitutions, dites « idéales », qui sont supportés par deux types d'argumentation: inductive et déductive. En guise de conclusion, nous suggérons qu'un modèle compréhensif du processus de substitution doit inclure les trois sous-processus suivants : la construction des nouveaux « outils » (voire « produits ») dans le monde physique, la construction des nouveaux « faits » dans le monde des idées, ainsi que la construction de nouvelles « règles » dans le monde des idées. Jusqu'à ce jour, la littérature a conceptualisé le processus de substitution comme un concours ou comme une lutte dans des marchés. La présente thèse conclut que le processus de substitution se conceptualise davantage comme trois « luttes » simultanées et difficiles à isoler les unes des autres : les luttes pour « l'Éfficacité », les luttes pour « la Vérité » et les luttes pour « la Justice ».

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And although all have contributed to the journey leading to this dissertation, I alone am responsible for its contents, particularly errors and omissions.

INTRODUCTION

This is not a typical thesis for the discipline of strategic management because it is, in many ways, a biography. But it is not the biography of a celebrated CEO or charismatic leader. Rather, it is the biography of a *molecule*: 1,1,1-trichloro-2,2-bis(4-chlorophenyl)ethane, or DDT. This thesis documents the rise and fall of this celebrated and controversial synthetic organic chemical.

Measured in terms of the public's attention, the insecticide DDT is perhaps the most famous chemical product ever manufactured. It emerged from World War Two as a war hero, credited with saving the lives of literally millions of people - a symbol of the marvel and promise of technological progress in modern economies. Yet less than twenty years later, it was condemned as a dangerous and deadly poison. Then too it served as symbol, becoming an omnipresent reminder of all that could go wrong when the full consequences of new technologies finally came to light.

To this day, DDT still arouses passions. Recent efforts by the United Nations Environment Program to coordinate the negotiation of an "International Legally Binding Instrument for Implementing International Action on Certain Persistent Organic Pollutants" have once again put DDT at center stage. Many readers will be surprised to hear that this substance is still in use in a number of countries around the world, and still receives the official support of scientists, governments, and intergovernmental organizations in its use against mosquito populations within malaria control programs. But many other scientists, governments, inter- and non-governmental organizations remain convinced that DDT is neither *safe* nor *necessary*, and that growing problems of insect resistance are evidence that it may not even be *effective* in its primary function as an insect control technology. Meetings, research and negotiations continue. So although the final chapter of this dissertation has been (finally!) completed, that of the full biography of DDT remains to be written.

The fate of this infamous molecule is, however, sealed in the United States as well as in other developed economies. In 1972, DDT became the first of its class of insecticides - the chlorinated hydrocarbons or "organochlorines", which had entered the economy just subsequent to WWII - to exit the U.S. economy as the result of a national ban imposed by the United States Environmental Protection Agency. Subsequently, other organochlorine substances, like aldrin, chlordane, dieldrin, endrin, heptachlor, hexachlorocyclohexane, mirex, and toxaphene followed, their registrations for various uses forcibly "cancelled" by authorities or "voluntarily withdrawn" by their manufacturers.

One reads biographies for many reasons. Well done, they capture, illuminate and perhaps offer insights into the complexities of events in subjects' - and readers' - worlds. The story of an individual is simultaneously the story of their times and of the places and peoples that they found themselves amidst: of triumph and tragedy, of conflict and coexistence, of questions asked and answers offered, of unshakable certainties and unyielding mysteries. This is also the case with our focal molecule, DDT.

Indeed, the richness of the tale of DDT leaves a humbled biographer a wealth of possibilities. Delimiting the boundaries of this fascinating story quickly brings a researcher to the reality of tragic choice, of promising paths not taken. Perhaps I will be forgiven, at least partially, for the unreasonably length of time it took me to prepare this document once readers get some sense of all the interesting places - in time, space and concepts - that the research took me.

Following the story of DDT meant following DDT itself: from the beakers of industrial chemists to Allied trenches in WWII Europe; from greenfield chemical processing plants to green fields of cotton, corn and other crop plants in the United States; from the outflow of spraying equipment used by the Department of Agriculture in their insect eradication campaigns, to the inflow of residue measuring equipment used by the Department of the

Interior's Fish and Wildlife Service scientists who were finding DDT in birds, fish, and mammals.

The specific physical and chemical properties of DDT meant that it could - and can still - be found everywhere on Earth. Literally; you, the reader, have DDT in your body fat. Purity is gone. The discomforting conclusion motivating many environmentalists today - that the *natural* cannot escape the *synthetic* - was to a great extent made unavoidable by the molecule DDT and its properties.

Documenting the story of DDT meant documenting its accumulation in ecosystems around the globe, along with the parallel though lagging accumulation of knowledge of this pervasive contamination. DDT residues contaminated almost sacred places, from the body fat of bald eagles, symbolic of the United States' freedom and power and whose populations were threatened, to the body fat of penguins in Antarctica, a place which after DDT can no longer be symbolic of the pristine and untainted. Even mother's milk contained traces of DDT beginning in the 1950s. Today, processes of global "distillation" are occurring in which DDT used in southern climes is transported around the globe and deposited in the colder north, where scientists continue to monitor its accumulation in the species - and peoples - of the Arctic. The Vice President for Canada of the Inuit Circumpolar Conference laments a world where *"As we put our babies to our breasts, we feed them a noxious chemical cocktail that foreshadows neurological disorders, cancer, kidney failure, reproductive dysfunction, et cetera."* (Watt-Cloutier, 1998, p 24).

As molecules of DDT spread, so did talk of it: from the R&D laboratories of chemical companies to the Agricultural Experiment Stations at land grant universities; from the pages of scientific journals of entomology to those of wildlife biology, pharmacology and toxicology; from the Nobel Lecture given by the scientist awarded his prize for bringing DDT into the economy to the testimony of hundreds of witnesses at formal hearings into whether it should be banished from the economy forever; from town hall meetings around the U.S. where local citizens debated the merits of insect spraying programs to senate meetings on Capitol Hill, in Washington, where their representatives debated similar issues on a wider scale. Through each of the numerous texts - the cold, technical jargon of scientific papers, the inspiring prose of Rachel Carson, the characteristic legalist language of regulatory statutes - the nature(s) and meaning(s) of DDT are revealed.

This fascinating story of one synthetic chemical is simultaneously the story of great individuals: Nobel prize-winning scientists played central roles, and other important actors have come to take on almost mythical status, like Rachel Carson, the celebrated author of *Silent Spring*. The story of DDT is in many ways the story of the environmental movement itself. New nongovernmental organizations like the Environmental Defense Fund and government agencies like the Environmental Protection Agency were brought into the world at least partly because of this molecule and its properties, and these organizations continue to play important roles in the construction, discussion and resolution of environmental issues to this day.

I must say here a few words here about the perspective and path actually taken with this research, and, in particular, about the theme of *contestation* that has come to characterize the findings. Of course, with *substitution* as the focal phenomena under examination in this project, it was no surprise that concepts like contestation and competition would play a central role, but at the outset I had little idea that it would be necessary to expand the use of these notions beyond the arena of the marketplace. Over and over again, in my efforts to describe what was happening as the process of substitution of DDT played itself out, and to compress this description into a handful of useful concepts and insightful relationships between them, I found myself resorting to the language of *conflict* and *struggles for dominance*. Now this raises the question as to whether this was merely the projection of my own preoccupations onto the data or whether the data actually spoke, itself, in a language of war. Certainly I cannot claim an absence of interpretation during the pouring over of the data. In inductive, qualitative research, the researcher himself is an unavoidable instrument. But I do think that, after reading this dissertation and weighing the evidence presented, readers will agree that this phenomena of contestation was both the objectively observable reality as well as the subjectively experienced reality of many of the actors involved. Actors in the studied domain understood and recounted the events surrounding the history of DDT using the discourse of war.

Indeed, battles, fights and conflicts are everywhere in the data. This theme of conflict was difficult to miss even in background reading undertaken in preparation for the case study. Introductory texts on entomology and insect control routinely begin with a characterization of the history of the relationship of man with insects as an ongoing high stakes war. Agricultural chemicals are commonly referred to as, and understood to be, arms in an ongoing struggle, be it against insects which plundered fields for food or insects which served as vectors of transmission for serious and deadly diseases. In addition, modern synthetic insecticides have their roots in the events of WWII, where military priorities and considerations played a major role in their development and deployment. DDT emerged from WWII as a war hero, credited with stopping a typhus epidemic, while other commercially significant agricultural chemicals have lineage traceable to military R&D, chemical weapons, and even formally planned genocide.

But the tale of the rise and fall of DDT - its entry into, and exit from, the economy - is not merely one of Man-Insect struggles in the material world of bollworm-infested cotton fields, mosquito-filled jungles, and louse-ridden soldiers' barracks. Nor, less dramatically, is it a simple story of competing generations of technological artifacts rising to dominance in the marketplace based on their economic merits and relative performance. No, a complete biography of this molecule must also include a description of *struggles for dominance in the realm of ideas*. People involved in the identification and resolution of the environmental controversies surrounding DDT and other pesticides would, when describing the complex process of scientific debate and regulatory change in which they were engaged, regularly characterize what was happening in stark military terms: they had "enemies" as well as "allies" in what their fights over the *facts* about DDT as well as the *rules* to govern its use, both of which were contested.

So, whereas I began this research aimed at understanding our focal phenomena of substitution - the process by which new technological products replace incumbent products - with a clear focus on the physical realm of *action* and *artifacts*, I eventually found myself, in order to understand that process, also investigating the ideational or discursive realm of *talk*. In order to understand and track competition between rival products, I found it necessary to describe and track competition between rival *beliefs*. Was DDT safe and effective? Many believed it was, but many others held the exact opposite views. I also found it necessary to describe and track competition between rival *values* as well. Should the rights of citizens to a clean environment outweigh those of chemical companies and farmers to earn a living? Were dead robins found on people's lawns a fair exchange for warding off Dutch Elm disease on tree-lined suburban streets? Different actors valued these potentially conflicting rights differently.

In resolving these two sorts of questions, one *descriptive* and the other *normative*, actors engaged in discursive struggle. That is, they entered into the social arenas in which the fate of beliefs and values were decided. There, they made and promoted their claims, offering evidence, justification and reasons why their beliefs and values should prevail over competing ones. Through this process, certain beliefs became widespread and institutionalized until finally, in the absence of further contestation, they had become hardened into "facts". Similarly, the values, preferences and decision rules promoted by some actors became, through contestation and clashes with rival values, the "rules" as particular tradeoffs and preferences became institutionalized and applied in a widespread manner, informally as norms or formally as regulations.

And so from my study of the phenomena of substitution, of struggle for dominance in the marketplace, has come a description of three parallel, simultaneous and entangled processes: struggles over "Efficiency", struggles over "Truth", and struggles over "Justice".

SECTION I

Research Design

This Section presents the motivations behind this research as well as the methodology which guided it.

After pointing to the practical need for increasing our understanding of the study's focal phenomena, **substitution**, the organizational literature is reviewed and critiqued. Important concepts and conceptual tools are presented, with their advantages and disadvantages noted. Gaps in our theoretical understanding of substitution are identified and juxtaposed with promising lines of inquiry.

Finally, the research project around which this dissertation is based is presented, along with details of the methods employed.

1 Research Motivations and Framing

This Chapter describes what has motivated the research presented in this dissertation. The research questions have been posed in such a manner so as to give priority to gaining insights into *practical concerns* about current environmental problems, the resolution of which will have serious implications for technological evolution and hence strategists and managers in a number of industries. It was anticipated that a study aimed at answering the primary research question would also shed light on important *theoretical concerns* of researchers in the field of strategy, and these furnished basic concepts used to frame the research questions and to focus the study.

The Chapter begins first with a presentation of the practical concerns motivating this research, situating them within larger research contexts associated with **sustainable development** and **organizational strategy**. These are then connected by a conceptual bridge built around the notion of **substitution,** which is the focal phenomena investigated in the study. A literature review follows which presents and summarizes theorizing about this focal phenomena within the discipline of strategy, identifies its shortcomings, and suggests the avenues for investigation that oriented this research.

1.1 Practical Concerns Motivating the Research

1.1.1 Real and Pressing Concerns for All Citizens: The Economy Continues to Generate Environmental and Health Problems

There is little doubt that the world is experiencing an increase in the number, scope and scale of unintended and undesirable environmental problems (Brown et al, 1998; Goudie, 1991; MacNeill et al, 1991; Strong, 1988; WCED, 1987), nor that these environmental problems are increasingly being reflected in the concerns, attention and actions of social actors: citizens, scientists, firms, governments and non-governmental organizations (NGOs) (Weale, 1992; Cairncross, 1992; WCED, 1987). There is a growing consensus amongst business leader themselves that these problems present challenges that affect and will continue to affect industry in a major and even profound way (Schot & Fischer, 1993; Schmidheiny, 1992; Deloitte & Touche, 1991; WCED, 1987). In response to the growing myriad of environmental problems has emerged the general policy goal of "sustainable development".

We focus here on the chemical industry, where strategists and managers are convinced that achieving "sustainable development" will require significant change (Chemical Manufacturers Association, 1994; Canadian Chemical Producers Association, 1994; Magretta, 1997; Avial & Whitehead, 1993; Newall, 1990). The products of this particular sector of the economy are such that their production and consumption are frequently implicated in incidents of unintended and undesirable consequences in ecosystems and the human body. Indeed, examples abound.

DDT, PCBs, CFCs, tetra-ethyl lead, methyl bromide - what do each of these products have in common? Subsequent to being successfully inserted into various markets and achieving commercial success, they have come to be banned or severely restricted in many jurisdictions and removed from the web of goods and services that is the economy. From the chemical industry's perspective, the changes necessary to achieve sustainable development can indeed be significant. Recent history is full of examples of society "changing its mind" about the appropriateness of various chemical products, and subsequently "changing its behaviour" to accommodate the phase-out and absence of the product through processes of **substitution**. In 1994, the United Nations' *Consolidated List of Products Whose Consumption has been Banned, Severely Restricted or not Approved by Governments* contained almost 600 such molecules with agricultural, industrial or pharmaceutical value and has grown since (United Nations, 1994). The practical concerns motivating this research are real, and Table 1.1.1.1 - Practical Concerns Motivating the Research summarizes them.

Table 1.1.1.1 - Practical Concerns Motivating the Research

Unintended, Undesirable Consequences

Product	***Existing***	***New***
Existing	Same old, Same Old ...	New Alarm Bells ...
New	Repeating Our Mistakes?	Journey into the Unknown

Same Old, Same Old ...

Many recognized and unfortunately familiar problems of unintended consequences continue to pose difficult challenges for firms, governments and NGOs. Activists and scientists continue to link existing products with a diverse set of undesirable effects, like *cancer* and *resistance* among a long list of others such as birth defects, sterility, liver damage, ecosystem disruption, etc.

Cancer rates are on the rise in the developed world (IARC, 1999), and although there is much debate about its causes, activists and scientists are lobbying for more research into the role of synthetic chemicals in the environment (Steingraber, 1997). To date a large number of substances have been introduced only to be later removed from the marketplace due to their suspected oncogenicity (United Nations, 1994). Yet this process is far from, and may never be, complete. Many economically important agricultural and industrial chemicals remain the subject of controversy, ongoing research and potential withdrawal from individual jurisdictions. It is highly likely that we will witness even more exits from different countries' economies by suspected oncogens.

With respect to resistance, many claim that insects and bacteria are winning the arms race to which mankind has challenged them, as their ability to defy our current arsenal of pesticides and antibiotics is growing. The number of species of insects that are resistant to the insecticides used to control them is growing, threatening public health initiatives (spraying of mosquitoes to control malaria) as well as the economic viability of entire agricultural sectors in some regions (Ware, 1994; Kiss & Meerman, 1991; Pimental, 1987).

Table 1.1.1.1 (continued) - Practical Concerns Motivating the Research

New Alarm Bells ... Lesbianism in seagulls; female snails growing penises; alligators with shrunken and dysfunctional penises; declining human male sperm counts; rising rates of testicular cancer; and growing attention deficit disorder in children. Each of these may be a symptom of a new class of problem of unintended consequences being associated with exposure to synthetic chemicals in the environment known as *endocrine disruption*, wherein the hormonal activity of humans and animals goes awry due to exposure to very small amounts (in the parts per million range) of various substances. Rounded up and standing accused are some of the usual suspects like DDT and PCBs, but also included in the scientific police line-up are substances which to this date have been relatively uncontroversial and which currently play very important roles in the web of goods and services that is the economy, including: the herbicides 2,4-D, atrazine and alachlor, along with many other agricultural chemicals; plasticizing compounds known as phthalates which are found ubiquitously in items as diverse as footwear, carpet backing, nail polish, shower curtains, paints, and caulking; and surfactants known as alkyl phenol ethoxylates used in greases, lubricating oils and detergents (Colborn et al, 1997). Should removal of all or even some of these substances from the economy be judged necessary, the amount of systemic change required of the economy will be enormous. Research, lobbying, argumentation and debate continues.

Repeating Our Mistakes? Partly in response to a growing mistrust of widespread and intensive use of synthetic chemicals, many actors from the industry that brought the world DDT and other pesticides are currently investing heavily in new emerging biotechnologies, like Monsanto and DuPont for example. Transgenic crops (plants with manipulated genetic makeup) have been created which can tolerate very intensive applications of a particular herbicides manufactured, typically, by those with property rights to the transgenic seeds. The genes of bacteria which produce "natural" toxins that act on insects have been successfully spliced into the genetic strings of plants to yield new strains of crops which "naturally" produce these toxins. There is concern and criticism however that the widespread utilization of these innovations will only lead to another round of battles against familiar problems of unintended consequences. Take *resistance* for example, where it is feared that widespread and continued exposure of pests to so-called "natural" toxins will eventually mirror our experience with synthetic toxins, substituting one technological treadmill for another (Benson, Arax & Burstein, 1997).

Journey into the Unknown ...

In addition to known and reasonably understood problems, nobody knows nor can predict what other challenges the adoption of these innovations may hold for humanity. Some argue that we cannot worry about undefined and potentially nonexistent problems, yet others disagree. Indeed, it would be very surprising if the new emerging biotechnologies did *not* generate new types of surprises and unintended consequences. Cornucopian arguments by technological optimists can be turned on their head to support this claim.

Recently it has become fashionable to claim that we are ushering in the dawn of a new era of an explosion of new *opportunities* and *technologies* using combinatorial arguments, wherein new technologies are seen as seen as the *unanticipated but desirable* consequences of combinations of older technologies - "valuable wholes" assembled by combining old technologies acting as parts (Kauffman, 1995). But if such a deterministic process of technological evolution is indeed in operation and plays itself out, then as more and more combinations are experimented with by actors who are not omniscient, we would also expect that more and more *unanticipated* and *undesirable* consequences would also come into existence. Indeed, philosophers of science argue convincingly that as societies acquire, apply and implement more and more *knowledge* - introducing more and more objects into their material and conceptual worlds, artifacts in the former case and constructs in the latter - the number of possible linkages between all of these also increases. "*Thus we face the paradox that while our knowledge continues to grow exponentially, our relevant ignorance also does so, even more rapidly*" (Ravetz, 1986, p 423).

Already critics have raised concerns about possible new problems. A number of "latent" allergies may begin to produce symptoms and cause problems as the genetic origins of what constitute food are manipulated (Benson, Arax & Burstein, 1997). These do not exist today because, for example, people do not eat such things as a petunia, but they might be eating one of its genetically designed cousins in the future. Additionally, once released into ecosystems, humans' control over particular genes, genotypes and genetic evolution is weak at best, giving rise to the possibility of the appearance of "super-weeds" or "super-diseases". This is because the desirable properties of toughness against insects and herbicides that have been designed into certain crops through genetic engineering may spread to weed species through hybridizing. Or the "crop" may become a "weed", invading and overwhelming ecosystems other than the agro-ecosystem for which it was designed (Rissler & Mellon, 1996).

The chemical industry has been one of the most innovative sectors of the economy during this past century. Currently there are over 70,000 traded substances in economies - and therefore also in ecosystems - around the world (WCED, 1987). Given the prevailing technological optimism and ecological ignorance of earlier this century, as well as the novel challenge that these substances posed for institutions at the time of their introduction, it is highly likely that the groundwork for a number of latent "surprises" has already been prepared and that society will be forced to deal with even more problems of unintended and undesirable consequences in the future. More recently, corporations from this innovative industry have turned their attention to biotechnology. Firms formerly known as "chemical" companies and who had built competences in the science of "death" (insecti*cides*, herb*icides*, fung*icides*, etc.), like Monsanto, Novartis and DuPont, are fast transforming themselves into "life sciences" companies and in the process building a new sector. New product technologies are being brought to market in the midst of debates filled with discourse, both promotional and oppositional, that echoes - eerily - that heard earlier this century when synthetic organic chemicals, many of which would ultimately be banned, were introduced. Inevitably, more and new problems of unintended and undesirable consequences will indeed be encountered as a result of these new technologies, and some will come to be removed from the economy.

Hence, an understanding of how economies react to the surprises of unintended and undesirable consequences of products is an important practical concern. Achieving a better understanding of our focal phenomena of substitution is of much practical significance.

1.1.2 Real and Pressing Concerns for Strategists: Environmental and Health Problems Affect Organizational Profitability and Legitimacy

Of importance to organizational researchers, concerns about environmental problems increasingly preoccupy organizations and the strategists leading them (Schot & Fischer, 1993; Schmidheiny, 1992; Winsemius & Guntram, 1992). This is especially true in the chemical industry (Chemical Manufacturers Association, 1994; Canadian Chemical Producers Association, 1994). This is unsurprising given that the discovery that a product has unintended and undesirable consequences for the environment and human health can seriously affect organizational viability, posing threats to both profitability and legitimacy.

1.1.2.1 Threats

Firms survive by producing and selling goods and services at a profit in various markets. Obviously, if activities like the production, transport, export, purchase, possession and/or use of a product are prohibited in particular markets, this has direct economic consequences for firms involved in its manufacture. Banned products do not help the bottom line.

In addition, firms upstream and downstream in the value chain are also affected. Suppliers of raw materials see demand for their products drop, and customers are forced to find and integrate substitutes into their activities. These substitutes can be more expensive and less effective, imposing a recurring direct cost of change on these firms as well. The ubiquity of chemical products in the economy, with product shipments radiating out from this core sector to the value chains of almost every other sector, is significant. Bans on products from this sector can affect many others, and perhaps the entire economy. Indeed, the impact on the economy of a *sudden* product withdrawal is analogous to that of a supply shock.

The significance of the threat of a product ban to an individual producing firm depends upon many factors: the degree of diversification of the firm's portfolio, the pace at which the product leaves the economy, regulators' compensation policy, etc. Yet the stakes can be enormous. Let's put these into perspective.

What affects the chemicals sector affects everyone. Worldwide, annual revenues in the chemical industry are over $1.3 trillion. In the United States, the industry employs some 1.1 million people who are involved in producing shipments valued at $314 billion, almost 2% of US GDP. Each year, the sector invests $21.8 billion in new plant and equipment while funding R&D to the tune of $16.7 billion (all figures from CMA, 1994, p 21). The numbers are smaller if we limit ourselves to agricultural chemicals, but the stakes are staggering nonetheless. In 1996, sales of pesticides topped $31 billion (British Agrochemical Association, cited in Agrow, 1997 01 11) All of the top ten agrochemical companies in terms of sales grossed over $1.5 billion each, with the top firm (Novartis, which resulted from the merger of Ciba-Geigy and Sandoz) pulling in over $4.5 billion and the runner up (Monsanto) generating almost $3 billion (Agrow, 1997 04 18).

Yet consider that Monsanto's herbicide Alachlor, which had sales of $320 million in 1986, is currently under attack in the US for its suspected oncogenicity, and has already been banned in Canada and the Netherlands (Fagin et al, 1996; UN, 1994). Or consider that the herbicide Atrazine, which represented 25% of Ciba-Geigy's (now part of Novartis) crop chemical business in 1995, is a suspected oncogen and has been fingered as well as an endocrine disrupter (Fagin et al, 1996; Colborne et al, 1997). I could go on for a long time listing products, their importance to individual firms and the economy, and the critiques against them, but suffice it to say that there are currently numerous high stakes struggles being played out between supporters and critics of these and other substances.

1.1.2.2 Opportunities

To this point the focus has been negative, looking at potential *threats* to organizational viability, but these controversial products can represent *opportunities* for some organizations, offering the potential for an increase in viability. The potential gains to manufacturers of substitute products should controversial products be banned are an obvious example of such opportunities.

But even for manufacturers of controversial products, these episodes may also represent opportunities *relative* to other manufacturers, especially if their strategies prior to and/or during the episode diverge. The direct costs of a controversy to producers may not be homogeneously distributed across the industry, permitting relative gains by particular firms. Technologically more advanced firms may actively seek strict regulation to increase the strategic and competitive value of their advantage (Cairncross, 1992). It is also possible that certain industry incumbents may be the source of substitute products. Indeed, in the case of CFCs, the search stimulated by the ozone hole eventually led to the discovery of substances that turned out to be more economical for some uses. Or consider that Monsanto has turned criticism of chemical-intensive agriculture into a justification of its diversification into agri-biotech, which has helped it to become a leader in that emerging sector. The CEO of Monsanto also claims that its transformation from a "chemical" company to a "life sciences" company working towards "sustainability" has improved worker morale (Magretta, 1997) Reputation effects may be heterogeneously distributed as well. For example, compared to its European and especially its British counterparts (ICI), the American chemical industry (and especially DuPont) looked progressive and socially responsible throughout the CFC debate and the knitting together of the Montreal protocol (Benedick, 1991).

Once again, the practical concerns motivating this research - the threats and opportunities faced by companies - are real. Achieving a better understanding of our focal phenomena of substitution is of much practical significance.

1.2 Theoretical Concerns Orienting the Research

1.2.1 Research Questions

"What is the process by which one product substitutes for another one?"

This is the most general statement of my research question. **Substitution** is the focal phenomena under investigation in this research. A comprehensive model of this process would describe not only uncontroversial instances of product substitution, but also those instances of substitution driven by environmental and health problems. To explicitly capture these *practical concerns*, the research question can also be expressed as follows:

> ***"What is the process by which products enter the economy, enjoy commercial success, then come to be viewed as unacceptably damaging to the environment and/or human health, with their subsequent use dramatically reduced as they are substituted for by alternative products?"***

Our focal phenomena of substitution is one at the heart of the strategy discipline. It is central to explanations of sustainable competitive advantage (Porter, 1980; Barney, 1991) and technological evolution, itself of increasing importance to the strategy field (Tushman & Anderson, 1986; Itami & Numagami, 1992). Yet it is a phenomena about which gaps in understanding and *theoretical concerns* exist.

In subsequent sections of this Chapter, it is demonstrated how the focal phenomena of substitution serves as a conceptual bridge linking practical concerns about environmental problems and sustainable development to the discipline of strategy. A literature review follows which presents (1) concepts, theories and models from the strategy and organization science literature which are relevant to understanding, framing and answering our research questions, (2) the limitations of these, and finally (3) directions in which exploratory research could probe to contribute to building a more comprehensive theory of substitution.

My review of the strategy literature, and the treatment of the focal phenomena of substitution therein, concludes that there is a need for research that goes beyond the deterministic economic models which currently dominate by adopting a more socio-political perspective. So whereas prior research on substitution has been conducted around the notion of *industry* and the institution of the *market*, the research presented in this dissertation investigates a wider set of actors, organizations and social institutions at the slightly higher level of analysis of *interorganizational domain*. In addition, the literature review also concludes that there is a need for research that gets beyond the physical world to include and explore actors' ideas about that world, both their descriptions of it and their prescriptions for it. So whereas prior research on substitution has focused attention on the material realm of competing products (or "technologies" or "artifacts"), this research investigates both the material and ideational realms.

1.2.2 Strategy and Sustainable Development

Social responses to environmental problems are frequently lumped together under the notion of **sustainable development**, a concept which has captured the attention of governments, non-governmental organizations, activists, scientists and businesspeople. It is frequently referred to in the speeches of corporate leaders as well as in the mission statements they develop to shape their corporate identity and to guide their actions. Since its entry into popular discourse in 1987 with the publication of the Brundtland Report, also known as *Our Common Future* (WCED, 1987), the meaning and implications of the concept of sustainable development have been debated and developed by natural and social scientists around the globe. In this section, we introduce this concept and connect it to the strategy literature.

First, it is important to underline that there is no universally accepted interpretation of the term "sustainable development". The definition most widely adopted is that from the publication of *Our Common Future* which is *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs."* (WCED, 1987, p 43). As is evident, this statement leaves much room for interpretation and different operationalizations, as what constitutes "development" or "needs" will inevitably incorporate value judgments.

> *"**No single definition of sustainable development is universally acceptable or correct.** Each country, region, and people will assign different weights to the various ways that exist for achieving a sustainable future through sustainable development. It is however possible to delineate the scope of the concept, the principles and elements which it encompasses and the challenges it presents."*
>
> (Bregha et al, 1990, p 1)

> *"Although it is possible to state the general directions in which development must proceed in order to be more rather than less sustainable ... **it is not yet possible to define the precise conditions for sustainability** in respect to each specific development. Nor is it necessary. At this point, sustainability is best regarded both as a social goal and as a criterion for development. In this respect it resembles other worthy and*

> ***widely accepted but conceptually difficult*** *social goals such as democracy, justice or even national security, economic development and a healthy environment."*
>
> (MacNeill et al, 1991, p 27)

To criticize its lack of precision would be to miss the strategic value of its ambiguity. The term has an *existence* and a *functionality* outside of the technical and scientific discourses of economics and ecology, and it was not meant to be a rigid and fixed foundation for an elegant theoretical infrastructure. Since the publication of the Brundtland Report, "sustainable development" has become a popular (in the sense of mainstream and widespread) policy goal guiding individuals, organizations and politicians in their decision-making as well as a problem domain for academic research. Its ambiguity serves it well in both of these roles.

As a policy goal, its imprecision is essential. Vague and ambiguous goals are themselves resilient and provide resilience to the system or organizations using them. Ambiguity and goal fluidity are the glue of tenuous coalitions within organizations (Cyert & March, 1963) as well as outside. The notion of sustainable development is *"a strong yoke for different objectives and views"* (Bregha et al, 1990).

The expression has taken on symbolic content as well, becoming the rallying point for activists, politicians and the general public. Again, its ambiguous nature is an asset from this perspective because *"successful symbols are vague, multivocal, open to different meanings and applications"* (Spooner, 1984).

The notion's fluidity and ambiguity also make it an enduring domain for a diverse set of scientific researchers. As a problématique that is consciously and necessarily multidisciplinary, the expression's openness acts as a magnet for different disciplines, preventing its appropriation by any one of them. Indeed, many argue that it is precisely this tendency for individual disciplines to wrestle monopoly control over certain concepts and problem domains that is at the root of current environmental problems (WCED, 1987; Redclift, 1988; Norgaard, 1988; Holling, 1989). Sustainable development has drawn the attention of the "harder" scientists in economics and ecology and spawned collaborative interdisciplinary research in a way that other ideals and organizing principles like "justice" and "democracy" have not. By helping to bridge the gap between social and natural scientists, the notion of *sustainable development* may contribute to the evolution of scientific thought in a way far more significant than any "rigourous" term ever could.

But ultimately, for the purposes of our research, this ambiguity must be reduced and we must state what we mean by the sustainable development and how we expect to connect it to the field of strategy and our proposed research project.

We adopt here a process view of development as qualitative change, and believe that development is better understood as a complex societal process of learning (qualitative ideational change) and evolution (qualitative material change) which can be explored in terms of multiple dimensions: the ecological, the economic, the political and the cultural (Brown, 1989; Bregha et al, 1990).

> *"Sustainable development can be most usefully seen as an on-going process that moves the world towards a more desirable future by orienting development patterns, strategies, methods, and attitudes to better address a slate of social and environmental imperatives facing the world."*
>
> (Bregha et al, 1990, p 2)

> *"Yet in the end, sustainable development is not a fixed state of harmony, but rather a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are made consistent with future as well as present needs. We do not pretend that the process is easy or straightforward. Painful choices have to be made. Thus in the final analysis, sustainable development must rest on political will."*
>
> (WCED, 1987, p 9)

Development can be defined as *"the modification of the biosphere and the application of human, financial, living and non-living resources to satisfy human needs and to improve the quality of human life"* (IUCN, 1980). Development is distinguished from growth in that the former implies qualitative change in economic activity and not merely quantitative change (WCED, 1987; Munn, 1989). Qualitative change - in both social and ecological systems - implies the "creative destruction" of the present, or the "destructive creation" of the future (Schumpeter, 1943; Holling, 1986). In social as opposed to natural systems, this process of "creative destruction" plays itself out in both the material *and* ideational worlds as new behaviours, technologies and artifacts *along with* new ideas, insights, plans and visions replace old ones.

As to the "sustainability" of development processes, this is a very difficult question because the cause-effect relationships which characterize our physical environment are the subject of much scientific research and debate. Given the current rate at which ecological understanding is changing, that which is viewed as "sustainable" or ecologically "acceptable" today may be labeled as "unsustainable" or ecologically "unacceptable" in the near future. This "changing of the mind" poses particular and significant challenges to firms, so it is important that it be one object of our inquiry. The aims of this research include understanding how social systems and the actors therein go about, themselves, interpreting "sustainability" or, to be more precise, how they go about determining the acceptability of particular products and their environmental impacts. Hence the focus is on how modern social systems go about reconciling (and perhaps reorienting) their "development" with their prevailing views of "ecosystems" and "sustainability". Natural and social scientists agree that there is a need for empirically grounded research which investigates the coevolution of social systems - including organizations - with ecosystems (Norgaard, 1988; Holling, 1989; Dietz & van der Straaten, 1992; Gladwin, 1993; Holling, Berkes & Folke, 1997).

The identification and resolution of environmental problems involves, ultimately, some actors, somewhere, changing their products, industrial processes, practices, activities or behaviours. Old products, industrial processes, practices, activities or behaviours are, after having been categorized as ecologically undesirable, substituted for by more ecologically sound alternatives. Indeed, efforts to remove products from the economy quickly translate into an assessment of the existence, efficiency and efficacy of alternatives. If firms and their customers could substitute problematic and controversial products with safer or cleaner alternatives with zero impact - technologically, economically, organizationally, politically, or culturally - they would. Drawing upon the literature and theoretical tools of the discipline of strategy, we will address sustainable development by viewing and studying it through the lens of **substitution**.

1.2.3 Strategy and Substitution

In our quest for tools to address our primary research question, we turned to the literature on substitution. It was surprisingly thin. The keyword indexes for the *Strategic Management Journal* covering the period from 1980 - 1989, as well as that for *Administrative Science Quarterly* covering the period from 1956 - 1985, contain not one single reference to the concepts of "substitutes". The absence of a sustained discourse around the topic of *substitutes* is quite surprising, given that this concept is absolutely central to theories of sustainable competitive advantage (SCA), a construct that is, arguably, the raison d'être of the strategy discipline.

But this may be because understanding "substitutes" requires nothing less than a *substantive* or *qualitative* theory of value - how *utility* is created, maintained and destroyed, with an emphasis on the substantive nature of *demand*. This has not been the focus of strategy research, as much more effort has gone into explaining how *scarcity* arises, is maintained and destroyed. Research efforts have focused on explaining rents *quantitatively* in terms of product or resource *supply* being more limited than in the theoretical ideal of perfect markets, as well as how firms can ensure that the *rents* that are generated as a result of this situation are *appropriable*.

I look, here, at how substitution is addressed in the strategy literature, beginning with the literature focusing on sustainable competitive advantage. In the end, I conclude that the SCA literature has little to offer for understanding the *process* of substituting one product for another, but the prominence of substitution within that literature means that it merits treatment, if for no other reason than to demonstrate why it is of little utility.

1.2.3.1 Substitution within theories of sustainable competitive advantage

The notion of sustainable competitive advantage (SCA) is central to the strategy research program, and the work of Barney (1991) has gone along way in explicating what constitutes and underlies it.

> ***competitive advantage:*** *when a firm is implementing a value-creating strategy not simultaneously being implemented by any current or potential competitors*
>
> ***sustainable competitive advantage:*** *when a firm is implementing a value-creating strategy not simultaneously being implemented by any current or potential competitors, PLUS when these other firms are unable to duplicate (the benefits of) this strategy*

Much of the research in the strategy literature is devoted to discovering the conditions necessary for SCA, from which it is hoped "success factors" and "winning" strategies can then be deduced (Ghemawat, 1991). But different theoretical frameworks approach this phenomena from different perspectives, work at different levels of analysis, and employ different conceptions of fundamental components of the definition, especially "firm" and "strategy". How firms and their strategies are to be viewed, operationalized, recognized and labeled is at the centre of these debates, outlined briefly here.

A firm's strategy is frequently decomposed into two components: corporate level strategy and business level strategy (Miller, 1986). Corporate strategy is a firm's solution of what Miles & Snow refer to as the "entrepreneurial problem" facing all firms, and for new firms is singular: *"a specific product or service and a target market or market segment"* (Miles & Snow, 1978) which *"locates the core business"* (Mintzberg, 1988). Corporate strategy represents the firm's choice of products and markets within which it will become a competitor. The process of making such product-market choices is sometimes referred to as *strategic management* (Ansoff, 1991). Business level strategy applies to individual business units in the firm and represents the manner in which they compete within their respective industry or product-market domain (Porter, 1980). Decisions related to competing within a given industry are sometimes referred to as *competitive management* (Ansoff, 1991), or *distinguishing* the core business (Mintzberg, 1988). Typologies of generic strategies which have been suggested for achieving or maintaining *penetration* (Ansoff, 1965) of a product-market domain include *cost leadership, differentiation*, and *niche* (Porter, 1980) as well as *quality, design, support, image*, and *price* (Mintzberg, 1988).

Each of these generic recipes are aimed at *distinguishing* the firm from its competitors, rendering its product *unique* along some dimension (including price) important to customers such that revenues exceed costs (i.e. *value-creating*, as per the above definition), generating rents for the firm and giving the firm a *competitive advantage*. But firms do not just desire the *existence* of uniqueness and appropriable rents, they also desire their *persistence* over some time frame such that their competitive advantage warrants the adjective *sustainable* (Porter, 1980).

The dimensions used to characterize business strategy are based upon relative scales, with comparison to rivals implicitly or explicitly carried out in order to categorize the firm's strategy. This is not the case with corporate strategy, where a firm is either in a product-market domain or it is not, and no reference to rivals is needed to determine this. With business strategy however, the definition of such things as "low cost" and "differentiated" products is always contingent upon the action of rivals. To capture this relativity, business strategy is frequently defined as a *position* relative to rivals and potential new entrants (Porter, 1980; Mintzberg, 1987; Mintzberg, 1990).

This positionist thinking is typically identified with researchers working within the industrial organization (IO) framework, but is also in evidence more recently with researchers adopting the other popular strategy framework inherited from economics, which is the resource-based view of the firm (RBVF). As highlighted in Table 1.2.3.1.1, both IO and RBVF make essentially the same positionist arguments, stressing the importance of the appropriable-rent-generating potential of the position, along with the inability of others of attaining the same position (Porter, 1980; Rumelt, 1984; Peteraf, 1993). The two views are simply discussing two different conceptual "spaces". IO approaches the firm from the outside in, "knowing" it - identifying it and characterizing it *relative* to other firms - in terms of *differences* in products (including prices) and markets, while RBVF approaches the firm from the inside out, "knowing" it - identifying it and characterizing it *relative* to other firms - in terms of *differences* in the resources it possesses, its capabilities and its competences.

Table 1.2.3.1.1
Sustainable Competitive Advantage: Two Views from the Strategy Literature

	IO	RBVF
focus of analysis:	products, markets	resources
view of firm:	portfolio of products (or product-market couples)	portfolio of resources

Competitive advantage

	IO	RBVF
nature of **firm heterogeneity** underlying *existence* of *appropriable* rents:	"unique" product (low cost or differentiated products)	"unique" resources (permitting low cost or differentiated products)
type of **rents**:	Monopoly	Scarcity

Sustainable competitive advantage

	IO	RBVF
persistence of the *appropriability* of rents:	low negotiating power of suppliers and customers	non-tradability of resources
persistence of rents due to **supply frictions** (i.e. firm immobility) and continued scarcity or quantitative "uniqueness":	barriers to imitation for rivals and barriers to entry for potential new entrants result in inimitability of product position	isolating mechanisms result in inimitability of resource by rivals and potential new entrants
persistence of rents due to **demand frictions** and continued qualitative "uniqueness":	non-substitutability of product by customers (i.e. barriers to substitution)	non-substitutability of resource by rivals and incumbents (i.e. barriers to substitution)

And so while IO research has concentrated its efforts on characterizing a perfect form of products and industry structure from the perspective of the firm through the rigourous explication of which "opportunities", if exploited, are most likely to lead to SCA, the contribution of the RBVF approach has been the *"characterization of a perfect form of resources"* (p 257) through the rigourous explication of which of a firm's "strengths", if exploited, are most likely to lead to SCA by identifying the properties of firm resources necessary for this (Montgomery, 1995).

Both of these perspectives are useful, and indeed were seen to complement each other when RBVF originally became popular in strategy (Wernerfelt, 1984 & 1995). Analyses which ignore one or the other are incomplete because the definition of "better" resources or "better" products must presume the other. Unique resources acquire their value or "resourceness" only as they are employed to produce low-cost or differentiated products which are valued by customers, although this contingency tends to be masked by the frequent use of a value-laden definition of what constitutes a resource (for such a definition, see Barney, 1991; for a critique, see Montgomery, 1995). Others say essentially the same thing when they stress the importance to firms of possessing resources which *"overlap with strategic industry factors"* (Amit & Schoemaker, 1993). Conversely, low cost and differentiated products are not squeezed out of abstract production functions through calculation and deduction, and in fact these mathematical expressions represent real physical and human capital that is in a process of continuous construction and is not always mobile nor tradable. In short, "better" resources and "better" products mutually define each other.

So despite apparent differences between IO and RBVF research, there are many parallels in their underlying logics which are due to their common roots in the equilibrium framework of microeconomic theory, and I have attempted to highlight these in Table 1.2.3.1.1. Both IO and RBVF approaches emphasize "content" over "process" and ultimately they explain SCA in terms of the *persistence of appropriable rents* which arise from the *quantitative* and *qualitative uniqueness* of a firm (described in terms of either products or resources) in some product market. Moreover, within both approaches, research has been preoccupied with intra-industry rivalry and how the rent-generating uniqueness of a firm is maintained *quantitatively* due to supply-side frictions, conceptualized as isolating mechanisms at the level of the firm, mobility barriers at the level of the strategic group, and entry barriers at the level of the industry (for a comprehensive list, see Mahoney & Pandian, 1992). Neither Porter nor subsequent IO researchers elaborate on industry-level "barriers to substitution", and RBVF researchers have similarly ignored "substitutability" at the level of resources. In other words, the emphasis has been on the *existence* and *scarcity* - rather than *functionality* - of firms' products and resources.

This is understandable given the origins of these models in microeconomics where the unit of analysis is, overwhelmingly, a single industry. Technically, within microeconomic models, if new entrants or imitating firms are successful, they increase the *supply* of a focal product; if makers of substitute products are successful, they decrease the *demand* for a focal product. But in the bulk of microeconomic analysis which informs strategy research, demand is explicitly treated as exogenous and given in order to model and comprehend the dynamics of supply. SCA research has tended to focus on and study firms' actions and decision-making within a single industry. But studying substitutes and substitution means studying activities and decision-making in multiple industries: that of the focal product, that of the substitute product, and that of customers. In this respect, SCA research has serious limitations when it comes to understanding our focal phenomena of substitution.

The two views of SCA presented in the above Table do differ in terms of how they conceive of *rents,* which are defined as returns in excess of a resource owner's opportunity costs (Tollison, 1982). Monopoly rents are returns made possible by market power and the restriction of possible output; Scarcity rents are returns to unique resources producing output at some unrestricted maximum capacity. Both are notions developed within *equilibrium* frameworks, and in fact, the definition of SCA employed above has been drawn from such a framework: *"his definition of sustained competitive advantage is an equilibrium definition"* (Barney, 1991, p 102). Notice the absence of the construct of *time* in the definition of SCA. This atemporality is a clear indication that it applies to a closed system at equilibrium. Monopoly rents exist in the long run after entry attempts (i.e. attempts to increase the supply of the rent-generating product) have ceased and Scarcity rents exist in the long run after imitative attempts (i.e. attempts to increase the supply of the rent-generating resource) have ceased (Barney, 1991).

A third type of rent, termed a Schumpeterian or Entrepreneurial rent, has been postulated which represents returns to risk-taking and entrepreneurial insight (Schumpeter, 1934). Schumpeterian rents are assumed to be inherently transient, dissipating over some finite time frame due to either (1) the bringing to market of similar products by other actors which destroys the *scarcity* of a product through *imitation* or (2) novel entrepreneurial activity by other actors which destroys the *value* of a product through *innovation,* as with our focal phenomena of substitution (Schumpeter, 1934; Schoemaker, 1990).

But within the strategy literature, SCA is rarely addressed in terms of Schumpeterian rents nor process models. This dominance of equilibrium notions of rents and the over-emphasis on content over process in SCA research has been criticized (see, for example, Williams, 1992; Winter, 1995). The centrality of the notion of *rates* to strategy is underlined by Williams (1992), who states that *"time, the denominator of economic value, eventually renders nearly all advantages obsolete"* (p 29), and argues for the development of process models employing a Schumpeterian notion of rents. But to date such models of the *creative destruction of value* are rare within the SCA literature.

Some work has been done on how the *scarcity* component of value is destroyed through imitation which occurs at some rate or pace. Because Schumpeterian rents, by definition, exist within a dynamic context and are always "at risk" over some time scale, they can be related back to Monopoly or Ricardian rents probabilistically by tuning this risk and/or this time scale to a low value. Researchers, instead of working with resources/products of *impossible* imitability in their models, which would mean the existence of Monopoly or Ricardian rents, have begun to incorporate the notion of resources/products of *uncertain* or *imperfect* imitability, which means the existence of Schumpeterian rents that are at risk of dissipating over some time frame (Lippman & Rumelt, 1982; Rumelt, 1984). But to date, no strategy researchers have investigated *uncertain* or *imperfect substitutability* which would require investigating how the *utility* component of value comes to be creatively destroyed.

All in all, one can conclude that the strategy literature has had much more success in explaining how, once created, value is maintained or destroyed *quantitatively* in the sense that value flows from *scarcity* of *supply*, be it supply of products or resources. As illustrated in Table 1.2.3.1.1, researchers working within the industrial organization (IO) paradigm argue that Monopoly rents are protected by barriers to entry which limit the *supply* of a focal product (example of barriers to industry entry: economies of scale, favourable access to raw materials or technologies through property rights and patents, regulations, etc.), while those researchers adopting a resource-based view of the firm (RBVF) argue that Ricardian rents are protected by barriers to imitation, thus limiting the *supply* of key resources necessary to profitably manufacture the focal product, and by extension, the *supply* of the focal product (example of barriers to resource imitation: intellectual property rights, causal ambiguity, tacitness, social complexity, need for complementary assets, etc.).

In addition, the IO and RBVF perspectives have also been quite successful at explaining the *locus* of value appropriation - who claims and appropriates (surplus) value and why it is not bargained nor bid away from the firm enjoying SCA. IO researchers point to the weak bargaining power of suppliers and customers (due to their number and competition amongst them) and RBVF researchers point to the non-tradability of rent-generating resources (due to transaction costs related to ill-defined property rights and specialized assets).

But strategy researchers have had very little success in explaining the creation, maintenance and destruction of value substantively (i.e. *qualitatively*), conferred on products due to their *utility* at satisfying *demand*. This will ultimately be required for any theory of how value is created then destroyed that goes beyond good and bad "luck", an explanation we find in the literature (Barney, 1986). Conspicuously absent from theories of SCA is that configuration of elements which confers utility value on products and the resources employed to produce them: customers' needs or *preferences* for a particular *functionality* and their *beliefs* or expectations about how well competing products satisfy that functionality. *How* and *at what rate* do these change? Understanding demand will be central to any theory or model of our focal phenomena of substitution.

Studying and understanding demand means studying and understanding the activities of actors outside a focal industry, and in order to build such a model, one must get beyond the confines of microeconomic theory. I propose to do just that by accessing literatures that are less formalistic and mathematical but also less constraining: (1) by replacing an emphasis on "products" with one on "technology", and (2) by extending that set of actors considered relevant beyond those captured by the notion of "industry" to those captured by the notion of "domain".

1.2.3.2 Substitution within theories of technological change

Technological evolution and change have become an increasingly important topic in the organizational and strategy literature (Anderson & Tushman, 1990; Itami & Numagami, 1992). In order to escape the iron-cage of institutionalized ways of thinking built upon imported Newtonian models of simple systems - with assumptions of market equilibrium, exogenous demand, negative feedback, decreasing returns, and an optimizing Invisible Hand - as soon as one tries to research or even talk about *products*, economists and organizational researchers concerned with explaining empirical outcomes in the economy have increasingly turned to the more abstract concept of *technology* in the production of their discourse. This seemingly subtle shift in emphasis, because of the ambiguity of that latter notion, has been crucial to the process by which they eked out a space for themselves to discuss the economy in a radically different way that is increasingly accepted by strategy researchers and strategists alike: as a complex system, far-from-equilibrium, with coevolving supply and demand processes and which at times may be characterized by positive feedback loops, increasing returns, and lock-in on sub-optimal yet nevertheless dominant designs. The (de- & re-)construction of reality begins with the manufacture of ambiguity.

Orthodox economics had staked out a difficult-to-contest discursive monopoly when it came to "products" and "competition" between them. Note how the boundary and definition of a "product" is unambiguously given by the market exchange transactions in which it is involved. *By definition*, in economic discourse, "products" are those goods exchanged in the "market", and hence come with numerous uncontestable (or at least difficult to contest) assumptions and even "facts"" or "truths" connected to a long-standing and orthodox understanding of that particular institution: consumers are sovereign; their preferences are consistent, stable and exogeneous; supply and demand equilibrate and the outcome is Pareto optimal; information is "objective" and is gathered or discovered but never "constructed"; etc. But when it comes to "technologies", not only is there a long tradition of research into how these are socially constructed (Berger & Luckman, 1967) and hence potentially "arbitrary" rather than "optimal" (Mackenzie & Wajcman, 1985), but even those researchers who adopt a technologically deterministic stance do grant that, at a minimum, at least the "boundaries" or "scale" at which technologies are or should be defined and studied is ambiguous. Even determinists accept the notions of competing "technological systems", "socio-technical systems", or entire "technological trajectories". The scale at which competition is occuring between technologies - the level at which processes of "creative destruction" are occuring - is ambiguous and multiple. Many other actors are integral parts of such technological systems, so, with this concept it will be easier to get at the dynamics of demand.

Early technology research by organization scientists concentrated on the impact of technological change on industries, organizations, individuals, and their organizational roles, but recently, much more emphasis has been placed on the nature and dynamics of technological change and competition. Because a firm's technological environment is an important source of both opportunities and threats and its technological resources may be the source of its strengths and ultimately SCA, the pace and direction of technological change are of obvious interest to strategists and strategy researchers (Andrews, 1971; Itami & Numagami, 1992).

Typologies of technological change exist, and within these one finds our focal phenomena of substitution. Tushman and Anderson (1986) classify technological changes by drawing distinctions between products (i.e. goods sold) and processes (i.e. manufacturing activities, machines, etc.), and also between changes which build upon current expertise, knowledge and know-how so they are "competence-enhancing" and those which draw upon new skills and are therefore "competence-destroying" (Tushman & Anderson, 1986; Anderson & Tushman, 1990). I feel that these are important concepts but they are unfortunately poorly labeled: it is not competences themselves which are enhanced or destroyed but rather the *value* of these competences. The abilities to manufacture low-cost buggy whips, saddles or horseshoes were not affected by the introduction of the automobile, although certainly the *utility* and *relevance* of these competences were. This regrettable terminology is a common problem in the RBVF literature where resources and competences are defined in value-laden terms (Montgomery, 1995).

But despite their value-laden terminology, Tushman & Anderson's typology is nevertheless quite illustrative and well accepted. It is shown below, with our focal phenomena highlighted in bold italics. Because they assume substitution to be an inter-industry (rather than intra-industry) competitive process initiated by non-incumbent firms, these authors argue that it is likely to be "competence-destroying" from the perspective of incumbents (Tushman & Anderson, 1986).

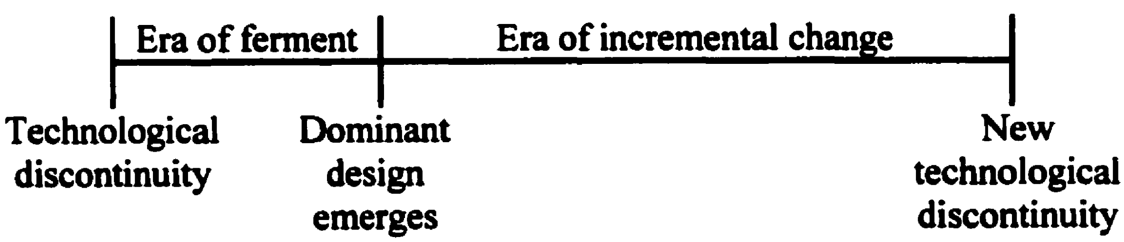
Table 1.2.3.2.1 - A Typology of Technological Changes

	Products	Processes
Competence-enhancing	- major product improvements - incremental product improvements - crystallization of dominant designs	- major process improvements - incremental process improvements
Competence-destroying	- new product class ***- product substitution***	- process substitution

• Table is from Tushman & Anderson (1986)

These same researchers are also responsible for what has become probably the most generally accepted model of technological change in the literature, which is their cyclical evolutionary model (Anderson & Tushman, 1990). One cycle of this process is illustrated in Figure 1.2.3.2.1.

Figure 1.2.3.2.1 - A Cyclical Model of Technological Change



• Figure is from Anderson & Tushman (1990)

In their model, technological change is characterized by the following cyclical process:

(1) the appearance of a technological discontinuity (defined as a dramatic increase in an artifact's performance/price ratio),

(2) an era of ferment in which many widely divergent designs are experimented with as actors place their bets on and follow different research directions,

(3) a second discontinuity at which point there is a crystallization or precipitation of dominant design with the acceptance and adoption of common standards,

(4) an era of incremental change where researchers "fiddle with the details" of a given technology, then

(5) the appearance of another technological discontinuity (i.e. go to 1).

In such a model, the process of substitution begins slowly during the era of ferment, then proceeds more quickly once the superiority of the new technology is established (Fisher and Pry, 1971) or a dominant design for the new technology emerges (Utterback & Abernathy, 1975). A number of authors have even suggested that substitution follows a classic logistics curve driven by a "diffusion" process of adoption of innovations, and have modeled this formally (Rogers, 1982; Waterson, 1984). The rate of substitution in these models (say, for example, switching from product "Y" to product "X") depends upon the proportion of incumbent product ("Y") users already switched. In the beginning of the process of substitution, triggered by the arrival of a new product and its adoption by at least one customer, the substitution rate is slow because, with few users, the new product's benefits are unclear and uncertain to those who have not yet switched. The substitution rate is slow at the end of the process as well, because there remain few potential switchers left. This is evident from the form of the most common model, the so-called "logistic function":

$$F / (1 - F) = \exp(Kt)$$

Here, F is the fraction of potential market already switched, and K is a constant representing some inherent motivation for substitution, acting as a deterministic driving force. It is related to the relative values of "Y" and "X" to customers (i.e. the benefits and costs of their use), switching costs, and customers' attitudinal propensity for switching which combined make up *"the economics of substitution"* (Porter, 1985). Notice here how, again, as with the microeconomic models informing SCA research, the origins of value - the benefits and costs associated with using products "X" or "Y", and of switching - are neatly sidestepped, assumed to exist objectively. These benefits and costs underpin and, indeed, are responsible for demand. Like that construct, for researchers employing formal models, they just *are*.

Consider the following table which displays the possible substitution scenarios if a new artifact "X" appears and is offered as a potential substitute for an incumbent artifact "Y".

Table 1.2.3.2.2 - Potential Substitution Scenarios

Relative *price* of "X", with respect to "Y"	Relative *performance* of challenger product "X", with respect to incumbent product "Y"		
	Better	**Same**	**Worse**
Lower	X substitutes for Y	X substitutes for Y	X substitutes for Y, if: decrease in price compensates for decrease in performance
Same	X substitutes for Y	X & Y are equivalent; Y persists if non-zero switching costs	Y persists
Higher	X substitutes for Y, if: increase in price is compensated by increase in performance	Y persists	Y persists

* Switching costs are assumed to be zero for simplicity's sake.

An artifact's "performance/price ratio" with unspecified units or dimensionality can be reduced to a single unitless measure by conceiving of performance in unidimensional financial terms, or in other words, by attaching an economic value to it. Hence Porter (1985), working within a purely microeconomic framework, discusses substitution in terms of unitless "relative value/price" ratios or RVP. The terms are quite similar, but we prefer the former because it allows for a multi-dimensional operationalization of "performance" in terms, perhaps qualitative, that are not merely financial.

Everything else being equal, the rate of substitution of "X" for "Y" will increase with the following ratios:

$$\frac{\text{(price of "Y")}}{\text{(price of "X")}} \quad \text{and} \quad \frac{\text{(performance of "X")}}{\text{(performance of "Y")}}$$

Stated in terms of Porter's RVP, the rate of substitution increases very sharply from 0 when the RVP measure transitions from values less than 1 to values which are greater than 1. In other words, any and all events which affect the "performance" or "price" of either X or Y can affect the process of substitution.

Technology researchers who promote diffusion models of substitution tend to adopt a technologically deterministic stance, viewing reality as falling neatly and objectively into one cell or another in Table 1.2.3.2.2. In their models, there is no ambiguity - performance and price are objectively defined and observed by actors - and substitution proceeds at a rate which increases exponentially with the value/price gradient between "X" and "Y".

On the other hand, there is a stream of theorizing about technological evolution that places more explanatory weight on processes of "social construction" (Berger & Luckmann, 1967) that would argue that, depending upon how it is constructed (or de-&-re-constructed), "reality" may indeed be shifted from one cell to another (Mackenzie & Wajcman, 1985). This literature has developed along with, and is complemented by, studies from the sociology of knowledge and science (see, for example, Kuhn, 1970; Woolgar, 1981; Latour, 1987; Epstein, 1996).

Of particular interest to the instances of substitution that motivate this study - those characterized by unintended and undesirable consequences of an artifact's use - important dimensions of products' performance may be ignored, unknown, uncertain or even contested. The purchase cost of a product may be transparent, but what about the "total costs" of its use? Even if one ignores the complications of "externalities" (benefits and costs borne by others not party to the transaction), some "costs" to users may be hidden or lagged in time, appearing later as "problems" are identified and named as such. Ultimately, views of how well a product performs - the impacts, benefits, and costs of its use - are "constructed" and subject to processes of argumentation and legitimation.

Perceived performance depends upon which outcomes and consequences of a product's use are considered important and monitored: is cancer risk an outcome that should be weighed in evaluating a product? effects upon ecosystems? endocrine disruption? potential public relations problems? In other words, which *goals, preferences and evaluation criteria* are to be employed when selecting and using a particular product technology over another one?

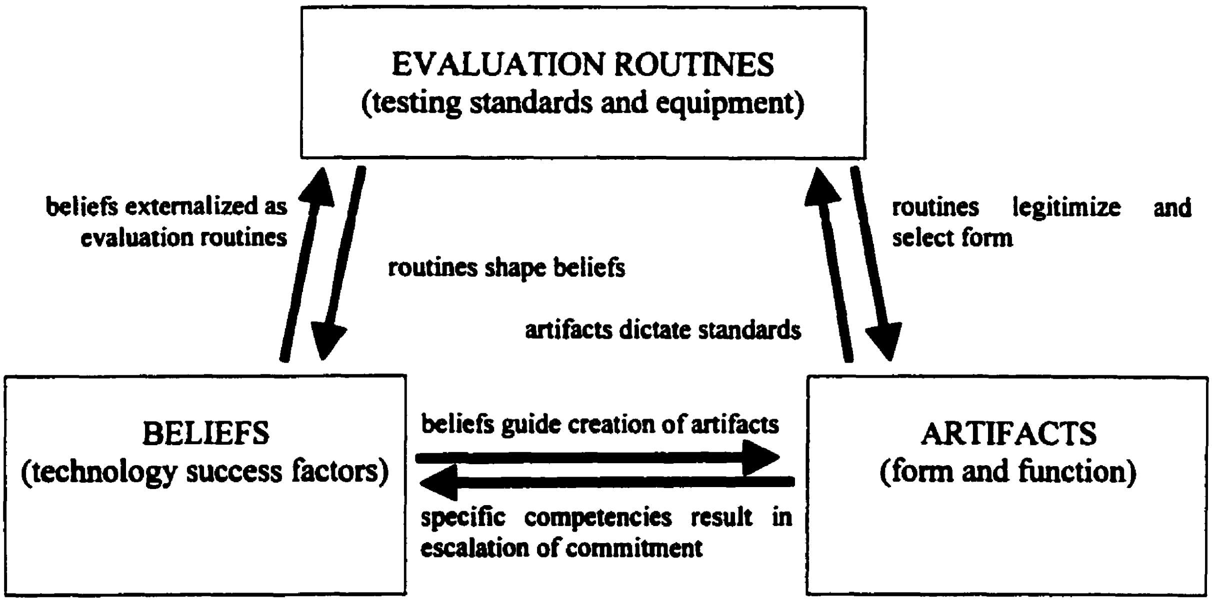
But even if these goals and performance criteria are certain, uncertainty or even ambiguity can still result. Consider the case where carcinogenicity (oncogenicity) matters and this is uncontested. It is still possible that there can be differing views or measures of the carcinogenicity of a product, perhaps because of different toxicological methodologies or even different interpretations of a common, shared data set. In other words, which *beliefs* are to be employed when selecting and using a particular product over another one?

Clearly the ideational world of beliefs and values plays an important role in the process of substitution. We suggest that the "creation" and "destruction" of product value may involve processes of argumentation, legitimation and the transformation of actors' conceptual models and goals. Though "competence-enhancing" and "competence-destroying" *technological* discontinuities have been the object of research in the strategy literature (Tushman & Anderson, 1986; Anderson & Tushman, 1990), their *ideational* or *ideological* counterparts have not. I suspect that cognitive events, be they the appearance of new models in the minds of scientists or a reordering of consumer preferences based on the (emotional!) argumentation of environmentalists, can be just as "competence-enhancing" or "competence-destroying" as the sudden appearance of a new artifact in the material world. Our research will investigate and explore this possibility.

To do so, I will draw upon some recent work by researchers investigating technological change who, rather than adopting a technologically deterministic stance, view technological change as being simultaneous with institutional and ideational change. This "coevolutionary" view seeks to reconcile what have until recently been competing views of technical change: technological determinism and institutional determinism. Within this view, difficult-to-predict processes of social construction and chance can play important roles in the emergence and lock-in on a technological trajectory (Arthur, 1989; Van de Ven & Garud, 1993)

In particular, I wish to employ a coevolutionary model first developed to explain events in the "era of ferment" of a technological cycle, following the appearance of a "new product class". This is the model of Garud & Rappa (1994). In their study of the development of cochlear implants for improving hearing in the deaf, they documented the coevolution of researchers' *beliefs* or expectations about what was considered technically feasible and desirable with the physical technological *artifacts* they created, and with the *evaluation routines* they employed to measure how well their artifacts met their expectations. The model flowing from that work is presented in Figure 1.2.3.2.2.

Figure 1.2.3.2.2. - A Socio-Cognitive Model of Technology Evolution



* Figure is from Garud & Rappa (1994).

The work of Garud & Rappa (1994) focused on events just subsequent to the appearance of a new technology: its entry into the marketplace, and the competition during this period between radically different designs. Their work showed how, at a macro level, a process of institutionalization occurs wherein a common set of beliefs about the technology and the evaluation routines used to distinguish "better" artifacts from the rest become shared amongst researchers as the dominant design crystallized and became more widespread. In addition, on a more micro level, they identified a process of "inversion" wherein the evaluation routines used by individual researchers reinforced their existing beliefs; claims about artifacts that invoked other evaluation criteria were seen as less relevant and were perceived as noise rather than as information.

I believe that their model will be of much use in understanding our focal phenomena of substitution, but I will apply it (1) over longer time frames and (2) across a wider set of actors. Their model was developed by examining only the era of ferment following the appearance of a new technology. They demonstrated how these three constructs -

artifacts, beliefs, and evaluation criteria - came to demonstrate mutual consistency as the dominant design emerged. I wish to examine and track the evolution of these three constructs over the *complete* technology cycle presented above.

If one combines their model with the work of Anderson and Tushman (1990), it becomes clear that the latter isolate "artifacts" as the sole locus of "technological discontinuities" and as the engine of their technology cycle. But I suspect that when it comes to those substitution processes motivated by environmental and health problems, ideational and institutional discontinuities reflected in "beliefs" and "evaluation routines" may also be very important.

Hence this research will explore the possible connections between these two well-accepted models of technological change: cyclical and coevolutionary.

1.2.3.3 Substitution and theories of interorganizational domains

Finally, another literature that offers valuable insights into the focal phenomena of substitution, although it does not specifically address it, is that on interorganizational relations, collaboration and the development of problem domains (Emery & Trist, 1965; Trist, 1983; Hardy, 1994). Trist (1983) argues that one characteristic of modern complex societies is the emergence of sets or systems of problems, sometimes termed meta-problems, problématiques or messes. What characterizes these problems is that their resolution is beyond the capacity of any one organization, necessitating interorganizational interaction and perhaps collaboration at the *domain level,* where domains are defined as *"functional social systems which occupy a position in social space between the society as a whole and the single organization".* Certainly the unintended and undesirable consequences of chemical products have given rise to or become intimately associated with a number of "problems" around which domains have developed: cancer, ozone holes, endocrine disruption, etc. And, frequently, resolution of these "problems" involves our focal phenomena of substitution of one product for another.

The importance of the ideas and cognitive events to the formation and maintenance of domains is highlighted in this literature. *"It is important to realize that domains are cognitive as well as organizational structures. Domains are based on ... acts of appreciation, ... a complex perceptual and conceptual process which melds together judgments of reality and judgments of value"* (p 273).

This raises fundamental questions relating to those events prior to and during the social construction of problem domains. The physical, chemical and biological consequences of controversial substances around which problem domains are constructed - and which can lead ultimately to our focal phenomena of substitution - are "real" and have an existence prior to and independent from their perception by organizational actors: tumours grow, birds die, ozone molecules are reacted away, etc. So how does a "problem domain" *become* in the first place? How is it that a "problem" is recognized, framed and named as such? What events must occur for a focal problématique to come into existence in the minds of problem domain participants? To capture their attention? Their imagination? Their hearts? Their wallets? Who participates in this process? What roles do they play? Who is excluded? Whose *evaluation routines* and *beliefs* are invoked in this process? What if no consensual conceptualization or even language to express the problem can be found? Who is granted a "voice" in conversations and discourses relevant to the "problem" and why? And what if the legitimacy of certain actors is contested? All of these interesting questions are relevant to building a comprehensive model of substitution.

Let's juxtapose the construct of *problem domain* with that of *industry*. I suggest here that these two concepts are tightly linked: an "industry" can be considered as a particular kind of simple problem domain organized around a "problem" that is defined by a set of only two actors - manufacturers and customers. An industry is a hyper-organized and uncontested "problem domain" as Trist (1983) and Gray (1985) define them. When firms and their customers interact to define and solve a problem through the design, manufacture and sale of a product or service, we call this an "industry". If others, like NGOs, activists or politicians for instance, get involved and try to alter their interactions - by demanding that a product design be changed or even that a particular product be banned - we call this a "problem domain".

Are not certain types of "problems" *appropriated* by existing industries? Firms, their customers and embedding regulatory agencies are continuously "problem-setting", "direction-setting" and "structuring" (Gray, 1985). They share a common conceptualization (Gray, 1985) and language (Gray, 1985) of the "problems" they are trying to collectively solve and for the most part these actors just get on with this task - without outside interference - through marketplace competition, innovation, technological change, all of which are captured within traditional conceptions of strategy. Contestation occurs *within* these *domains characterized by exchange*, and the place of an individual firm or product can rise or fall through intra-industry competition. But the activities within industries - domains characterized by exchanges - and what are considered the legitimate assumptions, aims, concerns and preoccupations of actors therein, and how they fit into the larger socio-economic system, are uncontested.

I suggest that what researchers label "problem domains" linked to environmental or health problems are attempts by "excluded" actors and stakeholders to interrupt and alter particular industry *exchanges*. They are attempts to interrupt and alter *conversations* between customers and manufacturers about how to operationalize product performance. They are attempts to enter into discussions relevant to the design of a product and to have their concerns, preoccupations and interests - their piece of the "problem" as they see it - included in the calculus of product design decisions made by industrial actors.

In other words, only after the efforts of "new entrants" into conversations about product design did it become "normal" to believe such things as: agricultural chemicals should be designed so as not to cause an unacceptable risk of cancer; industrial solvents should be designed so as to not cause an unacceptable risk of reproductive dysfunction in those handling them; automobile fuels should be designed so as to not be implicated in lead poisoning; refrigerants should be designed so as to not contribute to ozone holes; etc. Industries which were functioning "normally" (or at least without incident) with a particular operationalization of product "performance" suddenly become linked with or give rise to particular "problems" and the interorganizational domains constructed around them. Attempts to resolve or cope with the problems follow, as the ideas and concerns of a now wider set of actors are brought to bear on the industry's products. In the limit, the resolution of these problems can lead to the focal phenomena of substitution.

This brings me to back to an important theoretical question for strategists that this research will explore: which societal *conversations* are important and relevant to the maintenance of which *exchanges*? Whose beliefs and values, whose mental models, whose "talk", and which *discourses* are relevant to the perceived efficiency, efficacy, legitimacy, acceptability - and ultimately, the *substantive* or *utility value* - of products?

This is a very important but much neglected question for a discipline like strategy which purports to address how to "create" and "add" value for firm success. Certainly customers are important. and microeconomic models wisely focus on their cost-benefit calculus. But a complete answer, I believe, extends far beyond this one set of actors, to include scientists and engineers, regulatory agencies, citizens, and legislators as well as manufacturers of complementary products, customers of customers, etc. It is clear that, left *talking* amongst themselves, chemical manufacturers and their customers would certainly not formulate the same set of problems and issues related to a particular product as those addressed once other actors succeed at "constructing" a "problem domain" and inserting themselves into the process of discussing and resolving it.

Recall the substances mentioned earlier in our presentation of what has motivated our research - DDT, PCBs, CFCs, tetra-ethyl lead, and methyl bromide. The value of these substances (i.e. products) *and* of the patents, machinery, skills and expertise for producing them (i.e. resources), would appear to have been "creatively destroyed" through particular "talk" by a number of different "talkers" as much as it was through the particular "actions" of actors like industry rivals or the producers of substitute substances.

This suggests that firm strategy may involve "patterned talk" as well as "patterned action". A conception of firms as participants in and/or dependent upon particular *discourses* as well as *exchanges* will, I believe, be necessary to develop realistic and comprehensive models of "creative destruction" in social systems and our focal phenomena of substitution.

1.3 Conclusion

This Chapter has described the practical and theoretical concerns that have motivated the research presented in this dissertation. These were connected by a conceptual bridge built around the notion of **substitution,** which is the focal phenomena investigated in the study. A literature review presented and summarized theorizing about this focal phenomena within the discipline of strategy, identified some gaps, and throughout suggested important concepts and avenues for investigation to orient exploratory research.

This research seeks to get beyond the shortcomings of current approaches outlined in this Chapter in a number of ways:

> (1) The threat of substitutes is an important but little-researched component of sustainable competitive advantage. Prior research on sustainable competitive advantage has tended to treat demand as exogenous and has focused on the dynamics of industry *supply* and the *scarcity* dimension of *value*. The research presented in this dissertation investigates the dynamics of *both supply and demand* and the *utility* dimension of value.
>
> (2) Substitution, in both the sustainable competitive advantage and technology evolution literatures, tends to be studied in purely economic terms; actors' actions are assumed to be governed by their *objective assessment of the relative performance/price ratios of alternative artifacts.*

The research presented in this dissertation investigates the possibility that *product performance is subjectively defined and historically contingent, arising out of processes of social construction and negotiation.*

(3) Whereas much prior research on technology evolution and substitution has been conducted around the notion of *industry* and the institution of the market, the research presented in this dissertation investigates a wider set of actors, organizations and social institutions at the higher level of analysis of *interorganizational domain.*

(4) Whereas much prior research on technology evolution and substitution has focused attention squarely on the *material realm of competing products* (or "technologies" or "artifacts"), the research presented in this dissertation investigates *both the material and ideational realms.*

(5) Whereas much prior research on technology evolution and substitution has a bias towards looking at the innovation process, commercialization and the *entry* into markets of *new* products, the research presented in this dissertation investigates *old* products and the processes involved in their *exit* from markets.

In the next Chapter, a methodology is outlined for exploratory research which aims to contribute to building a more comprehensive theory of substitution.

2 Research Design and Methodology

2.1 Research Questions

The most general statement of my research question is as follows:

What is the process by which one product substitutes for another one?

Substitution is the focal phenomena under investigation in this research. A comprehensive model of this process would describe not only uncontroversial instances of product substitution, but also those instances of substitution driven by environmental and health problems. To explicitly capture these *practical concerns*, the research question can also be expressed as follows:

What is the process by which products enter the economy, enjoy commercial success, then come to be viewed as unacceptably damaging to the environment and/or human health, with their subsequent use dramatically reduced as they are substituted for by alternative products?

The rest of this Chapter describes the design and methodology of the theory-building research undertaken and presented in this dissertation

2.2 A Single Exploratory Case Study

This research project examined processes of substitution associated with the entry into and exit from the economy of a chemical substance which were linked to unintended and undesirable environmental and health consequences of its use. The research design was of the type *"single case study, with embedded (multiple) units of analysis"* (Yin, 1989, p 23).

"A case study is an empirical inquiry that: investigates a contemporary phenomena within its real-life context; when the boundaries between phenomena and context are not clearly evident; and in which multiple sources of evidence are used."

(Yin, 1989, p 23).

"The case study is a research strategy which focuses on understanding the dynamics present within single settings"

(Eisenhardt, 1989)

Given that this research was aimed at theory-building and sought to answer questions of "how and why" related to a longitudinal change process, it was appropriate to begin with an initial exploratory case study (Eisenhardt, 1989; Yin, 1989). I did indeed investigate the dynamics of a contemporary phenomena (the process of eliminating a controversial substance from the economy) for which the boundary between the phenomena and context was not clear (this process was a complicated one involving the coevolution of industries, institutions and problem domains) by drawing upon multiple sources of evidence (documents, archives, and interviews). The unit of analysis was "incidents of product substitution" and was multiple because the substance investigated exited different markets and jurisdictions at different times, at different rates, and for different reasons.

2.2.1 Purpose, Brief Description, and Criteria of Success

In the absence of hypotheses to be tested, exploratory research should begin with a statement of its purpose and the criteria to be used to judge its success (Yin, 1989).

At the outset of this research, two objectives were set. The first objective of the research was one of *description* of processes of substitution. Hence, in this dissertation I documented the events of the case, in a structured manner, capturing "what happened" and "who did or said what, when and why?" in everyday language. The second objective of the research was one of *explanation* of processes of substitution. Hence, I then compressed the description, through a process of qualitative analysis, into a more abstract, generalizable language comprised of a parsimonious set of constructs.

This case study employed a strategy of *"direct research"* (Mintzberg, 1979), although it was conducted from a perspective that is wider than that typically associated with that methodology. The research is built around the history of a substance around which controversy arose due to unintended and undesirable environmental and health effects attributed to it. Rather than investigate one actor and their strategy (as did, for example, Mintzberg & Waters (1982), or Mintzberg & McHugh (1985)), I identified and investigated a "system of actors" whose activities and "strategies" were relevant to the process of removing the substance from the economy.

I wish to underline here that the focus was on this **system** of actors and strategies, and NOT a single decision by a regulatory body, or customer, or company. Decision-making figures prominently in this research, but was not its focus. This language of systems is helpful for restating the study's objectives: (1) to develop a useful description of the system, (2) to describe the system's dynamics, and (3) to link system dynamics with outcomes.

The criteria of success that I set for my characterization of processes of substitution was agreement amongst the members of my dissertation committee as to the practical and theoretical contributions of my findings.

2.2.2 Case Selection

This case study focuses on a substance from the family of agricultural chemicals known as organochlorines which were introduced into economies - and hence also into ecosystems and into human bodies - just subsequent to World War II. The most (in)famous of this class of substances is the insecticide dichlorodiphenyltrichloroethane (DDT) which, because of the comparative wealth of documentation available, was selected as the focal product for this study of substitution. I describe and explain processes of substitution in which this molecule was involved in both possible roles - as the incoming challenger product as well as the outgoing incumbent product (i.e. I describe and explain both DDT's *entry into* and *exit from* the economy). Geographically, I confine the case study to that area set by the borders of the United States. Temporally, I track the fate of this molecule for more than a century, from its synthesis in 1874 until today, although the climax of our story comes in 1972 when it was formally banned in the United States.

My choice converged on this case study because the history of this substance has *"rare or unique"* qualities that, besides further justifying our "single case study" research design (Yin, 1989), make it attractive from both a theoretical and practical perspective. It makes sense to choose cases such as extreme situations and polar types in which the process of interest is *"transparently observable"* (Eisenhardt, 1989). Just as medical researchers learn about "health" and the "normal" operation of the human body by studying disease and dysfunction, it was anticipated that a study of an extreme and pathological case of product substitution would be revealing of dimensions of more mundane "normal" substitution processes that are perhaps too subtle and hidden to have attracted researchers' attention.

2.2.3 Theoretical Justification of Case Selection

The story of DDT stands out from those of other banned substances along dimensions which are of particular theoretical importance, justifying the selection of this specific case as a result of *"theoretical sampling"* (Yin, 1989; Eisenhardt, 1989).

First, cases of banned agricultural chemicals - as contrasted with banned molecules with pharmaceutical or industrial uses for instance - are particularly *complex*, involving *multiple* and *heterogeneous problem domains*. These cases would therefore be expected to be especially rich for theory-building. Indeed, one is struck by the sheer *diversity of problématiques* and hence *diversity of reasons* given for substituting pesticides. This diversity of problématiques, with the ensuing diversity of relevant institutional, industrial and non-governmental actors involved in these problem domains, enhanced the potential for comparison of different embedded units of analysis as well as the case's potential for theory-building (Yin, 1989).

Second, within the set of all agricultural chemicals for which substitution has occurred due to unintended and undesirable consequences (> 200 molecules), the case of DDT in particular has *"rare or unique"* qualities, as attributed by actors in the industry and associated problem domains. For example, as part of their 100th anniversary edition (1894 - 1994), the editors of the U.S. trade journal "Farm Chemicals" invited readers to nominate and vote on the *"top 10 events, products, people and regulations which have had the greatest industry influence"*, (Farm Chemicals, 1994, p D14). Our case study captures 2 of the top 10 events (the publication in 1962 of the book "Silent Spring" by Rachel Carson; the banning of DDT in the United States in 1972), 1 of the top 10 products (DDT), 2 of the top 10 people (Rachel Carson; William Ruckelshaus, the EPA administrator who banned DDT) and at least 4 of the top 10 regulations (the Federal Food, Drug and Cosmetic Act (FFDCA) of 1938; the Delaney Clause amended to it in 1958; the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) of 1947, which subsumed the Insecticide Act of 1910; and the Environmental Protection Act of 1970 giving rise to the Environmental Protection Agency (EPA)).

Finally, within the set of all agricultural chemicals for which substitution has occurred due to unintended and undesirable consequences (> 200 molecules), DDT stands out additionally by the dramatic extent of its fall from grace, as well as by the ongoing controversy it continues to sustain. Once hailed as *"one of the greatest scientific discoveries of the last decade"* (West & Campbell, 1950) and leading to a Nobel prize for the discoverer of its insecticidal properties, DDT would later come to be routinely described as a *"persistent organic pollutant"* by even its most ardent supporters. Immediately after its entry into commerce, DDT became the top selling insecticide in the United States with usage climbing to almost 80,000,000 lbs. annually at its peak, all of which was eventually substituted for.

2.2.4 Practical Justification of Case Selection

The story of DDT also stands out from those of other substances which have been substituted due to unintended and undesirable consequences for other, very practical reasons that make it attractive to investigators.

Of much importance, its infamous status has greatly facilitated *data collection*. For not only was the process of substituting DDT a very public one and *"transparently observable"* (Eisenhardt, 1989) for which written transcripts, archives and other documents are available, but reputable, scholarly histories also exist. Also, these official records, many of which come from hearing-like settings, record the voices of both the proponents and opponents of different views, which presented a unique opportunity for ensuring that a critical perspective was not lost. This is in the spirit of presuming a priori to case study research that *"all perspectives are valuable"*, which is advocated by methodologists (Taylor & Bogdan, 1984). In addition, the ongoing nature of the debates surrounding DDT - it is on a list of twelve substances which are currently the object of intergovernmental negotiations, spearheaded by the United Nations Environment Program (UNEP), aimed at achieving an "International Legally Binding Instrument for Implementing International Action on Certain Persistent Organic Pollutants (POPs)" - meant that interviews with actors directly and currently involved in the problem domain were feasible.

Finally, it was anticipated that this specific case would prove to be of particular practical value. One of the reasons to study the past is to avoid being condemned to repeat it. Many of the same institutional and industrial actors involved in the story of DDT and other organochlorines are currently major players in debates over new agricultural biotechnologies (agri-biotech). Indeed, having become familiar with the history of DDT and chemical-intensive agriculture in general, it is difficult not to be struck by the similarity of the discourse - both promotional and critical - currently surrounding agri-biotech with that documented in the DDT story. Whether or not transgenic crops will help us to *"feed the world"* as claims Monsanto's CEO Robert Shapiro (Magretta, 1997;

Benson, Arax & Burstein, 1997) or whether *"social problems aside, this new agricultural biotechnology is on much shakier scientific ground than the Green Revolution ever was"* as claim certain biologists (see, for example, Ehrenfeld, 1997), I make no claims of special knowledge. But, as a result of my analysis of the fascinating story of the rise then fall of DDT - the *"atomic bomb of insecticides"* - I do feel that I understand much better the underlying processes at work when technologies enter and exit the economy. I hope that readers have the same feeling when they finish reading this dissertation.

2.3 Case Study Method

2.3.1 Overview

The *direct research* methodology (Mintzberg, 1979) informed the data collection and data analysis efforts. Following Mintzberg's prescriptions, this research:

(a) began as purely descriptive as possible using real terms from the field;

(b) relied on simple, inelegant methodologies;

(c) was inductive yet systematic;

(d) included "reality checks" that findings were supported by anecdotal data from the field before drawing conclusions; and

(e) sought to synthesize and integrate diverse findings into an idealized model.

This method has previously been used to "track strategy", patterns in the decisions and actions which make up the histories of organizations. These histories were presented in terms which highlighted important dimensions and variables known a priori and traditionally captured by the notion of "strategy". From these histories, relationships linking various strategy variables were induced and theory thus built (Mintzberg & Waters, 1982; Mintzberg & McHugh, 1985).

My efforts were similar but differed in that the unit of analysis was not a single actor but rather a system or set of actors. This set of actors was comprised of individuals and organizations who were brought together around DDT and other pesticides and who hence comprised the pesticides "interorganizational domain". I defined the domain broadly and in line with the review of the literature; it included actors involved in both *exchanges* (who was manufacturing, selling, buying and using DDT?) and *discourses* (who was talking about DDT?) involving the focal product. Thus I tracked both the actions and texts produced by actors involved in the history of DDT, focusing particularly of course on instances of our focal phenomena of substitution.

2.3.2 Data Collection

One of the advantages of case study research over other methodologies is the opportunity to use multiple sources and types of evidence to achieve triangulation (Yin, 1989). This was exploited in this research. Of the six possible sources of case study data listed by Yin (1989), this research drew upon four. The main sources of data were (1) *archival records* and (2) *documentation*. These were supplemented by (3) *interviews* and five days of attendance permitting (4) *direct observation* of meetings of the "United Nations Environment Program's Inter-governmental Negotiating Committee for an Internationally Legally Binding Instrument for Implementing International Action on Certain Persistent Organic Pollutants (POPs)".

Temporally, as per the *direct research* methodology, I began with more general documentation, then shifted to interviews and archives later on.

> *"We first spend a good deal of time reading whatever historical documents we can find, in order to develop thorough chronologies of decisions in various strategy areas. We then switch to interviews to fill in the gaps in the decision chronologies and to probe into reasons for breaks in the patterns (i.e. for strategic changes)."*
>
> (Mintzberg, 1979, p 106).

Table 2.3.2.1 illustrates the data collection process, while Table 2.3.2.2 lists interviewees. Given the historical nature of this research, opportunities for interviews were limited but these were capitalized upon. I must say that one of the highlights of this research was having tea with Ms. Shirley Briggs, a longtime friend of Rachel Carson, the author of *Silent Spring*. In addition, I did manage to track down interviews with a number of actors important to the case study which had been conducted by an historian and archived.

Table 2.3.2.1 - Data Collection

DOCUMENTATION: BACKGROUND & CONTEXT DATA

• To familiarize myself with the issues and the terminology used to discuss them.
- entomology textbooks, pest management textbooks, pest management handbooks
- POPs negotiations briefing documents; POPs reports and position papers of NGOs, industry, and governments
- chemical industry trade journals
- agricultural chemicals databases and handbooks
- descriptions of pesticide regulations and other EPA documentation

↓

DIRECT OBSERVATION

United Nations Environment Program's Intergovernmental Negotiating Committee for an Internationally Legally Binding Instrument for Implementing International Action on Certain Persistent Organic Pollutants
(first session: Montreal, 1998 06 29 - 1998 07 03)

• To further familiarize myself with issues and terminology.
• To establish contacts and to hear first-hand the arguments of important actors.

↓

SECONDARY DATA SOURCES: DOCUMENTATION

• To familiarize myself quickly with the case study (products, markets, actors, etc.).
• To build the first draft of the "event history database".
• To exploit authors' footnotes, endnotes and bibliographies in uncovering relevant primary sources.

see Table 2.3.2.3 - Important Secondary Sources

SECONDARY DATA SOURCES: INTERVIEWS

• To familiarize myself quickly with the case study (products, markets, actors, etc.) described in the language of observers, analysts of the case.
• To build the first draft of the "event history database".

see Table 2.3.2.2 - Interviewees

↓

PRIMARY DATA SOURCES: ARCHIVES & DOCUMENTATION

• To complete & to triangulate the "event history database".
• To read and to interpret first-hand important archival records and various documents as they evolved through the years.
- scientific articles and books (entomology, wildlife biology, ecology, medicine)
- student textbooks (economic entomology)
- popular press articles (ex. New York Times, Time, Newsweek, New Yorker, Science, etc.)
- books on DDT; CBS TV documentary on DDT
- government reports, transcripts from public hearings, speeches

PRIMARY DATA SOURCES: INTERVIEWS

• To hear and to capture case study events, described in the language of actors in the case.
• To understand actors' attributions of importance and significance to certain events.

see Table 2.3.2.2 - Interviewees

Table 2.3.2.2 - Interviewees

Eleven hours of tape recorded interviews recorded in 1971-72 (each 30 - 90 minutes) with **participants in the Wisconsin DDT hearings of 1968-69**, obtained from Archives Division of the State Historical Society of Wisconsin. Interviewees were interviewed by historian Thomas R. Dunlap as part of his Ph.D. dissertation research, which was eventually turned into his 1981 book.

- R. Keith Chapman, University of Wisconsin entomologist; witness for DDT

- Francis B. Coon, analytical chemist and Director of the Wisconsin Alumni Research Foundation (WARF) Laboratories Pesticide Analysis Section

- E.H. Fisher, entomologist and Coordinator of Pesticide Use Education at the University of Wisconsin; witness for DDT

- Joseph Hickey, University of Wisconsin wildlife ecologist and expert on eggshell thinning; witness against DDT

- Hugh Iltis, University of Wisconsin botanist; witness against DDT

- Orie Loucks, University of Wisconsin botanist; witness against DDT

- Lorrie Otto, housewife & local activist against DDT who brought the Environmental Defense Fund (EDF) to Wisconsin

- Maurice Van Susteren, Hearing Examiner of the Wisconsin Department of Natural Resources

- Charles F. Wurster, Jr., biochemist/ecologist and co-founder of the Environmental Defense Fund; witness against DDT

- Victor J. Yannacone, Jr., lawyer and co-founder of the Environmental Defense Fund who called witnesses against DDT and cross-examined witnesses for DDT

Table 2.3.2.2 (continued) - Interviewees

Formal interviews undertaken by myself in 1998-99 (each 30 - 150 minutes) with **participants in the historical &/or ongoing debates over DDT, organochlorine pesticides and POPs**

- Arnold Aspelin, Senior Economist at the Environmental Protection Agency; was the EPA economist who compiled a major 1975 document reviewing the EPA's decision to ban DDT; spent 5 days testifying at subsequent DDT hearings; is currently working on what will become an official EPA manuscript documenting the history of pesticide usage in the United States. *After our interview, I showed him my "event history database", we exchanged idea and I went over my findings.* ***At that point, he requested that I act as peer reviewer for his manuscript.*** *This unexpected reversal of roles confirmed my own growing sense that I had achieved "saturation" in terms of data collection and analysis, at which point I turned my attention to writing.*

- Shirley Briggs, longtime friend of Rachel Carson; recently retired as head of the Rachel Carson Council which she had helped found; author of *Basic Guide to Pesticides* (1992).

- Leonard Gianessi, Senior Research Associate, National Centre for Food & Agricultural Policy; industry analyst; has appeared frequently before Congress for industry and others as a neutral witness; was referred to my by the American Crop Protection Association (ACPA).

- Ed Glass, retired Professor of entomology at Cornell University at the New York State agricultural experiment station in Geneva, New York and an expert on pest management in apple and pear orchards; intimately involved with DDT, especially its introduction into then exit from use against the codling moth in apple orchards; currently writing a 100 year history of the Geneva state agricultural experiment station in Geneva New York

- George Larocca, Product Manager in the Registration Division (RD) of the Environmental Protection Agency; involved with organochlorines

- Gordon Lloyd, Vice President of Technical Affairs, Canadian Chemical Producers' Association

- Bill Murray, Senior Project Manager in the Regulatory Affairs & Innovations Division of the Pest Management Regulatory Agency (PMRA) at Health Canada

- Karen Perry, Associate Director of the Environment & Health Program of Physicians for Social Responsibility; Chief Coordinator of the International POPs Elimination Network (IPEN), an NGO seeking global elimination of DDT.

- David Pimentel, Cornell entomologist and renowned pest management expert; author of numerous books on pest management; member of several important and prestigious committees assembled by the U.S. government, including those that authored the Mrak Report of 1969.

- Jim Roelofs, expert on organochlorine pesticides at the EPA, and recipient of that organization's Silver Medal for Superior Performance *"for excellence developing the technical support document and concluding a negotiated settlement with industry on the pesticide chlordane."*

- James Skaptason, Assistant to the Director of the Biopesticides and Pollution Prevention Division (BPPD) of the EPA

- Morag Simpson, Toxics Campaigner at Greenpeace, Toronto

- John T. Trumble, Professor in the Department of Entomology, University of California; Chair of Section F (Crop & Urban Pest Management) of the Entomological Society of America

Table 2.3.2.2 (continued) - Interviewees

Others involved in the pesticides and POPs domains with whom I had informal conversations, exchanges of ideas, or who answered specific questions about DDT and other POPs in 1998-99.

- Craig Bojkovac, World Wildlife Fund, Canada

- Clifton Curtis, World Wildlife Fund, United States

- Suzanne Fortin, Project Manager, Regulatory Affairs, Pest Management Regulatory Agency, Health Canada

- Mr. Thomas J. Gilding, Director of Environmental Affairs in the Government Affairs Department of the American Crop Protection Association

- Julia Langar, World Wildlife Fund, Canada

- Bill Marshall, Professor of Food Science & Agricultural Chemistry at McGill University

- Monica Moore, Program Director at the Pesticide Action Network at their North American Regional Center

- James E. Throne, current editor of *Journal of Economic Entomology*; Research Leader, Biological Research Unit USDA-ARS Grain Marketing and Production Research Center

- Jack Weinberg, Senior Toxics Campaigner from Chicago; POPs Team Leader for Greenpeace International

I wish to say a few words here about secondary data, which played a very important role in this research. Well-documented histories of the science and technology of pesticides as well as histories of the relevant government policies and regulatory frameworks exist and are readily available and were drawn upon. In addition, the particular case of DDT has attracted the attention of historians and other scholars who have prepared books and articles. These too were drawn upon. To show my appreciation for the hard work of these authors, and to ensure complete transparency, they are listed in Table 2.3.2.3 - Important Secondary Sources. All sources are cited or referenced appropriately throughout this dissertation.

These histories served primarily to help me (1) to reconstruct the series of events relevant to the life of DDT, and (2) to locate primary data sources by mining authors' footnotes, endnotes and bibliographies. With recourse to primary data and having multiple secondary accounts, I was able to check and triangulate important "facts". I also sought out the opinions of relevant experts as to the quality of various secondary data sources, as well as for their suggestions of additional accounts I should get, be it by retrieving particular documents or by interviewing particular people. For example, in my search for respected and trustworthy sources, I began by contacting the Entomological Society of America and the Journal of Economic Entomology, who directed me to a number of my interviewees. I also contacted government officials as well as representatives of environmentalist NGOs. When checking and triangulating, efforts were made to ensure balance by accessing, where possible, both "pro-DDT" accounts and "anti-DDT" accounts of events.

Wherever possible, recourse was made to original archives and documents. Ultimately, my research led me to collect, read and analyze a wide variety of scientific articles and books, textbooks, government reports, industry documentation, popular press articles, and popular books dealing with DDT and other pesticides through the years. I have accumulated a sizable DDT library.

Table 2.3.2.3 - Important Secondary Data Sources

Blodgett, John E., 1974 "Pesticides: Regulation of an Evolving Technology" in Epstein, Samuel S. & Grady, Richard D., (eds.), *Legislation of Product Safety*, MIT Press, Cambridge, MA 197 - 287

Bosso, Christopher J., 1987, *Pesticides and Politics: The Life Cycle of Public Issue*, University of Pittsburgh Press, Pittsburgh, PA

Brooks, Gerald T., 1974, *"Chlorinated Insecticides: Volume I - Technology and Applications & Volume II - Biological and Environmental Aspects"*, CRC Press, Cleveland, OH

Buckley, John, 1986, "Environmental Effects of DDT", in Committee on the Application of Ecological Theory to Environmental Problems, Commission on Life Sciences, National Research Council, (ed.), *Ecological Knowledge and Environmental Problem-Solving: Concepts and Case Studies*, National Academy Press, Washington, DC, 358-374

Casida, John E. & Quistad, Gary B., 1998, "Golden Age of Insecticide Research: Past, Present or Future", *Annual Review of Entomology*, 43, 1-16

Daniel, Pete, 1990, "A Rogue Bureaucracy: The USDA Fire Ant Campaign of the Late 1950s", *Agricultural History*, 64, 2, 99-115

Davis, Kenneth S., 1971, "The Deadly Dust: The Unhappy History of DDT", *American Heritage*, 22 (Feb 1971), 44 - 47 & 91 - 92

Dunlap, Thomas R., 1978, "DDT on Trial: The Wisconsin Hearing, 1968-1969", *Wisconsin Magazine of History*, Autumn 1978, 2-24

Dunlap, Thomas R., 1978, "Science as a Guide in Regulating Technology: The Case of DDT in the United States", *Social Studies of Science*, 8, 265-285

Dunlap, Thomas R., 1981, *"DDT: Scientists, Citizens and Public Policy"*, Princeton University Press, Princeton, NJ

Edwards, Clive A., 1973 (first edition) & 1975 (second edition), *Persistent Pesticides in the Environment*, CRC Press, Cleveland, OH

Flippen, J. Brooks, 1997, "Pests, Pollution and Politics", *Agricultural History*, 71, 4, 442-456

Graham, Frank, Jr., 1970, *Since Silent Spring*, Houghton Mifflin Company, Boston, MA

Gunter, Valerie J. & Harris, Craig K., 1998, "Noisy Winter: The DDT Controversy in the Years before *Silent Spring*", *Rural Sociology*, 63, 2, 179-198

Hayley, Denis, 1983, *The Catalyst: The First Fifty Years of NACA*, National Agricultural Chemicals Association (NACA), Washington, DC

Henkin, Harmon, Merta, Martin, & Staples, James, 1971, *The Environment, the Establishment, and the Law*, Houghton Mifflin Company, New York, NY

Jones, D. Price, 1973, "Agricultural Entomology", in Smith, Ray F., Mittler, Thomas E., & Smith, Carroll N. (eds.), *History of Entomology*, Annual Reviews Inc with the Entomological Society of America, 307-332

Table 2.3.2.3 (continued) - Important Secondary Data Sources

Kogan, Marcos, 1998, "Integrated Pest Management: Historical Perspectives and Contemporary Developments", *Annual Review of Entomology*, 43, 243-270

Lear, Linda, 1992, "Bombshell in Beltsville: The USDA and the Challenge of *Silent Spring*", *Agricultural History*, 66, 2, 151-170

Lear, Linda, 1997, *Rachel Carson: Witness for Nature*, Henry Holt & Company, New York, NY

MacIntyre, Angus, A., 1980, *The Politics of Nonincremental Domestic Change: Major Reform in Federal Pesticide and Predator Control Policy*, Ph.D. diss., Univ. of California, Davis, CA

MacIntyre, Angus, 1985, "Administrative Initiative and Theories of Implementation: Federal Pesticide Policy, 1970-1976", in Ingram, Helen M. & Godwin, R. Kenneth (eds.), *Public Policy and the Natural Environment*, JAI Press, Greenwich, CT, 205-238

MacIntyre, Angus, 1987, "Why Pesticides Received Extensive Use in America: The Political Economy of Pest Management to 1970", *Natural Resources Journal*, 27, no 3, 533 - 578

Mellanby, Kenneth, 1992, *The DDT Story*, British Crop Protection Council, Farnham Surrey, UK

Perkins, John H, 1978, "Reshaping Technology in Wartime: The Effect of Military Goals on Entomological Research & Insect Control Practices", *Technology and Culture*, 19, 169 - 186

Perkins, John H., 1980, "The Quest for Innovation in Agricultural Entomology, 1945-1978, in Pimentel, David & Perkins, John H., (eds.), *Pest Control: Cultural and Environmental Aspects*, AAAS Selected Symposium 43, Westview Press, Boulder CO, 23 - 80

Perkins, John H., 1982, *Insects, Experts, and the Insecticide Crisis: The Quest for New Pest Management Strategies*, Plenum Press, New York, NY

Perkins, John H., 1983, "Insects, Food and Hunger: The Paradox of Plenty for U.S. Entomology", *Environmental Review*, 7 (spring 1983), 71 - 96

Russell, Edmund p. III, 1996, "Speaking of Annihilation: Mobilizing for War Against Human and Insect Enemies", *Journal of American History*, 82 (March 1996), 1505 - 1529

USDA Centennial Committee, 1963, *Century of Service: The First 100 Years of the United States Department of Agriculture*, Economic Research Service, USDA, Washington, DC

Wargo, John, 1996, *Our Children's Toxic Legacy: How Science and Law Fail to Protect Us from Pesticides*, Yale University Press, New Haven, CT

Whorton, James C., 1971, "Insecticide Spray Residues and Public Health: 1865-1938", *Bulletin of the History of Medicine*, 45, 3, 219-241

Whorton, James C., 1974, *Before Silent Spring*, Princeton University Press, Princeton, NJ

Wurster, Charles F., 1975, *The Decision to Ban DDT: A Case Study*, prepared for Study on Decision Making for Regulating Chemicals in the Environment, Environmental Studies Board, National Research Council, National Academy of Sciences, at the request of the U.S. EPA, contract number 68-01-2262

I did not - and do not - believe that case study research, even if it is exploratory and aimed at theory-building, can be conducted in the absence of theoretical predisposition, as desirable as this may be. Given the potentially infinite supply of raw data available to case study researchers, the data collection process itself can be seen as actually a process of *anticipatory data reduction*, even though "data reduction" is traditionally associated with the data analysis phase of research (Miles & Huberman, 1984). Methodologists have concluded that the up-front acknowledgement of theoretical predisposition only strengthens the ultimate research.

> *"A priori specification of constructs can also help to shape the initial design of theory-building research. Although this type of specification is not common in theory-building studies to date, it is valuable because it permits researchers to measure constructs more accurately. If these constructs prove important as the study progresses, then researchers have a firmer empirical grounding for the emergent theory."*
>
> (Eisenhardt, 1989)

The concepts which oriented data collection were those identified in my review of the literature, and flow from my framing of the research around the concept of ***substitution*** which I viewed as a phenomena arising from ***competition*** between different ***products*** in various ***markets*** (embedded within particular regulatory frameworks), the outcomes of which are influenced by the ***beliefs*** and ***evaluation criteria*** of important ***actors***, especially their notions of what constitutes desirable ***product performance*** as well as undesirable ***product problems***. Therefore, as data was collected it was coded at a general level as being pertinent to these constructs.

A couple of specific tools were used to facilitate and to organize my data collection. As secondary and primary data sources were being reviewed systematically, significant "events" were extracted and stored in an "event history database" (Van de ven & Poole, 1990; Garud & Rappa, 1994) with a standardized format. To give readers an idea of the level of detail and sorts of events contained therein, Table 2.3.2.4 gives some examples of the ultimate contents of this database of more than 400 individual records that require some 60 pages to print. In addition, the Reader's Guide to Periodical Literature, a bibliographic summary of the U.S. popular press, was reviewed systematically for the years 1935 - 1983 and titles of articles listed under the subjects "pesticides", "insecticides", and "DDT" - as well as ten other particular insecticidal substances, including products that DDT substituted for as it entered the economy as well as products that substituted for DDT as it exited the economy - were extracted and organized into a "DDT discourse database" that contains some 1290 records. Table 2.3.2.5 gives the records for the periodical *Business Week* as examples.

Table 2.3.2.4 - Some Examples of Records in Event History Database

1943	DDT full-scale field use against typhus	DDT was first used on a large scale by Allied forces to arrest a typhus epidemic in Naples in December of 1943 and early 1944. It was here that it earned its reputation as a "miracle" insecticide. By the end of the epidemic, some 3,000,000 individuals (local citizens and Allied troops0 had been dusted one by one. A squirt gun forced DDT powder into subjects sleeves, waistband, collar pants' cuff, hair and hat. This technique SUBSTITUTED for a cumbersome system of baking subjects' clothes, shaving their heads and body hair and then painting the shaved areas with an ovicide. At peak operation, 72,000 people were dusted on one day. It became standard for British troops to wear DDT-impregnated shirts.
1945	Methoxychlor introduced by Geigy and DuPont as Marlate	Methoxychlor is a non-systemic contact and stomach insecticide introduced by Geigy and DuPont in 1945. Methoxychlor had similar, though slightly weaker, toxicities to a broad range of insects but it did not appear to accumulate in the body fat of animals or be excreted in the milk of dairy cows. Methoxychlor later SUBSTITUTED for DDT in its use for fly control in dairy barns.
1946	DDT recommended by USDA for some crops.	For the 1946 crop year, the USDA recommended DDT noting: no case of human poisoning had been brought to the attention of the Bureau of Entomology and Plant Quarantine; DDT's effect on higher animals was much less than the insecticides currently in use (arsenicals and nicotine). Formulations were recommended for home pests such as houseflies, bedbugs, ticks, ants, lice, fleas and mosquitoes. Other mixtures were recommended for shade trees and sugar beet grown for seed. Cabbage could be sprayed to control cabbage caterpillars, but before 30 days prior to sale of the crop. DDT was not recommended for cereal products or stored grains to be used for food. Seed grains could be sprayed however and DDT was subsequently applied to the walls and woodwork of storage areas. Instructions were also developed for cotton crops.
1962	President Kennedy fields questions on DDT at a White House press conference on Aug 29, 1962.	Subsequent to the serialization of Rachel Carson's Silent Spring, President Kennedy fields questions on DDT at a White House press conference on Aug 29, 1962. he answered that yes, he had asked the USDA and the PHS to take a closer look at the long term side effects of its use.
1969	Arizona DDT ban.	1 yr. moratorium for agricultural uses in Arizona

* A fourth field in each of these records exists but is not displayed. It captures "sources".

Table 2.3.2.5 - Some Examples of Records in DDT Discourse Database

41/43	Insecticides	Bus Week	More than cooties: insecticide supplies adequate for 42	May-42
43/45	DDT	Bus Week	DDT upsurge	Feb-44
43/45	Insecticides	Bus Week	Corn pest killer: compound is mixed with fertilizer to combat larvae	Apr-44
43/45	DDT	Bus Week	What's coming in chemicals war on bugs; report to executives	Nov-44
43/45	DDT	Bus Week	DDD or DDT: trademark fight	Dec-44
45/47	DDT	Bus Week	For man or beast, DDT routes airborne tormentors	Jul-45
45/47	DDT	Bus Week	Killer at large	Aug-45
45/47	DDT	Bus Week	DDT paint tested	Sep-45
45/47	DDT	Bus Week	More reports on DDT	Mar-46
47/49	DDT	Bus Week	New jobs for DDT	Feb-48
49/51	DDT	Bus Week	DDT scare	Apr-49
49/51	DDT	Bus Week	DDT aftermath	May-49
51/53	Insecticides	Bus Week	How the battle is going	Jul-51
51/53	Insecticides	Bus Week	But the bugs are eating it up	Feb-52
55/57	Insecticides	Bus Week	personal business	Jun-55
55/57	Insecticides	Bus Week	Tighter control sought on lethal spray sales	May-56
61/63	Insecticides (injurious effects)	Bus Week	Are we poisoning ourselves? Storm of controversy over Silent Spring	Sep-62
63/65	Pesticides (injurious effects)	Bus Week	After Weisner report: feeling little pain; pesticide manufacturers	May-63
63/65	Pesticides (injurious effects)	Bus Week	verdict on pesticides: guilty: tighter federal control	May-63
63/65	Pesticides (injurious effects)	Bus Week	GHQ for pollution fighters: controversy over fish killed by pesticides	Apr-64
67/68	Pesticides (injurious effects)	Bus Week	Science predicts a growing danger: Legator-Verrett report on pesticide effects on humans	Mar-67
69/70	DDT	Bus Week	DDT ban sprays a wilting business	Nov-69
69/70	DDT	Bus Week	DDT: where will the ban stop	Jan-70
70/71	Pesticides	Bus Week	Weeding out the pesticides	Sep-70
71/72	Pesticides	Bus Week	Plague descends on pesticides	Jul-71
71/72	Pesticides (laws regulations)	Bus Week	pesticide bill that industry can live with	Nov-71
72/73	DDT (injurious effects)	Bus Week	Defeat for scientific integrity: scientists testifying in DDT hearing	Jul-72
72/73	Pesticides	Bus Week	pesticides bloom in the wet spring	Jul-72
72/73	DDT	Bus Week	DDT may profit from law's delay	Nov-72
73/74	DDT	Bus Week	Tussock moths gnaw at ban on DDT	Sep-73
76/77	Insecticides (injurious effects)	Bus Week	How the Kepone case threatens the cities	May-76
76/77	Pesticides (injurious effects)	Bus Week	Pesticide quandary in Canadian forests: possible link between spruce budworm pesticides and Reyes syndrome	May-76
77/78	Pesticides (injurious effects)	Bus Week	Sterility scare sends OHSA scurrying	Sep-77
80/81	Pesticides (laws and regulations)	Bus Week	California makes EPA look lenient	Mar-80
81/82	Pesticides (patents)	Bus Week	Drive to extend the life of patents (pharmaceuticals and pesticides industries)	Feb-81
81/82	Pesticides	Bus Week	Medfly could be here to stay	Sep-81
81/82	Pesticides (injurious effects)	Bus Week	Medfly: spreads a pesticide panic	Nov-81

* From Reader's Guide to Periodical Literature, 1935-1982

2.3.3 Data Analysis

Qualitative case study data analysis includes the activities of (1) data reduction, (2) data display, and (3) conclusion drawing with verification (Miles & Huberman, 1984). This third activity can be seen to include tasks related to shaping hypotheses and enfolding literature, suggested by Eisenhardt (1989) as being important to theory-building case study research. Each of these authors stresses the highly iterative nature of these three activities.

My data analysis began during the data collection phase, which is appropriate for theory-building research: *"Overlapping data analysis with data collection not only gives the researcher a head start in analysis but, more importantly, allows researchers to take advantage of flexible data collection"* (Eisenhardt, 1989). Throughout the research, my ideas and thoughts as to potential avenues for conceptualization of the case and aspects of it were recorded in a "field note database".

I used four main techniques to achieve data reduction and data display in our analysis: (1) the preparation of *chronologies* and the display of important variables as a function of time; (2) the preparation of *tables*; and (3) the preparation of *material and information flow diagrams*; and (4) selective *content analysis* via *coding* of important data. The utilization of these techniques was quite standard (see Eisenhardt (1989) for an excellent discussion of "analyzing within-case data"), and none requires much comment here, although I do wish to address their relative importance.

Because we sought to develop a model of a process, it was natural that chronologies played an important role in our analysis. Chronological display is at the heart of the direct research methodology (Mintzberg & Waters, 1982; Mintzberg & McHugh, 1985). Tables were also important tools because this case study sought to draw together data from diverse sources that is not usually found together. Through these, I harnessed the power of juxtaposition. Since the ultimate goal was a process model, it was natural that flow diagrams were important tools. My theoretical disposition led me to favour flow diagrams which highlighted and contrasted material flows and information flows. Where did DDT go physically (material flows)? Then who subsequently talked about or produced knowledge of this, and how (information flows)? And how did this information then feed back into subsequent material and information flows? Did it affect processes of substitution? These sorts of questions were asked and addressed in the analysis. Finally, I have qualified the use of content analysis as "selective". This is because the volume of potential textual material upon which content analysis could have been performed was enormous. Feasibility considerations necessitated being highly selective of the use of this technique.

In executing this research, the suggested techniques of methodologists for achieving validity and reliability were employed where feasible. Table 2.3.3.1 summarizes these.

Table 2.3.3.1 - Considerations of Validity and Reliability

Throughout the design and implementation of this research methodology, steps have been taken to increase or ensure both reliability and validity.

Achieving **construct validity** means *"establishing correct operational measures for the concepts being studied"*. Steps taken to ensure construct validity include:

- use of multiple sources of evidence to achieve *convergent validity* (Yin, 1989; Leonard-Barton, 1990)
- iterative tabulation of evidence for each construct (Eisenhardt, 1989)

Ensuring **internal validity** means *"establishing a causal relationship, whereby certain conditions are shown to lead to other conditions, as distinguished from spurious relationships"*. Steps taken to ensure the internal validity of findings include:

- use of time-series analysis and chronologies (Yin, 1989; Miles & Huberman, 1984)
- search for evidence of the "why" behind any posited relationships (Eisenhardt, 1989)
- iterating the activity of conclusion drawing with verification (Yin, 1989; Eisenhardt, 1989)
- demonstrating why rival hypotheses and conclusions cannot be supported by the case study evidence (Yin, 1989)
- comparison with conflicting literature during enfolding of literature (Eisenhardt, 1989)

Enhancing **external validity** or generalizability means *"establishing the domain to which a study's findings can be generalized"*. Steps taken to increase the generalizability of findings include:

- use of existing constructs from the literature to guide initial data collection and analysis (though none of these were guaranteed a place in any resultant theory)
- comparison with confirming literature during enfolding of literature (Eisenhardt, 1989)

Achieving **reliability** means *"demonstrating that the operation of the study, such as the data collection procedures, can be repeated with the same results"*. Steps taken to achieve reliability include:

- maintenance of a case study data base with data itself, a description of the procedures used to collect it, and cross-references from the data to the final report (Yin, 1989)
- inclusion of extensive field notes (or "case study notes" using the terms of Yin (1989)) in case study data base (Eisenhardt, 1989)

* Definitions in italics are from Yin (1989, p 40).

2.3.4 Findings

As is the case with qualitative research, not all of this analysis was equally fruitful, and false starts were common. On the other hand, some very promising but finely-grained analyses are still in progress, having proved more time-consuming than expected. In other words, this dissertation reports on particular completed work and findings; my research on DDT, a story more fascinating than I could possibly imagine at the outset, is ongoing.

For the findings reported on in this dissertation, what can be considered "core" or "essential" data collection and analysis was completed as follows.

> (1) The "biography" of DDT was compiled, using the data collection methods outlined above.
>
> (2) From the story of DDT, different instances of substitution involving that molecule then identified. Substitution was defined using the definition introduced earlier - the supplanting of one product by another in a given market. Readers may be surprised to find out that not only did DDT have many "markets", but it was substituted for by different alternative "products" at different times throughout its history. These substitution events occurred for different reasons, were triggered through different processes, and involved different actors playing important roles. So, for instance, the story of DDT's entry, use, then exit due to substitution in the market represented by cotton-growers differs from that of the story of DDT's entry, use, then exit due to substitution in the markets represented by dairy-farmers, by apple orchardists, by public health users, etc.
>
> (3) Through elementary coding, categories of different types of substitution events involving DDT were generated, and these were organized into a taxonomy of substitution processes.

Enfolding findings with the literature came next, because *"an essential feature of theory building is comparison of the emergent concepts, theory, or hypotheses with the extant literature. This involves asking what is this similar to, what does it contradict, and why. A key to this process is to consider a broad range of literature."* (Eisenhardt, 1989, p

544). So in order to anchor theoretically my empirical findings, one more activity was completed as follows.

> (4) The taxonomy of substitution processes was then linked conceptually to a typology of substitution processes which can be derived from basic economic models of choice.

It is these particular empirical results, firmly anchored and supported by a demonstration of their connections to existing theory, that are reported upon in this dissertation. The dissertation concludes with a discussion of the broader implications of my findings.

SECTION II

Case Study and Findings

This Section describes the case study and the findings that form the backbone of this dissertation, recounting the history of DDT within the wider context of other insecticide products and the function of insect control in general. Constructing it was a daunting task, given the length of time it covers, the technical nature of many of the data sources drawn upon, as well as the sheer richness of the data.

Hence, unavoidably, raw data and information has been filtered, framed and organized in the process of compressing the story of DDT into a single, manageable and readable chapter. Throughout this process, however, an important consideration has served as guide: the focal phenomena under investigation is that of *substitution* - *"the process by which one product or service supplants another in performing a particular function or functions for a buyer"* (Porter, 1985, p 273). Certainly, this particular case study could serve as a window into all sorts of fascinating phenomena of interest to organizational scholars, but as interesting as other stories might be - for example: the birth and growth of the environmental movement in the United States; the singular impact of Rachel Carson's book *Silent Spring* on science, government and industry; the history of ideas within the scientific disciplines of economic entomology, ecology and ecotoxicology; the competitive dynamics of the agri-chemical industry; etc. - for reasons of space and purpose these must play a supporting role. In this dissertation I restrict myself to just one: the entry and exit of DDT and other insecticide products into and from the web of goods and services that is the economy as they *"supplant another in performing a particular function or functions"*.

This framing around the concept of ***substitution*** means that an effort has been made to focus on and to present elements and events in the case study which are linked conceptually to that phenomena. As per the review of the literature, substitution is viewed as a phenomena arising from ***competition*** between different ***products*** in various ***markets*** embedded within particular ***regulatory frameworks***, the outcomes of which are influenced by the ***beliefs*** and ***evaluation criteria*** of important ***actors***, especially their notions of what constitutes desirable ***product performance*** as well as undesirable ***product problems***.

The Section begins with an introduction to pesticides to clarify some of the terminology used throughout the dissertation, and this is followed by a brief presentation of the focal molecule, DDT, and its properties. Next, the function of insect control in the economy is discussed. Alternative technologies for accomplishing insect control are then presented, and these are placed into a historical context of technological evolution, spanning the entire lifetime of DDT in the U.S. economy. Those processes of substitution involving DDT - as both the new challenger product entering the economy, and the old incumbent product exiting the economy - are identified, as are issues of product performance and product problems relevant to understanding these. This overview is meant (a) to provide readers with a broad and general understanding of events in the case study before presenting the detailed biography of DDT, as well as (b) to frame the biography and to introduce concepts and language important to analyses. Then, the detailed case study is presented. It begins with a description of insect control in pre-WWII United States which establishes the context into which DDT and other organochlorine insecticides were introduced and enthusiastically adopted. The specific events surrounding the introduction of DDT into the domestic United States economy are then presented, as are events of the later controversies in which the focal molecule was implicated (the plural here is significant, as will become clear later). Details of the reduction in use and eventual exit of DDT from various markets - its substitution by alternative products, in other words - are also presented.

Please note that, in order to avoid what was judged to be excessive repetition of case details in prior drafts of this document, analysis of particular processes of substitution involving DDT appears *along with* the descriptions of these processes. In other words, in Chapters 4, 5, 6 and 7, case details are presented first in everyday language then, periodically throughout the story of DDT's rise and fall, they are *interpreted* and *translated* into the conceptual language I am advocating. This format, resembling a running commentary, was judged acceptable given that the case is sandwiched between a comprehensive overview that introduces the key concepts (Chapter 3) and a summary recap (Chapter 8) which anchors them firmly in accepted theory.

The scope of this research in both time and conceptual space means that this Section and the Chapters herein are not short. But, in an effort to facilitate and speed the reader's task, a few techniques have been employed which serve to structure the text hierarchically: (1) different sections, sub-section, sub-sub-sections, etc. of Chapters are clearly indicated with appropriate headings and numbering; (2) tables, figures, and text boxes are employed wherever possible; and (3) **key points in my arguments** as well as **key portions of quoted works** are indicated in bold.

3 Case Study: Context and Overview of Findings

3.1 Purpose and Outline

This Chapter provides readers with technical and background information about the function of insect control and insecticides which facilitates later reading of the detailed case study. Understanding agricultural chemicals is not a straightforward exercise, even for agricultural specialists, as evidenced by this preface to the volume devoted to insecticides in the *Advanced Series in Agricultural Sciences* (a volume that, unfortunately, did not exist when this research began!):

> *"In general, the expert is knowledgeable in his own area of science, but for most agricultural scientists, students and teachers, it is a difficult and time consuming task to gain a general understanding of the area of insecticides, which is under continuous development and progress. Taking as an example the mode of action of pyrethroids, one will be inundated by scientific papers and reviews, and only after enormous effort will one be able to make the correct conclusions from the diverse information available. Old-fashioned insecticides which are, in many cases, no longer in use, are not mentioned sufficiently in modern textbooks, and older editions are not always available. However, when found, the reader may be swamped by a mass of literature."*
>
> (Perry, Yamamoto, Ishaaya & Perry, 1998, p ix)

The Chapter also presents an overview of how insect control technologies have evolved over time, in order to establish an appropriate context for recounting the full story of the rise and fall of DDT a bit later. This overview is both past and future referential from the perspective of DDT. In other words, my biography of DDT will not be completely linear; I reveal here some salient details from the life of that molecule, framed and interpreted so as to foreshadow later analysis and arguments.

Pre-anchoring the detailed story of DDT like this, (a) to an introduction of some of the technical matters relating to insecticides, (b) to some details of both the pre-DDT and post-DDT history of insect control, and (c) to the particular concepts and framing used to express my findings, was judged necessary in order to equip readers with some basic information and to orient their attention.

3.2 A Pesticide Primer

Something that must be done early in this dissertation is to distinguish a few terms that are similar but cannot, strictly speaking, be used interchangeably. In addition, the scientific status of certain terms must also be clarified, and a few technical distinctions made in order to delineate the boundaries of the case study and to facilitate its reading.

Pesticides and insecticides are different things, with the former being the more global or encompassing term. "*Pesticides are chemical substances used to kill or control pests*"[1] Unfortunately, even scientists admit that it is impossible to define "pests" scientifically. All definitions are anthropocentric and historically contingent; they inevitably reflect human beliefs, values and even the state of technology or explicit economic cost-benefit calculations at a given point in time. Much like petroleum reserves become "resources" when the price of oil and the cost of extraction coincide such that it is economic to extract them, plants, fungi, mites, insects, and other organisms that man purposefully kills (see Table 3.2.1 for a summary) become "pests" when they are judged undesirable and the costs of controlling their populations falls below the costs avoided by purposefully killing them.

[1] The quotation is from *The Pesticide Book* by Ware (1994, p 4); this textbook provided much of the general information on pesticides reported here.

Table 3.2.1 - Classes of Pesticides

Pesticide class	Function	Root-word derivation
Acaricide	Kills mites	Gr. *akari*, "mite or tick"
Algicide	Kills algae	L. *alga*, "seaweed"
Avicide	Kills or repels birds	L. *avis*, "bird"
Bactericide	Kills bacteria	L. *bacterium;* Gr. *baktron*, "a staff"
Fungicide	Kills fungi	L. *fungus*, Gr. *spongos*, "mushroom"
Herbicide	Kills weeds	L. *herba*, "an annual plant"
Insecticide	Kills insects	L. *insectum*, "cut or divided into segments"
Larvicide	Kills larvae (usually mosquito)	L. *lar*, "mask or evil spirit"
Miticide	Mills mites	Synonymous with Acaricide
Molluscicide	Kills snails and slugs (may include oysters, clams, mussels)	L. *molluscus*, "soft- or thin-shelled"
Nematicide	Kills nematodes (i.e. worms)	L. *nematoda;* Gr. *nema*, "thread"
Ovicide	Destroys eggs	L. *ovum*, "egg"
Pediculicide	Kills lice (head, body, crab)	L. *pedis*, "louse"
Piscicide	Kills fish	L. *piscis*, "a fish"
Predicide	Kills predators (coyotes, usually)	L. *praeda*, "prey"
Rodenticide	Kills rodents	L. *rodere*, "to gnaw"
Silvicide	Kills trees and brush	L. *silva*, "forest"
Slimicide	Kills slimes	Anglo-Saxon *slim*
Termiticide	Kills termites	L. *termes*, "wood-boring worm"

Chemicals classed as pesticides not bearing the -cide suffix

Attractants	Attract insects
Chemosterilants	Sterilize insects or pest vertebrates (birds, rodents)
Defoliants	Remove leaves
Desiccants	Speed drying of plants
Disinfectants	Destroy or inactivate harmful microorganisms
Growth regulators	Stimulate or retard growth of plants or insects
Pheromones	Attract insects or vertebrates
Repellents	Repel insects, mites and ticks, or pest vertebrates (dogs, rabbits, deer, birds)

(1) *Gr.* indicates Greek origin; *L.* indicates Latin origin.
(2) Table is from Ware (1994, p 24).

Hence it is often said that a pest is any organism in the wrong place at the wrong time:

> *"It is difficult to find a satisfactory definition of pest, other than to describe it as* ***a plant or animal living where man does not want it to live.*** *"*
>
> (Mellanby, 1970, p 18)

> *"Pests comprise competitors of humans for resources, enemies, including those that transmit diseases, and nuisance organisms.* ***The pest status of competitors is usually defined in terms of economics. Thus they are considered to be pests when it is economic to control them.*** *This may reflect both rational and irrational criteria, such as cosmetic standards for the appearance of food. Enemies and nuisance organisms may also be controlled in response to rational and irrational criteria. Weed-free lawns and insect-free recreation areas exemplify the latter."*
>
> (Hill, 1990, p 5)

The anthropocentric, contingent and economic dimension to "pests" and hence "pesticides" is an important feature that is often forgotten or left implicit in many discussions. But it is not a point lost on agricultural chemical companies though. "*In nature, there is no such thing as a pest. But in human economy, anything that competes with man for his means of subsistence may be considered a pest*" explained the Director of DuPont's new Pest Control Research Section at the opening of a brand new "*anti-pest laboratory*" in 1937[2]. Over time, as new and less expensive chemical products were developed and deployed in more and more markets as *pesticides,* more and more species took on the status of *pest.*

"Insects" on the other hand is the label of a scientific category. It refers to organisms classed in the group *Insecta* or *Hexapoda,* within the phylum *Arthropoda,* a large category containing such diverse creatures as the lobster, the centipede, the scorpion, the spider and the mite. Insects are distinguished from other arthropods by a body divided

[2] "DuPont v. Pests", *Time*, 1937 04 19

into three distinct regions: a head bearing one pair of antennae, a thorax with three pairs of legs and usually two pairs of wings, and an abdomen usually devoid of legs[3].

"Entomology" is the study of insects, and "economic entomology" or "applied entomology" refers to the application of entomological knowledge to solve practical problems facing Man, such as the destruction of agricultural crops by insects or the spread of insect-borne diseases. One might conclude from these categories that the study of such pests as spiders and mites (which possess eight legs as adults) falls outside of economic entomology, but this is not so.

> *"... in practice, the entomologist tackles a number of problems which lie outside the strictly academic definition, and thus economic entomology not only embraces the field of insect control, but also that of certain other crop and animal pests."*
>
> (West, Hardy & Ford, 1951, p 7)

Although it was also used as a rodenticide against rats, DDT's primary use was against insects and therefore the class of pesticides known as "insecticides" will be the main focus. In addition, I will adopt the convention of economic entomologists of including substances technically known as "acaracides" and "miticides" within this category. Hence in this document, unless otherwise explicitly noted, "insecticide" will refer to any chemical substance used to influence, manage or control the populations of injurious species of insects, spiders, or mites.

Some final clarifications that need to be made regarding insecticides have to do with "active ingredients", "technical mixtures, and "formulations".

> *"Formulation is the processing of a pesticidal compound by any method that will improve its properties of storage, handling, application, effectiveness, or safety. The term formulation is usually reserved for*

[3] The textbook that provided information on insects is *An Introduction to the Study of Insects* (5th. ed.), Borror et al. (1981).

commercial preparation prior to actual use and does not include the final dilution in application equipment."

(Ware, 1994, p 27)

Prior to formulation, insecticidal compounds are produced, stored and handled in their "technical" form, which is a standardized material produced and sold by original manufacturers of "active ingredients". Active ingredients are those particular chemical compounds that have pesticidal activity. In other words, they are the specific molecules with killing power.

Though not entirely accurate, technical mixtures of active ingredients can be considered for the purpose of this document to be pure and composed of only the active ingredient. In reality, the technical products emerging from the last stages of synthesis at chemical manufacturing plants are rarely pure at 100% and often contain unreacted raw materials and unwanted byproducts as contaminants. The consequences of this lack of purity are not insignificant. For example, the insecticide dicofol has come under criticism and received the attention of environmental agencies in governments not because of the properties of the dicofol molecule itself, but because manufactured dicofol contains traces of DDT, an intermediate product in its manufacture, as a contaminant. Another complication when it comes to discussions of purity stems from isomers. These are chemical molecules made up from the same atoms but which are configured and placed differently in space relative to each other. Technical DDT, for example, is actually a mixture of two distinct molecules: the main component ρ,ρ'-DTT, along with a much smaller percentage of σ,ρ'-DDT, where the prefixes σ (ortho) and ρ (para) signal the precise placement of individual atoms according to the nuances of organic chemistry nomenclature. Chemical isomers can have dramatically different properties and have been the source of confusion early on in the life of new insecticidal compounds. For example, it was eventually discovered that only the gamma (γ) isomer of the product hexachlorocyclohexane (HCH), making up less than 15% of the technical mixture, has insecticidal properties. Indeed, once isolated and purified, the gamma isomer becomes a different insecticide with its own distinct identity, called lindane. So technical mixtures of active ingredients are not actually pure, but they are substances with a known and standardized chemical composition with respect to these possible complications of isomers and contaminants.

In the process of formulation, technical mixtures of active ingredients may be combined with "inert ingredients" and/or "synergists". The former are compounds which do not themselves have any pesticidal activity, but add to the value of formulated mixtures because of other properties. Most commonly, their physical state facilitates the dispersal and delivery of active ingredients to pests, as with solvents, propellants, surfactants, emulsifiers, wetting agents, and diluents. The latter are compounds which do not have pesticidal activity on their own but, when added to an active ingredient, they increase its killing power. For example, the process of formulation may include the addition of a compound that inhibits a pest's innate biochemical ability to detoxify a primary poison.

The proliferation of distinct formulations from a smaller number of active ingredients complicates analysis of the pesticide industry. For instance, in 1965 there were more than 400 different active ingredients in commercial use in the United States, and these had been formulated into some 60,000 different pesticide products (i.e. each with its own recipe and trade name) officially registered with the USDA[4]. In 1980, after the creation of the Environmental Protection Agency and the elimination of a number of organochlorine substances from the economy including DDT, about 500 different active ingredients were being mixed into some 35,000 different pesticide formulations[5].

Table 3.2.2, Common Formulations of Pesticides, gives the reader an idea of the diversity and complexity of what can be meant by "pesticide" products.

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[4] Blodgett (1974, p 201)
[5] NRC (1980, p 4)

Table 3.2.2 - Common Formulations of Pesticides

1. Sprays (insecticides, herbicides, fungicides)
   a. Emulsifiable concentrates (also emulsible concentrates)
   b. Water-miscible liquids, sometimes referred to as liquids
   c. Wettable powders
   d. Water-soluble powders, e.g., prepackaged, tank drop-ins, for agricultural and pest control operator use.
   e. Gels, packaged in water-soluble bags, e.g. Buctril Gel
   f. Oil solutions, e.g., barn and corral ready-to-use sprays, and mosquito larvicides
   g. Soluble pellets for water-hose attachments
   h. Flowable or sprayable suspensions
   i. Flowable microencapsulated suspensions, e.g., Penncap M, Dursban ME
   j. Ultralow-volume (ULV) concentrates (agricultural and forestry use only)
   k. Fogging concentrates, e.g., public health mosquito and fly abatement loggers
2. Dusts (insecticides, fungicides)
   a. Undiluted toxic agent
   b. Toxic agent with active diluent, e.g., sulfur, diatomaceous earth
   c. Toxic agents with inert diluent, e.g., home garden insecticide-fungicide combination in pyrophyllite carrier
   d. Aerosol dust, e.g., silica aerogel in aerosol form
3. Aerosols (insecticides, repellents, disinfectants)
   a. Pushbutton
   b. Total release
4. Granulars (insecticides, herbicides, algicides)
   a. Inert carrier impregnated with pesticide
   b. Soluble granules, e.g., dry flowable herbicides
   c. Water dispersable granules
5. Fumigants (insecticides, nematicides, herbicides)
   a. Stored products and space treatment, e.g., liquids, gases, moth crystals
   b. Soil treatment liquids that vaporize
   c. Greenhouse smoke generators, e.g., Nico-Fume
6. Impregnates (insecticides, fungicides, herbicides)
   a. Polymeric materials containing a volatile insecticides, e.g., No-Pest Strips, pet collars
   b. Polymeric materials containing non-volatile insecticides, e.g., pet collars, adhesive tapes, livestock eartags
   c. Shelf papers containing a contact insecticide
   d. Mothproofing agents for woolens
   e. Wood preservatives
   f. Wax bars (herbicides)
   g. Insecticide soaps for pets
7. Fertilizer combinations with herbicides, insecticides, or fungicides
8. Baits (insecticides, molluscicides, rodenticides, and avicides)
9. Slow-release insecticides
   a. Microencapsulated materials for agriculture, mosquito abatement, household, e.g., Penncap M
   b. Paint-on lacquers for pest control operators, e.g., Killmaster II
   c. Interior latex house paints for home use
   d. Adhesive tapes for pest control operators and homeowners, e.g., Hercon Insectapes
   e. Resin strips containing volatile organophosphate fumigant, e.g., No-Pest Strips or pyrethroids used in livestock eartags
10. Insect repellents
    a. Aerosols
    b. Rub-ons (liquids, lotions, paper wipes, and sticks)
    c. Vapor-producing candles, torch fuels, smoldering "punk" or coils.
11. Insect attractants
    a. Food, e.g., Japanese beetle traps, ant and grasshopper, hornet and wasp, and Mediterranean fruit fly baits
    b. Sex lures, e.g., pheromones for agricultural and forest pests (gypsy moth), household (cockroach traps)
12. Animal systemics (insecticides, parasiticides)
    a. Oral (premeasured capsules or liquids)
    b. Dermal (pour-on or sprays)
    c. Feed-additive, e.g., impregnated salt block and feed concentrates

(1) Table is from Ware (1994, p 29).

Given all these possible complications, it is imperative that I carefully define the boundaries of the case study. I will be focusing on the "insecticide" category of pesticides, and, specifically, the singular "technical mixture" of a particular active ingredient rather than the numerous formulations which are prepared from it. So henceforth in this document, unless otherwise explicitly noted, references to an insecticide product "X" (ex. "DDT") will refer to the technical mixture of the active ingredient "X", where "X" is a substance used to influence, manage or control the populations of injurious species of insects, spiders, or mites.

Finally, because the regulatory framework plays such a prominent role in the case study, it is important to note that in most state and federal laws, throughout most of this century pesticides were legally classed as "economic poisons", defined as follows:

> *"The term 'economic poison' means (1) any substance or mixture of substances intended for preventing, destroying, repelling or mitigating any insects, rodents, nematodes, fungi, weeds, and other forms of plant or animal life or viruses, except viruses on or in living man or other animals, which the Secretary shall name a pest, and (2) any substance or mixture of substances intended for use as a plant regulator, defoliant or desiccant."*
>
> *"The term 'insecticide' means any substance or mixture of substances intended for preventing, destroying, repelling or mitigating any insects which may be present in any environment whatsoever."*[6]

These terms, pesticides and economic poisons, will be used interchangeably in this document.

---

[6] from FIFRA, Approved June 25, 1947 (61 Stat. 163) as amended by the Nematocide, Plant Regulator, Defoliant, and Desiccant Amendment of 1959 (73 Stat. 286) as amended by the Act of March 29, 1961 (75 Stat. 42) and the Act of May 12, 1964 (p.L. 88-305, 78 Stat 190): reprinted in Bloom and Degler (1969, p 63)

3.3 A DDT Primer

3.3.1 The Truth about DDT: A Caveat

In this section I introduce DDT, perhaps the best known and most widely researched of all synthetic chemicals. To do so, I draw upon *existing* categorizations, characterizations and understandings of this molecule. Although I do not believe that sources absolutely free of bias exist, I have attempted to locate and present here details about DDT from sources that those in the pesticides domain regard as being as neutral as possible.

In addition, it is important to note that the *descriptive claims* (i.e. beliefs, or even "facts") summarized here have not always been the descriptive claims employed by actors relevant to DDT's history. True, its chemical formula and physico-chemical properties like molecular mass, boiling point, volatility, etc. have been known since its first synthesis and have not changed over time. But other claims described here relating to DDT's toxicological effects, ecological effects and environmental fate are not so straightforward. Some, like the claim of a causal connection between DDT residues and egg-shell thinning in birds for instance, were unknown early in DDT's career as an insecticide. They came into existence later, clashed publicly with competing rival claims (i.e. that DDT was *not* the cause of egg-shell thinning) and eventually triumphed in the sense that the contestation has more or less ceased and these claims are the ones widely held. Still other claims, like those asserting a causal connection between DDT and human cancer for instance, are contested to this very day.

Because of this, it would be highly inappropriate for me to: (a) simply report these as the "facts" or "Truth" about DDT; (b) to extract or to report claims unattributed or out of context; and especially (c) to attempt interpretation of complex scientific data. Instead, I invoke Latour's (1987) *"first rule of method"* when studying science and technology, which says *"study science in action and not ready made science or technology; to do so, we either arrive before the facts and machines are blackboxed or we follow the* *controversies that reopen them.*[7]" As will become clear as readers progress through this document, this allows me to develop a truly *process* theory of substitution that requires no appeals to a metanarrative nor the positing of teleological forces "pulling" social reality in any particular direction of "progress". So, for instance, claims that the economy actually generates *efficient* outcomes, or the scientific method actually generates *truth*, or the U.S. political and judicial system actually generates *justice* with its decision-making on pesticides, are neither a priori assumptions, nor - here at least - concerns of mine.

3.3.2 Basic Information about DDT

DDT is the much more convenient name given by an official in the British Ministry of Supply during WWII to the substance "1,1,1-trichloro-2,2-bis(4-chlorophenyl)ethane", also known as "1,1'-(2,2,2-trichloroethylidene)bis[4-chlorobenzene]" or "dichlorodiphenyltrichlorethane"[8]. The physical properties of the focal molecule are summarized in Table 3.3.2.1.

[7] Latour (1987, p 258)
[8] West & Campbell (1950, p 4)

Table 3.3.2.1 - Physical Properties of DDT

Chemical Names:	1,1,1- trichloro-2,2-bis(4-chlorophenyl) ethane; 1,1'-(2,2,2-trichloroethylidene)bis[4-chlorobenzene]; dichlorodiphenyltrichloroethane
Appearance:	The physical appearance of the technical product DDT is a waxy solid, although in its pure form it consists of colorless crystals which are odourless or only slightly fragrant.
CAS Number:	50-29-3
Molecular Weight:	354.51
Water Solubility:	< 1 mg/L @ 20 degrees C
Solubility in Other Solvents:	cyclohexanone v.s., dioxane v.s., benzene v.s., xylene v.s., trichloroethylene v.s., dichloromethane v.s., acetone v.s., chloroform v.s., diethyl ether v.s., ethanol s. and methanol s. .
Melting Point:	108.5-109 degrees C
Vapor Pressure:	0.025 mPa @ 25 degrees C

* from Pesticide Information Profiles of "EXTOXNET" (Extension Toxicology Network), an online Pesticide Information Project of the Cooperative Extension Offices of Cornell University, Oregon State University, the University of Idaho, the University of California at Davis and the Institute for Environmental Toxicology, Michigan State University. The primary files of this database are maintained and archived at Oregon State University. See http://ace.ace.orst.edu/info/extoxnet/pips/ghindex.html

Although it can be uniquely identified by chemists, engineers and others around the world by its Chemical Abstract Service (CAS) registry number of 50-29-3, DDT does have many chemical and trade names. The most common synonyms and trade names for DDT are listed in Table 3.3.2.2.

Table 3.3.2.2 - Synonyms for DDT

Chlorophenothane; p,p'-DDT; Benzene, 1,1'-(2,2,2-trichloroethylidene)bis[4-chloro-; a,a-Bis(p-chlorophenyl)-b,b,b-trichlorethane; p,p'-Dichlorodiphenyltrichloroethane; Aavero-extra; Agritan; Arkotine; Azotox; Azotox M-33; Bosan supra; Bovidermol; Chlorphenothan; Chlorphenotoxum; Citox; Clofenotan; Clofenotane; Deoval; Detox; Detoxan; Dibovin; Dicophane; Dodat; Dykol; DDT; Estonate; Ethane, 1,1,1-Trichloro-2,2-bis(p-chlorophenyl)-; Ethane, 1,1,1-trichloro-2,2-bis(4-chlorophenyl)-; ENT-1506; Gesafid; Gesarol; Ivoran; Mutoxan; Neocid; Neocidol, Solid; Parachlorocidum; Pentachlorin; Penticidum; PEB1; Trichlorobis(4'-Chlorophenyl)ethane; Zerdane; 1,1-Bis(p-chlorophenyl)-2,2,2-trichloroethane; 1,1,1-Trichloro-2,2-bis(p-chlorophenyl)ethane; 1,1,1-Trichloro-2,2-bis(4,4'-dichlorodiphenyl)ethane; 2,2-Bis(p-chlorophenyl)-1,1,1-trichloroethane; 4,4'-Dichlorodiphenyltrichloroethane; 1,1-Bis(4-chlorophenyl)-2,2,2-trichloroethane; DDT (common name not adopted by ISO); 1,1,1-trichloro-2-2-bis(4-chlorophenyl)ethane; Anofex; Chlorphenotane; Dichlorodiphenyltrichloroethane; Didigam; Didimac; Genitox; Guesarol; Gyron; Ixodex; Kopsol; Neocidol; NCI-C00464; Pentech; Ppzeidan; Rukseam; Santobane; Tafidex; Trichlorobis(4-chlorophenyl)ethane; Zeidane; 1,1,1-Trichloor-2,2-bis(4-chloor fenyl)-ethaan; 1,1,1-Trichlor-2,2-bis(4-chlor-phenyl)-aethan; 1,1,1-Trichloro-2,2-bis(p-chlorophenyl)ethane chlorophenothane; 1,1,1-Trichloro-2,2-di(4-chlorophenyl)ethane; 1,1,1-Tricloro-2,2-bis(4-cloro-fenil)-etano; Chlorophenothan; Chlorophenotoxum; Dedelo; Dibovan; Diphenyltrichloroethane; ENT 1,506; Gesapon; Gesarex; Guesapon; Havero-extra; Hildit; Micro ddt 75; Mutoxin; NA 2761; OMS 16; R50; Rcra waste number U061; Tech ddt; Penticide; Zithiol; p,p-DDT; 2,2,2-Trichloro-1,1-bis(4-chlorophenyl)ethane; p,p'-Dichlorodiphenyltrichloromethylmethane

* from National Institute of Standards and Technology (NIST) online database (http://webbook.nist.gov)

The chemical formula of DDT is $C_{14}H_9Cl_5$. DDT is a nonsystemic contact and stomach poison, from the organochlorine family, with a very broad spectrum of strong insecticidal activity (i.e. it is highly toxic to many species of insects). The commercial product DDT contains a much smaller fraction (< 30%) of the isomer 1,1,1-trichloro-2-(2-chlorophenyl)-2-(4-chlorophenyl)ethane which, because of its own insecticidal action, is not removed from the technical mixture. At room temperature, the technical product is a waxy solid which is practically insoluble in water (i.e. it is "hydrophobic") but moderately soluble in petroleum oils and highly solvent in aromatic solvents (i.e. it is "lipophilic"). DDT can be formulated in several different forms: aerosols, dustable powders, emulsifiable concentrates, granules and wettable powders. With regards to formulation, it is compatible with many other pesticides, but incompatible with alkaline substances.

In 1874, DDT was first synthesized by Othman Zeidler, an Austrian chemist pursuing doctoral studies who was not trying to invent an insecticide but who was merely pursuing an interest in the chemistry of aromatic hydrocarbons. It was Dr. Paul Muller, a chemist at the company Geigy (Switzerland) which was working on a major research project initiated in 1932 and specifically aimed at developing a new moth-proofing agent, who discovered the insecticidal properties of DDT in 1939[9].

DDT was extensively used during WWII to protect both troops and civilians from the spread of typhus, malaria and other vector-borne diseases. After the War, it continued to be widely used in public health programmes, especially against populations of *Anopheles* mosquitoes, carriers of the *Plasmodium* parasites which cause malaria. Muller was awarded the Nobel prize in medicine in 1948 because of DDT's contribution to public health[10]. To this day, DDT is still used in numerous countries for this insect control function.

Large scale manufacture of DDT began in the United States in 1943 (with the Cincinnati Chemical Works at Norwood Ohio, a company partially controlled by Geigy) and reached 10,000,000 lbs/year in 1944 all allocated to the military[11]. In 1945, DDT was released into the civilian economy where its usage soon outstripped that of the formerly-dominant arsenical insecticides (i.e. compounds derived from arsenic). Compared with these older insecticides, DDT was considered *"magic"*[12]; it killed insects more effectively than any other substance, was much less poisonous than arsenic, and was incredibly cheap to manufacture. DDT very quickly became the leading single insecticide in the United States in terms of quantities applied[13].

DDT was widely used on a large variety of agricultural crops, including cotton, tobacco, corn, vegetables and fruits such as apples. In addition, DDT had many other applications: on the farm (example: against insects attacking livestock, applied directly to

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[9] The most widely accepted account of DDT's introduction to the Allied nations is that of West & Campbell (1950); these authors were among the earliest British scientists to work with DDT.
[10] The Nobel Lecture given by Muller on 1949 12 11, translated from the German, is reproduced in *The DDT Story* by Mellanby (1992, p 97)
[11] Perkins (1982, p 13)
[12] The adjective "*magic*" was used frequently to describe DDT. See *DDT - Killer of Killers* by Zimmerman & Levine (1946), for example. In his Presidential address to the 58th annual meeting of the American Association of Economic Entomologists, entitled *"Achievements and Possibilities in Pest Eradication"*, Clay Lyle reiterated *"**The entomologist has become a wizard** in the eyes of the uninitiated - and indeed some of the achievements seem little short of **magic**."* (Lyle, 1947, p 1)

the animals or to the barns which housed them); in organized USDA insect "eradication" campaigns (example: against gypsy moths, Japanese beetles); in the home (example: against flies, roaches and bedbugs); for gardens (example: against insects attacking ornamental plants); in forestry (example: against insects which defoliate trees); and in suburban neighbourhoods (example: against mosquitoes, bark beetles)[14].

Very soon after DDT was introduced into the economy, it became evident that it was being introduced into ecosystems and into humans as well[15]. Three of DDT's properties - its persistence (i.e. it does not readily break down), its mobility (i.e. even though it is relatively involatile, small quantities nevertheless do evaporate and can be transported by wind currents over great distances; similarly, even though it is hydrophobic, small quantities nevertheless do dissolve in water and can be transported by rivers and ocean currents over great distances) and its lipophilicity (i.e. it is readily dissolved in fats and oils, including those found in organisms) - meant that it began to appear in places far from where it was originally applied[16]. DDT and other persistent organochlorine pesticides were - and can still be - routinely found in human body fat and human breast milk, as well as in the fat of other mammals, fish, and birds[17]. Samples gathered in 1964 even showed DDT in the mammals, fishes and birds of remote and once-pristine Antarctica[18].

The implications of such widespread contamination were unclear, controversial and disputed. Ultimately, growing concerns about the adverse ecological effects of DDT, especially its impact on wild birds at the top of food chains, as well as controversies as to

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[13] Pesticide Situation (1955-56; 1957-58; 1959-60); also Pesticide Handbook (1965)

[14] See West & Campbell (1950) for what was already at that point a very long list of DDT applications.

[15] Evidence/concerns that DDT accumulated in animals' fat and could be excreted in mammalian milk existed prior to the USDA's issuing of the bulletin that *recommended* DDT for certain agricultural uses; it is mentioned therein (USDA bulletin, 1946 03 27).

[16] The testimony of Dr. Charles F. Wurster Jr. before the hearing examiner of the Wisconsin DDT trial in the fall of 1968 is particularly good and to the point on these properties. Portions are reproduced in Henkin et al (1971).

[17] As an example of how commonplace DDT residues have become, consider that the The World Health Organization (WHO) currently offers a web-based course on "EPIDEMIOLOGY FOR DECISION-MAKING" that has a practice exercise called "DDT AND BREAST MILK"; visit http://www.who.int/peh-super/epi_course/lec13/index.htm

its carcinogenicity and other endpoints of toxicological tests, led to severe restrictions and/or bans in many developed countries. Banned in Sweden, the country that had awarded Muller his Nobel prize, as well as in Norway in 1970, Canada severely limited its uses also in that year[19]. On June 14, 1972, DDT was banned in the United States by the Administrator of the Environmental Protection Agency, William D. Ruckelshaus, after a long and unprecedented hearing that was simultaneously highly technical and scientific and yet heated and emotional. Ruckelshaus based his decision on findings of *"persistence, transport, biomagnification, toxicological effects and an absence of benefits of DDT in relation to the availability of effective and less environmentally harmful substitutes"*[20].

Today, the use of DDT has been banned in 34 countries and severely restricted in 34 others[21]. One of twelve substances currently targeted by the United Nations Environment Program (UNEP) which has convened negotiations aimed at achieving an "International Legally Binding Instrument for Implementing International Action on Certain Persistent Organic Pollutants (POPs)", DDT may soon become subject to a global ban[22].

But DDT continues to arouse passions. In September of 1999, 350 malaria experts, including three Nobel prize winners, signed an open letter of protest against just such a ban.[23] This pits them against other scientists, environmental groups and even health-oriented NGOs such as Physicians for Social Responsibility, themselves winners of a Nobel peace prize, who are calling for the global elimination of DDT[24]. Struggles over DDT are proving to be as persistent as the molecule itself.

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[18] George & Frear (1966)
[19] see United Nations (1994, p 212); also visit http://ace.ace.orst.edu/info/extoxnet/pips/ddt.htm
[20] EPA (1975, p 255)
[21] Ritter, et al. (1995)
[22] Besides DDT, eight other organochlorine pesticides are on the UNEP POPs list: aldrin, chlordane, dieldrin, endrin, HCB, heptachlor, mirex, toxaphene. One industrial chemical (PCBs) and two pollutant byproducts (dioxins, furans) are the others. For information about the POPs negotiations, visit http://irptc.unep.ch
[23] New York Times, 1999 08 29, p 1

3.3.3 The Rise and Fall of DDT - A Quantitative Look

By 1945, when DDT was released into the U.S. civilian economy, no less than 14 firms were already listed as primary producers by the USDA, and 16 were formulating the active ingredient DDT into ready-for-use insecticides[25]. Wartime circumstances meant that DDT did not slowly penetrate the market with a lone patent-holding manufacturer adding capacity as market share warranted, as one might expect of a challenger product competing with incumbents. For not only was manufacturing capacity already in place, meaning that economies of scale and learning had already been achieved, but this capacity was spread out over multiple firms. Very uncharacteristically for the pesticide industry, DDT was brought to market without patent protection[26]; price competition occurred immediately.

Production of DDT rose dramatically after WWII, climbing to more than 110,000,000 lbs in 1952. It ultimately peaked in 1963 when 188,000,000 lbs of DDT was produced, although it is important to note that 61% of production was being exported by this time. Domestic usage of DDT peaked in the United States in 1959 when 79,000,000 lbs were sprayed or dusted onto fields of food, feed and fiber crops, swatches of forest, herds of livestock, as well as in barns, hospitals and suburban homes[27].

DDT maintained its U.S. market dominance in terms of quantities of active ingredient applied domestically until 1964, just subsequent - not coincidentally - to the publication of Rachel Carson's best-selling and controversial book *Silent Spring*[28]. Still, in the period from 1964 to 1966, only one other insecticide - toxaphene - was used in greater quantities, and only aldrin was applied on more farm crop acres[29].

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[24] Physicians for Social Responsibility is at http://www.psr.org. The POPs Elimination Platform Statement of the International POPs Elimination Network (IPEN) is at http://www.ipen.org.
[25] Perkins (1982, p 13)
[26] Geigy did receive a royalty from DDT manufacturers (see "New Jobs for DDT" in *Business Week*, February 7, 1948).
[27] All production and usages figures are from EPA (1975, p 149).
[28] Pesticide Situation (1955-56; 1957-58; 1959-60); also Pesticide Handbook (1965)
[29] USDA-ERS, Agricultural Economic Report no. 158 (1971)

Table 3.3.3.1 - The Rise and Fall of DDT, summarizes the quantitative history of DDT in the United States from its introduction until its ban in 1972.

Table 3.3.3.1 - The Rise and Fall of DDT

Domestic Production, Consumption, and Exports of DDT in the United States, 1950-1972 (100% basis)

Year	Production	Domestic Consumption (1000 lbs.)	Exports
1950	67,320	57,638	7,898
1951	97,875	72,686	NA
1952	115,717	70,074	32,288
1953	72,802	62,500	31,410
1954	90,712	45,117	42,743
1955	110,550	61,800	50,968
1956	137,747	75,000	54,821
1957	129,730	71,000	61,069
1958	131,862	66,700	69,523
1959	156,150	78,682	76,369
1960	160,007	70,146	86,611
1961	175,657	64,068	103,696
1962	162,633	67,245	106,940
1963	187,782	61,165	113,757
1964	135,749	50,542	77,178
1965	140,785	52,986	90,414
1966	141,349	46,672	90,914
1967	103,411	40,257	81,828
1968	139,401	32,753	109,148
1969	123,103	30,256	82,078
1970	59,316	25,457	69,550
1971	63,134 a/	18,000 a/	45,134
1972	57,427 a/	22,000 a/	35,424

a/ EPA estimates based on Pesticide Review 1973, pp. 10, 11, 22, 23.

* Source: USDA, ASCS, Pesticide Review 1973 and earlier years (reproduced as Table IIID.1, in EPA, 1975, p 149)

3.3.4 Additional Information about DDT

To equip readers with a sense of just which aspects of DDT are of relevance to the story of its rise then fall, I present here a couple of summaries of the toxicological and ecological effects of DDT. It is not necessary to read them completely - I highlight in bold those points which are of particular salience to this document - but readers may find them quite interesting nonetheless. Tables 3.3.4.1 and 3.3.4.2 together contain the summary description of the molecule used by the United Nations Environment Programme's Intergovernmental Negotiating Committee for an International Legally Binding Instrument for Implementing International Action on Certain Persistent Organic Pollutants (POPs). This summary description has been parsed into two portions, "toxicological and ecological effects" and "environmental fate", to facilitate comparison with the contents of Tables 3.3.4.3, 3.3.4.4, and 3.3.4.5. These latter tables present information found in the "pesticide information profiles" of the Extension Toxicology Network ("EXTOXNET"), an online Pesticide Information Project of the Cooperative Extension Offices of Cornell University, Oregon State University, the University of Idaho, the University of California at Davis and the Institute for Environmental Toxicology, Michigan State University.

Table 3.3.4.1
DDT Assessment Report of the International Programme on Chemical Safety Toxicological & Ecological Effects

DDT has been widely used in large numbers of people who were sprayed directly in programs to combat typhus, and in tropical countries to combat malaria. **Dermal exposure to DDT has not been associated with illness or irritation in a number of studies.** Studies involving human volunteers who ingested DDT for up to 21 months did not result in any observed adverse effects. **A non-significant increase in mortality from liver and biliary cancer** and **a significant increase in mortality from cerebrovascular disease has been observed in workers involved in the production of DDT. There is some evidence to suggest that DDT may be suppressive to the immune system**, possibly by depressing humoral immune responses. **Perinatal administration of weakly estrogenic pesticides such as DDT produces estrogen-like alterations of reproductive development**, and there is also limited data that suggest **a possible association between organochlorines, such as DDT and its metabolite DDE, and risk of breast cancer.**

DDT is not highly acutely toxic to laboratory animals, with acute oral LD50 values in the range of 100 mg/kg body weight for rats to 1,770 mg/kg for rabbits. In a six generation reproduction study in mice, no effect on fertility, gestation, viability, lactation or survival were observed at a dietary level of 25 ppm . A level of 100 ppm produced a slight reduction in lactation and survival in some generations, but not all, and the effect was not progressive. A level of 250 ppm produced clear adverse reproductive effects. In both these and other studies, **no evidence of teratogenicity has been observed.** IARC has concluded that while **there is inadequate evidence for the carcinogenicity of DDT in humans**, there is sufficient evidence in experimental animals. **IARC has classified DDT as a possible human carcinogen** (Group 2B).

DDT is highly toxic to fish, with 96-hour LC50 values in the range of 0.4 µg/L in shrimp to 42 µg/L in rainbow trout. It also affects fish behaviour. Atlantic salmon exposed to DDT as eggs experienced impaired balance and delayed appearance of normal behaviour patterns. DDT also affects temperature selection in fish.

DDT is acutely toxic to birds with acute oral LD50 values in the range of 595 mg/kg body weight in quail to 1,334 mg/kg in pheasant, however **it is best known for its adverse effects on reproduction, especially DDE, which causes egg shell thinning in birds with associated significant adverse impact on reproductive success.** There is considerable variation in the sensitivity of bird species to this effect, with birds of prey being the most susceptible and showing extensive egg shell thinning in the wild. American kestrels were fed day old cockerels injected with DDE. Residues of DDE in the eggs correlated closely with the dietary DDE concentration and there was a linear relationship between degree of egg shell thinning and the logarithm of the DDE residue in the egg. Data collected in the field has confirmed this trend. DDT (in conjunction with other halogenated aromatic hydrocarbons) has been linked with feminization and altered sex-ratios of Western Gull populations off the coast of southern California, and Herring Gull populations in the Great Lakes.

* from L. Ritter, et al.(1995), "Persistent Organic Pollutants: An Assessment Report on DDT, Aldrin, Dieldrin, Endrin, Chlordane, Heptachlor, Hexachlorobenzene, Mirex, Toxaphene, Polychlorinated Biphenyls, Dioxins, and Furans", an Assessment Report of the International Programme on Chemical Safety

** The International Programme on Chemical Safety (IPCS), established in 1980, is a joint programme of three Cooperating Organizations, ILO, UNEP and WHO, implementing activities related to chemical safety. IPCS is an intersectoral coordinated and scientifically based programme. WHO is the Executing Agency of the IPCS. The two main roles of IPCS are: to establish the scientific basis for safe use of chemicals and to strengthen national capabilities and capacities for chemical safety . IPCS areas of activity include: Evaluation of chemical risks to human health and the environment; Methodologies for Evaluation of Hazards and Risks; Prevention and management of toxic exposures and chemical emergencies; Development of the human resources required in the above areas.

Table 3.3.4.2
DDT Assessment Report of the International Programme on Chemical Safety
Environmental Fate

DDT and related compounds are very persistent in the environment, as much as 50% can remain in the soil 10-15 years after application. **This persistence, combined with a high partition coefficient (log KOW = 4.89-6.91) provides the necessary conditions for DDT to bioconcentrate in organisms.** Bioconcentration factors of 154,100 and 51,335 have been recorded for fathead minnows and rainbow trout, respectively. It has been suggested that higher accumulations of DDT at higher trophic levels in aquatic systems results from a tendency for organisms to accumulate more DDT directly from the water, rather than by biomagnification. The chemical properties of DDT (low water solubility, high stability and semi-volatility) favour its long range transport and DDT and its metabolites have been detected in arctic air, water and organisms. **DDT has also been detected in virtually all organochlorine monitoring programs and is generally believed to be ubiquitous throughout the global environment.**

DDT and its metabolites have been detected in food from all over the world and this route is likely the greatest source of exposure for the general population. DDE was the second most frequently found residue (21%) in a recent survey of domestic animal fats and eggs in Ontario, Canada, with a maximum residue of 0.410 mg/kg. Residues in domestic animals, however, have declined steadily over the past 20 years. In a survey of Spanish meat and meat products, 83% of lamb samples tested contained at least one of the DDT metabolites investigated, with a mean level of 25 ppb. An average of 76.25 ppb p,p'-DDE was detected in fish samples from Egypt. DDT was the most common organochlorine detected in foodstuffs in Vietnam with mean residue concentrations of 3.2 and 2.0 μg/g fat in meat and fish, respectively. The estimated daily intake of DDT and its metabolites in Vietnam was 19 μg/person/day. Average residues detected in meat and fish in India were 1.0 and 1.1 μg/g fat respectively, with an estimated daily intake of 48 μg/person/day for DDT and its metabolites.

DDT has also been detected in human breast milk. In a general survey of 16 separate compounds in the breast milk of lactating mothers in four remote villages in Papua, New Guinea, DDT was detected in 100% of samples (41), and was one of only two organochlorines detected. DDT has also been detected in the breast milk of Egyptian women, with an average total DDT detected of 57.59 ppb and an estimated daily intake of total DDT for breast feeding infants of 6.90 μg/kg body weight /day. While lower than the acceptable daily intake of 20.0 μg/kg body weight recommended by the Joint FAO/WHO Meeting on Pesticide Residues (JMPR), **its continuing presence raises serious concerns regarding potential effects on developing infants.**

* from L. Ritter, et al.(1995), "Persistent Organic Pollutants: An Assessment Report on DDT, Aldrin, Dieldrin, Endrin, Chlordane, Heptachlor, Hexachlorobenzene, Mirex, Toxaphene, Polychlorinated Biphenyls, Dioxins, and Furans", an Assessment Report of the International Programme on Chemical Safety

** The International Programme on Chemical Safety (IPCS), established in 1980, is a joint programme of three Cooperating Organizations, ILO, UNEP and WHO, implementing activities related to chemical safety. IPCS is an intersectoral coordinated and scientifically based programme. WHO is the Executing Agency of the IPCS. The two main roles of IPCS are: to establish the scientific basis for safe use of chemicals and to strengthen national capabilities and capacities for chemical safety . IPCS areas of activity include: Evaluation of chemical risks to human health and the environment; Methodologies for Evaluation of Hazards and Risks; Prevention and management of toxic exposures and chemical emergencies; Development of the human resources required in the above areas.

Table 3.3.4.3
DDT Information Profile of the Extension Toxicology Network
Toxicological Effects

Acute Toxicity:

DDT is moderately to slightly toxic to studied mammalian species via the oral route. Reported oral LD50s range from 113 to 800 mg/kg in rats (8,2); 150-300 mg/kg in mice (8); 300 mg/kg in guinea pigs (2); 400 mg/kg in rabbits (2) ; 500-750 mg/kg in dogs (8) and greater than 1,000 mg/kg in sheep and goats (8). Toxicity will vary according to formulation (8). DDT is readily absorbed through the gastrointestinal tract, with increased absorption in the presence of fats (2). One-time administration of DDT to rats at doses of 50 mg/kg led to decreased thyroid function and a single dose of 150 mg/kg led to increased blood levels of liver-produced enzymes and changes in the cellular chemistry in the central nervous system of monkeys (2). Single doses of 50-160 mg/kg produced tremors in rats, and single doses of 160 mg/kg produced hind leg paralysis in guinea pigs (2). Mice suffered convulsions following a one-time oral dose of 200 mg/kg. Single administrations of low doses to developing 10-day old mice are reported to have caused subtle effects on their neurological development (2). **DDT is slightly to practically non-toxic to test animals via the dermal route**, with reported dermal LD50s of 2,500-3,000 mg/kg in female rats (8, 2), 1000 in guinea pigs (2) and 300 in rabbits (2). It is not readily absorbed through the skin unless it is in solution (2). It is thought that inhalation exposure to DDT will not result in significant absorption through the lung alveoli (tiny gas-exchange sacs) but rather that it is probably trapped in mucous secretions and swallowed by exposed individuals following the tracheo-bronchial clearance of secretions by the cilia (2). Acute effects likely in humans due to low to moderate exposure may include nausea, diarrhea, increased liver enzyme activity, irritation (of the eyes, nose or throat), disturbed gait, malaise and excitability; at higher doses, tremors and convulsions are possible (2, 5). While adults appear to tolerate moderate to high ingested doses of up to 280 mg/kg, a case of fatal poisoning was seen in a child who ingested one ounce of a 5% DDT:kerosene solution (2).

Table 3.3.4.3 (continued)
DDT Information Profile of the Extension Toxicology Network
Toxicological Effects

Chronic Toxicity:

DDT has caused chronic effects on the nervous system, liver, kidneys, and immune systems in experimental animals (2, 3). Effects on the nervous system observed in test animals include: tremors in rats at doses of 16-32 mg/kg/day over 26 weeks; tremors in mice at doses of 6.5-13mg/kg/day over 80-140 weeks; changes in cellular chemistry in the central nervous system of monkeys at doses of 10 mg/kg/day over 100 days, and loss of equilibrium in monkeys at doses of 50 mg/kg/day for up to 6 months (2). The main effect on the liver seen in animal studies was localized liver damage. This effect was seen in rats given 3.75 mg/kg/day over 36 weeks, rats exposed to 5 mg/kg/day over 2 years and dogs at doses of 80 mg/kg/day over the course of 39 months (2). In many cases lower doses produced subtle changes in liver cell physiology, and in some cases higher doses produced more severe effects (2). In mice doses of 8.33 mg/kg/day over 28 days caused increased liver weight and increased liver enzyme activity (2). Liver enzymes are commonly involved in detoxification of foreign compounds, so it is unclear whether increased liver enzyme activity in itself would constitute an adverse effect. In some species (monkeys and hamsters), doses as high as 8-20 mg/kg/day caused no observed adverse effects over exposure periods as long as 3.5-7 years (2). Kidney effects observed in animal studies include adrenal gland hemorrhage in dogs at doses of 138.5 mg/kg/day over 10 days and adrenal gland damage at 50 mg/kg day over 150 days in dogs (2). Kidney damage was also seen in rats at doses of 10 mg/kg/day over 27 months (2). Immunological effects observed in test animals include: reduced antibody formation in mice following administration of 13 mg/kg/day for 3-12 weeks and reduced levels of immune cells in rats at doses of 1 mg/kg/day (2). No immune system effects were observed in mice at doses of 6.5 mg/kg/day for 3-12 weeks (2). Dose levels at which effects were observed in test animals are very much higher than those which may be typically encountered by humans (3). The most significant source of exposure to individuals in the United States is occupational, occurring only to those who work or worked in the production or formulation of DDT products for export (4). Analysis of U. S. market basket surveys showed approximately a 30-fold decrease in detected levels of DDT and metabolites in foodstuffs from 1969-1974, and another threefold drop from 1975-1981, with a final estimated daily dose of approximately 0.002 mg/person/day (2). Based on a standard 70-kg person, this results in a daily intake of approximately 0.00003 mg/kg/day. Due to the persistence of DDT and its metabolites in the environment, very low levels may continue to be detected in foodstuffs grown in some areas of prior use (2). It has been suggested that, depending on patterns of international DDT use and trade, it is possible that dietary exposure levels may actually increase over time (2). Persons eating fish contaminated with DDT or metabolites may also be exposed via bioaccumulation of the compound in fish (2). Even though current dietary levels are quite low, past and current exposures may result in measurable body burdens due to its persistence in the body (2). More information on the metabolism and storage of DDT and its metabolites in mammalian systems is provided below (Fate in Humans and Animals). **Adverse effects on the liver, kidney and immune system due to DDT exposure have not been demonstrated in humans in any of the studies which have been conducted to date** (2).

Table 3.3.4.3 (continued)
DDT Information Profile of the Extension Toxicology Network
Toxicological Effects

Reproductive Effects:

There is evidence that DDT causes reproductive effects in test animals. No reproductive effects were observed in rats at doses of 38 mg/kg/day administered at days 15-19 of gestation (2). In another study in rats, oral doses of 7.5 mg/kg/day for 36 weeks resulted in sterility (2). In rabbits, doses of 1 mg/kg/day administered on gestation days 4-7 resulted in decreased fetal weights and 10 mg/kg/day on days 7-9 of gestation resulted in increased resorptions (2). In mice, doses of 1.67 mg/kg/day resulted in decreased embryo implantation and irregularities in the estrus cycle over 28 weeks (2). **It is thought that many of these observed effects may be the result of disruptions in the endocrine (hormonal) system** (2). Available epidemiological evidence from two studies does not indicate that reproductive effects have occurred in humans as a result of DDT exposure (2). No associations between maternal blood levels of DDT and miscarriage nor premature rupture of fetal membranes were observed in two separate studies (2, 6, 7). **One study did report a significant association between maternal DDT blood levels and miscarriage, but the presence of other organochlorine chemicals (e.g., PCBs) in maternal blood which may have accounted for the effect make it impossible to attribute the effect to DDT and its metabolites (8).**

Teratogenic Effects:

There is evidence that DDT causes teratogenic effects in test animals as well. In mice, maternal doses of 26 mg/kg/day DDT from gestation through lactation resulted in impaired learning performance in maze tests (2). In a two-generational study of rats, 10 mg/kg/day resulted in abnormal tail development (2). Epidemiological evidence regarding the occurrence of teratogenic effects as a result of DDT exposure are unavailable (2). **It seems unlikely that teratogenic effects will occur in humans due to DDT at likely exposure levels.**

Mutagenic Effects:

The evidence for mutagenicity and genotoxicity is contradictory. In only 1 out of 11 mutagenicity assays in various cell cultures and organisms did DDT show positive results (2). Results of in vitro and in vivo genotoxicity assays for chromosomal aberrations indicated that DDT was genotoxic in 8 out of 12 cases, and weakly genotoxic in 1 case (2). In humans, blood cell cultures of men occupationally exposed to DDT showed an increase in chromosomal damage. In a separate study, significant increases in chromosomal damage were reported in workers who had direct and indirect occupational exposure to DDT (2). **Thus it appears that DDT may have the potential to cause genotoxic effects in humans, but does not appear to be strongly mutagenic.** It is unclear whether these effects may occur at exposure levels likely to be encountered by most people.

Table 3.3.4.3 (continued)
DDT Information Profile of the Extension Toxicology Network
Toxicological Effects

Carcinogenic Effects:

The evidence regarding the carcinogenicity of DDT is equivocal. It has been shown to cause increased tumor production (mainly in the liver and lung) in test animals such as rats, mice and hamsters in some studies but not in others (2) In rats, liver tumors were induced in three separate studies at doses of 12.5 mg/kg/day over periods of 78 weeks to life, and thyroid tumors were induced at doses of 85 mg/kg/day over 78 weeks (2). In mice, lifetime doses of 0.4 mg/kg/day resulted in lung tumors in the second generation and leukemia in the third generation; liver tumors were induced at oral doses of 0.26 mg/kg/day in two separate studies over several generations. In hamsters, significant increases in adrenal gland tumors were seen at doses of 83 mg/kg/day in females (but not males) , and in males (but not females) at doses of 40 mg/kg/day (2). In other studies, however, no carcinogenic activity was observed in rats at doses less than 25 mg/kg/day; no carcinogenic activity was seen in mice with at doses of 3-23 mg/kg/day over an unspecified period, and in other hamster studies there have been no indications of carcinogenic effects (2). **The available epidemiological evidence regarding DDT's carcinogenicity in humans, when taken as a whole, does not suggest that DDT and its metabolites are carcinogenic in humans at likely dose levels** (2). In several epidemiological studies, no significant associations were seen between DDT exposure and disease, but in one other study, a weak association was observed (2, 9). In this latter study, which found a significant association between long-term, high DDT exposures and pancreatic cancers in chemical workers, there were questions raised as to the reliability of the medical records of a large proportion of the cancer cases (2,9).

Organ Toxicity:

Acute human exposure data and animal studies reveal that DDT can affect the nervous system, liver, kidney (2). Increased tumor production in the liver and lung has been observed ir test animals (2). **An association with pancreatic cancer was suggested in humans in one study** (2, 9).

Fate in Humans & Animals:

DDT is very slowly transformed in animal systems (3). Initial degradates in mammalian systems are 1,1-dichloro-2,2-bis(p-dichlorodiphenyl)ethylene (DDE) and 1,1-dichloro-2,2-bis(p-chlorophenyl)ethane (DDD), which are very readily stored in fatty tissues (2). These compounds in turn are ultimately transformed into bis(dichlorodiphenyl) acetic acid (DDA) via other metabolites at a very slow rate (2). DDA, or conjugates of DDA, are readily excreted via the urine (2). **Available data from analysis of human blood and fat tissue samples collected in the early 1970s showed detectable levels in all samples, but a downward trend in the levels over time** (2). Later study of blood samples collected in the latter half of the 1970s showed that blood levels were declining further, but DDT or metabolites were still seen in a very high proportion of the samples (2). Levels of DDT or metabolites may occur in fatty tissues (e.g. fat cells, the brain, etc.) at levels of up to several hundred times that seen in the blood (2). **DDT or metabolites may also be eliminated via mother's milk by lactating women** (2).

Table 3.3.4.4
DDT Information Profile of the Extension Toxicology Network
Ecological Effects

Effects on Birds:

DDT may be slightly toxic to practically non-toxic to birds. Reported dietary LD50s range from greater than 2,240 mg/kg in mallard, 841 mg/kg in Japanese quail and 1,334 mg/kg in pheasant (10). Other reported dietary LD50s in such species as bobwhite quail, California quail, red-winged blackbird, cardinal, house sparrow, blue jay, sandhill crane and clapper rail also indicate slight toxicity both in acute 5-day trials and over longer periods of up to 100 days (11). In birds, exposure to DDT occurs mainly through the food web through predation on aquatic and/or terrestrial species having body burdens of DDT, such as fish, earthworms and other birds (11). **There has been much concern over chronic exposure of bird species to DDT and effects on reproduction, especially eggshell thinning and embryo deaths** (11). The mechanisms of eggshell thinning are not fully understood. It is thought that this may occur from the major metabolite, DDE, and that predator species of birds are the most sensitive to these effects (11). Laboratory studies on bird reproduction have demonstrated the potential of DDT and DDE to cause subtle effects on courtship behavior, delays in pairing and egg laying and decreases in egg weight in ring doves and Bengalese finches (11). The implications of these for long-term survival and reproduction of wild bird species is unclear. There is evidence that synergism may be possible between DDT's metabolites and organophosphate (cholinesterase-inhibiting) pesticides to produce greater toxicity to the nervous system and higher mortality (11). Aroclor (polychlorinated biphenyls, or PCBs) may result in additive effects on eggshell thinning (11).

Effects on Aquatic Species:

DDT is very highly toxic to many aquatic invertebrate species. Reported 96-hour LC50s in various aquatic invertebrates (e.g., stoneflies, midges, crayfish, sow bugs) range from 0.18 ug/L to 7.0 ug/L, and 48-hour LC50s are 4.7 ug/L for daphnids and 15 ug/L for sea shrimp (1). Other reported 96-hour LC50s for various aquatic invertebrate species are from 1.8 ug/L to 54 ug/L (11). Early developmental stages are more susceptible than adults to DDT's effects (11). The reversibility of some effects, as well as the development of some resistance, may be possible in some aquatic invertebrates (1). **DDT is very highly toxic to fish species as well.** Reported 96-hour LC50s are less than 10 ug/L in coho salmon (4.0 ug/L), rainbow trout (8.7 ug/L), northern pike (2.7 ug/L), black bullhead (4.8 ug/L), bluegill sunfish (8.6 ug/L), largemouth bass (1.5 ug/L), and walleye (2.9 ug/L) (1). The reported 96-hour LC50s in fathead minnow and channel catfish are 21.5 ug/L and 12.2 ug/L respectively (1). Other reported 96-hour LC50s in largemouth bass and guppy were 1.5 ug/L and 56 ug/L respectively (11). Observed toxicity in coho and chinook salmon was greater in smaller fish than in larger (11). It is reported that DDT levels of 1 ng/L in Lake Michigan were sufficient to affect the hatching of coho salmon eggs (3). DDT may be moderately toxic to some amphibian species and larval stages are probably more susceptible than adults (10, 11). **In addition to acute toxic effects, DDT may bioaccumulate significantly in fish and other aquatic species, leading to long-term exposure. This occurs mainly through uptake from sediment and water into aquatic flora and fauna, and also fish** (11). Fish uptake of DDT from the water will be size-dependent with smaller fish taking up relatively more than larger fish (11). A half-time for elimination of DDT from rainbow trout was estimated to be 160 days (11). The reported bioconcentration factor for DDT is 1,000 to 1,000,000 in various aquatic species (12), and bioaccumulation may occur in some species at very low environmental concentrations (1). **Bioaccumulation may also result in exposure to species which prey on fish or other aquatic organisms (e.g., birds of prey).**

Table 3.3.4.4 (continued)
DDT Information Profile of the Extension Toxicology Network
Ecological Effects

Effects on Other Animals (Nontarget species):
Earthworms are not susceptible to acute effects of DDT and its metabolites at levels higher than those likely to be found in the environment, but they may serve as an exposure source to species that feed on them (11). **DDT is non-toxic to bees**; the reported topical LD50 for DDT in honeybees is 27 ug/bee (11). Laboratory studies indicate that bats may be affected by DDT released from stored body fat during long migratory periods (11).

Table 3.3.4.5
DDT Information Profile of the Extension Toxicology Network
Environmental Fate

Breakdown in Soil and Groundwater:

DDT is very highly persistent in the environment, with a reported half life of between 2-15 years (12, 13) and is immobile in most soils. Routes of loss and degradation include runoff, volatilization, photolysis and biodegradation (aerobic and anaerobic) (2). These processes generally occur only very slowly. Breakdown products in the soil environment are DDE and DDD, which are also highly persistent and have similar chemical and physical properties (11, 13). Due to its extremely low solubility in water, DDT will be retained to a greater degree by soils and soil fractions with higher proportions of soil organic matter (11). It may accumulate in the top soil layer in situations where heavy applications are (or were) made annually; e.g., for apples (72). Generally DDT is tightly sorbed by soil organic matter, but it (along with its metabolites) has been detected in many locations in soil and groundwater where it may be available to organisms (11, 12). This is probably due to its high persistence; although it is immobile or only very slightly mobile, over very long periods of time it may be able to eventually leach into groundwater, especially in soils with little soil organic matter. Residues at the surface of the soil are much more likely to be broken down or otherwise dissipated than those below several inches (3). Studies in Arizona have shown that volatilization losses may be significant and rapid in soils with very low organic matter content (desert soils) and high irradiance of sunlight, with volatilization losses reported as high as 50% in 5 months (14). In other soils (Hood River and Medford) this rate may be as low as 17-18% over 5 years (14). Volatilization loss will vary with the amount of DDT applied, proportion of soil organic matter, proximity to soil-air interface and the amount of sunlight (11).

Breakdown of Chemical in Surface Water:

DDT may reach surface waters primarily by runoff, atmospheric transport, drift, or by direct application (e.g. to control mosquito-borne malaria) (2). The reported half-life for DDT in the water environment is 56 days in lake water and approximately 28 days in river water (12). The main pathways for loss are volatilization, photodegradation, adsorption to water-borne particulates and sedimentation (2) Aquatic organisms, as noted above, also readily take up and store DDT and its metabolites. Field and laboratory studies in the United Kingdom demonstrated that very little breakdown of DDT occurred in estuary sediments over the course of 46 days (11). **DDT has been widely detected in ambient surface water sampling in the United States at a median level of 1 ng/L (part per trillion)** (2, 5).

Breakdown of Chemical in Vegetation:

DDT does not appear to be taken up or stored by plants to a great extent. It was not translocated into alfalfa or soybean plants, and only trace amounts of DDT or its metabolites were observed in carrots, radishes and turnips all grown in DDT-treated soils (11). Some accumulation was reported in grain, maize and riceplants, but little translocation occurred and residues were located primarily in the roots (2).

NOTES for Table 3.3.4.3, Table 3.3.4.4; & Table 3.3.4.5: DDT Information Profile of the Extension Toxicology Network

• Tables are from Pesticide Information Profiles of "EXTOXNET" (Extension Toxicology Network), an online Pesticide Information Project of the Cooperative Extension Offices of Cornell University, Oregon State University, the University of Idaho, the University of California at Davis and the Institute for Environmental Toxicology, Michigan State University. The primary files of this database are maintained and archived at Oregon State University. See http://ace.ace.orst.edu/info/extoxnet/pips/ghindex.html

** Cited works are as follows:

(1) Johnson, W. W. and Finley, M. T. Handbook of Acute Toxicity of Chemicals to Fish and Aquatic Invertebrates, Resource Publication 137. U.S. Department of Interior, Fish and Wildlife Service, Washington, DC, 1980.6-56

(2) Agency for Toxic Substances and Diseases Registry (ATSDR)/US Public Health Service, Toxicological Profile for 4,4'-DDT, 4,4'-DDE, 4, 4'-DDD (Update). 1994. ATSDR. Atlanta, GA.

(3) World Health Organization (WHO). 1979. Environmental Health Criteria 9, DDT and its Derivatives. World Health Organization, Geneva.

(4) Sax, N. Irving. 1984. Dangerous Properties of Industrial Materials, Sixth edition. Van Nostrand Reinhold. New York, NY.

(5) Van Ert, M. and Sullivan, J.B. 1992. Organochlorine Pesticides In Sullivan, J.B. and Krieger, G.R., Hazardous Materials Toxicology, Clinical Principles of Environmental Health. Williams & Wilkins, Baltimore, MD.

(6) Leoni, V., Fabiani, L. and Marinelli, G. 1989. PCB and other organochlorines in blood of women with or without miscarriage: A hypothesis of correlation, Ecotoxicol Environ Safety 17:1-11.

(7) Ron, M., Cucos, S. and Rosenn, B. 1988. Maternal and fetal serum levels of organo-chlorine compounds in cases of premature rupture of membranes Acta Obstet Gynecol Scand 67:695-697.

(8) Wasserman, M., Ron, M., Bercovici, B., Wasserman, D., Cucos, S. and Pines, A. 1982. Premature delivery and organochlorine compounds: polychlorinated biphenyls and some organochlorine insecticides, Environ Res 28:106-112.

(9) Garabrant, D.H., Held, J., Langholz, B., Peters, J.M. and Mack, T.M. DDT and related compounds and risk of pancreatic cancer, J Natl Cancer Inst. 84:764-771.

(10) Hudson, R.H., Tucker, R.K. and Haegele, K. 1984. Handbook of Acute Toxicity of Pesticides to Wildlife. Resource Publication 153. U.S. Dept. of Interior, Fish and Wildlife Service, Washington, DC.

(11) World Health Organization (WHO). 1989. Environmental health Criteria 83, DDT and its DerivativesÑEnvironmental Effects. World Health Organization, Geneva.

(12) US Environmental Protection Agency. 1989. Environmental Fate and Effects Division, Pesticide Environmental Fate One Line Summary: DDT (p, p'). Washington, DC.

(13) Augustijn-Beckers, P.W.M., Hornsby, A.G. and Wauchope, R.D. 1994. SCS/ARS/CES Pesticide Properties Database for Environmental Decisionmaking II. Additional Properties Reviews of Environmental Contamination and Toxicology, Vol. 137.

(14) Jorgensen, S.E., Jorgensen, L.A. and Nielsen, S.N. 1991. Handbook of Ecological Parameters and Ecotoxicology. Elsevier. Amsterdam, Netherlands.

Besides familiarizing readers with the characteristics of DDT of relevance to the story of its rise and fall, the Tables above also serve to underline and foreshadow the importance of acts of *interpretation* and ultimately *reconciliation* of *descriptive claims* in the life and fate of the focal product. Compare the following matched claims, extracted from different Tables above, and which flow from a common data set comprised of all the scientific literature on DDT:

Toxicity to Birds:

DDT is acutely toxic to birds.

(IPCS)

DDT may be slightly toxic to practically non-toxic to birds.

(EXTOXNET)

Effect on Immune System:

There is some evidence to suggest that DDT may be suppressive to the immune system.

(IPCS)

Adverse effects on the liver, kidney and immune system due to DDT exposure have not been demonstrated in humans in any of the studies which have been conducted to date.

(EXTOXNET)

Carcinogenicity:

IARC has concluded that while there is inadequate evidence for the carcinogenicity of DDT in humans, there is sufficient evidence in experimental animals. IARC has classified DDT as a possible human carcinogen (Group 2B).

(IPCS)

The available epidemiological evidence regarding DDT's carcinogenicity in humans, when taken as a whole, does not suggest that DDT and its metabolites are carcinogenic in humans at likely dose levels.

(EXTOXNET)

So what do you think? Does DDT have a harmful effect on the immune system? Is DDT toxic to birds? Does DDT cause cancer? For that last question, does it help to know the additional information that the United States Department of Health and Human Services has determined that *"DDT may reasonably be anticipated to be a human carcinogen"* or that the EPA has classified DDT as a *"probable human carcinogen"*[30].

And so what if all of the worst claims about DDT are true? What if it is acutely toxic to birds, does suppress the immune system, and does cause cancer? Many commercially produced substances have these properties. Moreover, unlike other substances such as industrial chemicals for example, pesticides are specifically *designed* to be harmful to living things, are they not? Does its potential for harm mean that DDT should not be used in agriculture? What about in public health where, because of its low cost and high toxicity to mosquitoes, the World Health Organization still considers DDT to be an *"important, sometimes vital,"* component of malaria control programs, a disease which results in up to 2.7 million deaths each year and is killing children, while you read this, at a rate of 4 per minute[31]? Compare the following matched claims:

> *"DDT should be banned globally by no later than 2007 under the auspices of the International Convention on POPs."*
>
> (World Wildlife Fund, 1998, p 44)[32]

> *"While it is true that we don't know every last risk of using DDT, we know very well what the risk of malaria is - and on balance malaria is far, far more deadly than the worst that one could imagine about DDT. ... We are not in love with DDT. But the reality is that if you try to get rid of DDT without guaranteeing that money will be available for alternatives, you will kill people. If Western countries like the U.S. or U.K. want the environmental benefit of a DDT ban, let them pay for it Africa, Asia and South America have neither the technology nor money to research and implement alternatives to DDT. The rich countries do. For them to*

[30] Agency for Toxic Substances and Disease Registry (visit: www.atsdr.cdc.gov); also EPA's Office of Pesticide Programs report on "Pesticidal Chemicals Classified as Known, Probable or Possible Human Carcinogens" (visit: http://www.epa.gov/opp00001/carlist/index.htm).

[31] Quotation is from press release "WHO ARGUES BALANCED POSITION ON DDT" released 1999 09 10; Epidemiological statistics are from the WHO (visit: http://www.who.int/ctd/html/malaria.html).

[32] World Wildlife Fund Canada & U.S., 1998, *Resolving the DDT Dilemma: Protecting Biodiversity and Human Health*

advocate a DDT ban while holding tight the purse strings for those alternatives is obscene."

(Amir Attaran, Director, The Malaria Project, September 1999)[33]

Do the benefits of DDT outweigh its costs and risks? Are these benefits and risks distributed fairly across actors? These difficult questions foreshadow the importance of acts of *interpretation* and ultimately *reconciliation* of *normative claims* in the life and fate of the focal product.

Indeed, the evidence presented in this dissertation will demonstrate how even what appear to be the most simple, basic and settled of questions can become sites of contestation with determining influence on the fate of a product. For example, that DDT is an *insecticide* (i.e. it is a substance whose function it is to kill insects) that is *wide-spectrum* (i.e. it is toxic to many insect species) and has a *long residual action* (i.e. it is stable and persists in soil, water and sunlight, therefore its killing power lasts a long time) are claims so uncontested that they may be considered "truths" about DDT. But here again, so what? Imagine an alternative product competing with DDT, an insecticide that is equivalent on *all* other dimensions (including cost) to our focal molecule but which differs only on these two; it *kills fewer species* of insects than DDT and then because it breaks down more quickly it *kills even fewer numbers* of insects per species per unit of quantity applied. Which is the more *effective* insecticide, the one we would expect to score higher on *performance*? Or in other words, which product would you expect to substitute for the other: DDT for the alternative, or the alternative for DDT?

The answer to this final question is "it depends". This dissertation explains why.

3.4 Insect-Man Relations and the Function of Insect Control

It is common to think of Man as the only species on this planet who could be considered in the running for achieving world dominance, but if this is looked at along various

[33] cited in the Globe and Mail, 1999 09 02

measures of domination (see Table 3.4.1), it becomes apparent that those who argue that Man is in a close and nasty battle with insects to inherit the Earth may indeed have a point. I examine Insect-Man relations in this section.

Table 3.4.1 - Insects & Man: A Struggle for World Domination?

"Insects are the dominant group of animals on the earth today."

numbers:	- Populations can easily number many millions to an acre.
diversity:	- There are several hundred thousand different kinds of insects, which is 3 times as many as in the rest of the animal kingdom. - A typical North American backyard may have over a 1000 different insect varieties in it. - Insects have colonized habitats inhospitable to other species.
longevity:	- Insects have lived on the earth for about 350 million years, compared to less than 2 million for Man.
strength:	- It is not unusual for an insect to be able to lift 50 times its body weight. Some beetles manage 800 times. Grasshoppers and fleas jump distances that are like, relative to their size, Man broadjumping the length of a football field or over a 30-story building.
society:	- Bees, ants, termites and other insects live in organized social systems that engage in activities such as warfare with competing colonies, slavery, and even domestication of other insect species.
technology:	- Wasps, bees and other insects construct elaborate homes for themselves. Wasps make crude paper from wood pulp.

"Insects are the only animals giving man a real battle for supremacy."

(1) Facts and initial quotation are from Borror et al (1981).
(2) Final quotation is from Pfadt (1962).

Insect-Man relations have a long and complicated history, and the function of insect control is not a recent one in the evolution of human societies. Man has always been forced to engage with Insects as he first gathered, then later actively managed, controlled and organized the production of the nutrient-rich vegetable matter produced by plants converting the sun's energy into life itself. Insect-Man relations are not simple. They comprise a mix of conflictual competition as well as symbiotic collaboration, all of which takes place within complex, evolving ecosystems.

It is appropriate to adopt here an economic perspective, as this is the perspective that has most significantly mediated Man's interactions with Insects this century, through the scientific discipline of *economic* entomology. It is economic thinking and terminology that permeates the literature. Indeed, as mentioned above, the chemical technologies that are the focus of this dissertation are legally known as *economic* poisons.

Within that perspective, some insects and insect activities are clearly harmful to Man and result directly in less, or losses of, human welfare or utility. These are commonly termed *"injurious species"*[34]. From the annoying nuisance that mosquitoes, cockroaches or houseflies can cause individuals in their homes, to the complete destruction of a year's worth of a community's agricultural harvest by a swarm of locusts, the importance of different injurious species and the degree of damage they do varies greatly.

The codling moth, responsible for the infamous worm in the apple, the spruce budworm, responsible for destroying vast swatches of valuable forest, and the cotton bollworm, responsible for reduced yields of cotton crops, are three examples of significant insect pest species which harm Man through their collective metabolism: as they eat, reproduce and increase their populations, they leave less food, feed, forests and fibre available for humans. This reduction in quantity and quality of resources can be direct and immediate - as when the insects eat the fruit and foliage of plants that Man had intended for himself, like the codling moth - or it can be indirect and take more time - as when the insects' feeding activities, per se, are not harmful but the consequences of thriving insect populations are. As an example of this latter case, some insects serve as vectors (i.e. transmission vehicles) of diseases which attack plants or trees valued by man and which eventually kill them. Bark beetles carry the fungus responsible for Dutch elm disease and, as they move about, can infect all elm trees in a neighbourhood. Other insects may be deemed "injurious" because they serve as vectors of diseases of livestock and poultry. Table 3.4.2 - Examples of Injurious Species of Insects lists some injurious species of concern to farmers, foresters and the public in the United States.

Table 3.4.2 - Examples of Injurious Species of Insects

Injurious Species	Injury
black carpet beetle	damage to fabrics (carpets)
boll weevil	damage to agriculture (cotton)
bollworm	damage to agriculture (cotton)
budworm	damage to agriculture (tobacco)
codling moth	damage to agriculture (apples)
corn earworm	damage to agriculture (corn)
crab lice	damage to humans (as parasites)
European bark beetle	vector for plant disease (Dutch elm disease)
gypsy moth	damage to forests (hardwoods)
lice (various species)	damage to livestock (cattle, sheep, goats, swine, fowl)
meal & grain moths	damage to stored foodstuffs (flour, grain)
mites (various species)	damage to livestock (cattle, sheep, goats, swine, fowl)
mosquito	vector for human disease (malaria)
spruce budworm (tortricid moth)	damage to forests (softwoods)
termites	damage to human structures (wooden houses)
ticks	vector for livestock disease (anaplasmosis of cattle)

(1) Table represents "common knowledge" to entomologists and has been compiled from various sources, including USDA(1952); Rudd (1964); Borror et al (1981).

The economic dimension to pest definition begins to be revealed by Table 3.4.2: "important" injurious species are those that are harmful to "important" crops. Avoidance of "losses due to insect damage" in agriculture is the main function of insecticidal substances in the United States economy. The importance of this function is quite high, has grown, and will continue to grow along with agricultural productivity and output. The stakes are quite high. More than 10,000 species of pest insects cause agricultural losses, with 600 among them serious enough to warrant systematic control measures each growing season[35]. Applied entomology texts routinely estimated crop losses by insect damage at, conservatively, about 10% of crop production[36].

> *"The losses to national economies resulting from insect damage are enormous and rarely comprehended; thus ... on a conservative basis of a 10 per cent loss in total crop yield due to depredations by insects, ... not*

---

[34] This distinction between "injurious" and "beneficial" insects dates from the earliest days of entomology, and was well-entrenched by the turn of the century. See Folsom (1914, p 325) for example.
[35] Metcalf (1972); also Schwartz & Klassen (1981)
[36] Fernald & Shepard (1955); also West, Hardy & Ford (1951)

less than one-tenth of the human effort of the British Empire on basic industries such as agriculture is dissipated by our insect enemies."

(West, Hardy & Ford, 1951, p 20)

This figure is generally supported by other sources, as evidenced by the summary contained in Table 3.4.3 - Summary of Crop Losses to Insects

Table 3.4.3 - Summary of Crop Losses to Insects

Period	% Annual Loss
1904	9.8
1910 - 1935	10.5
1942 - 1951	7.1
1951 - 1960	12.9
1974	13.0
1986	13.0

(1) Table drawn from U.S. data, in Pimentel (1991).

Crop losses due to all pests (i.e. fungus, rodents, birds, worms, etc. in addition to insects) have been estimated to be about 30%, totaling $30 billion annually by the early 1990s[37].

In 1938, just prior to the introduction of DDT, crop losses due to insect damage amounted to $1.6 billion annually, a figure which had risen to $4 billion by 1955[38]. The introduction of DDT and other synthetic organic chemicals into agriculture is widely credited with higher farm yields and increased productivity in the agricultural sector[39].

Other insects (along with ticks and mites) serve as transmission vehicles - technically referred to as "vectors" - for human diseases, as shown in Table 3.4.4 - Insects as Disease Vectors. Hence the function of insect control is vital to programs of public health, especially in tropical climates. Of note in this list are two serious diseases: (1) typhus, spread by lice, and (2) malaria, with the anopheles mosquito as its vector. The first wide scale field use of DDT was by Allied forces in World War II to halt the spread of a

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[37] Schwartz & Klassen (1981); also Ware (1994, p 7)
[38] Fernald & Shepard (1955, p 33)
[39] Metcalf (1972)

typhus epidemic in Naples, Italy and this was credited with saving millions of lives[40]. Soon after, DDT became the insecticide of choice in malaria control, and to this day is credited with saving millions of lives.

Currently, the World Health Organization still considers DDT to be an "*important, sometimes vital,*" component of malaria control programs, although it is committed to implementing its own "*Action Plan for the Reduction of Reliance on DDT for Public Health Purposes*", a plan it presented recently to the third meeting of the Intergovernmental Negotiating Committee for an International Legally Binding Instrument for Implementing International Action on Certain Persistent Organic Pollutants (POPs). Elimination of DDT from the global economy remains highly controversial. Malaria continues to put 40% of the world's population at risk, with an incidence rate of 300 - 500 million cases annually resulting in some 1.5 - 2.7 million deaths each year, with 1 million of these being to children under 5 years of age[41].

[40] West & Campbell (1950, p 7)

[41] Quotation is from press release "WHO ARGUES BALANCED POSITION ON DDT" released 1999 09 10; Epidemiological statistics are from the WHO (visit: http://www.who.int/ctd/html/malaria.html).

Table 3.4.4 - Insects, Ticks & Mites as Disease Vectors

Disease	Vector
African sleeping sickness	Tsetse flies
Anthrax	Horse flies
Bubonic plague	A rat flea
Chagas' disease	Assassin bugs
Dengue fever	Two mosquitoes
Dysenteries	Several flies
Encephalitides	Several mosquitoes
Endemic typhus	Oriental rat flea
Epidemic typhus	Human louse
Filariasis	Several mosquitoes
Hemorrhagic fevers	Several mites and ticks
Leishmaniases	Psychodid flies
Louping ill	Castor bean tick
Lyme disease	*Ixodes* spp. ticks
Malaria	*Anopheles* mosquitoes
Onchocerciasis	Several black flies
Pappataci fever	A psychodid fly
Q fever	Ticks
Relapsing fevers	Several ticks
Rocky Mountain spotted fever	Two ticks
Scrub typhus	Chigger mites
St. Louis encephalitis	*Culex pipiens* mosquitoes
Trypanosomiasis	Several flies
Tularemia	Several flies, fleas, lice, ticks
Yaws	Several flies
Yellow fever	Several mosquitoes

*Table is from Ware (1994, p 33).

On the other hand, besides *"injurious species"* there are also many *"beneficial species"* of insects which, through their activities, contribute directly or indirectly to Man's welfare. For example, bees are an important mechanism in many regions of the world for the absolutely essential function, from both an ecological and economic perspective, of pollination. Of interest to the story of technological evolution in the field of insect control, the special status of bees as pollinators of important fruit crops and as producers of honey means that the impact of a new insecticide on the population of this "beneficial species" is a very important evaluation criteria used to judge the merits of the new product; substances especially toxic to bees are less desirable. As another example of a beneficial species, consider that silk culture, made possible by silkworms, is still an important economic activity, and goes back to Emperor Fu-hsi who lived at the beginning of the third millenium. Other species may be deemed "beneficial" because they are predators which help in controlling the population of prey species which have been deemed "injurious", such as the vedalia beetle which controls cottony cushion scale, a serious problem for citrus farmers.

One should note that, in general, the term "insect control" is reserved for describing only those purposeful human activities undertaken to affect or influence populations of injurious species of insects. Therefore, my review of the history of these technologies does not cover activities associated with managing beneficial species, like those of apiculturists or silk producers. This means that, despite a more balanced view in the scientific discipline of "entomology" as a whole, Insect-Man relations are typically looked upon negatively within the narrower discipline of "economic entomology" which concerns itself with "insect control". For economic entomologists, an "insect problem" is seen to exist and a generally hostile attitude towards them prevails. Indeed, a discourse of "war" and a language of conflict, battles, attacks, arsenals, weapons, etc. has clearly dominated in their interpretation of Man's relationship with insects[42]. It still pervades conversations about insect control to this day, although this is slowly changing, partly as a result of events described in this case study. Table 3.4.5 - "War" Against the "Insect Problem" gives some typical examples of this view, ordered chronologically and spanning the entire time period discussed in this Chapter, from pre-DDT, to DDT, to post-DDT insect control:

[42] For a fascinating discussion on the links between war and insect control technology, see Russell (1996).

Table 3.4.5 - "War" Against the "Insect Problem"

Pre-DDT:

> *"**The struggle between man and insects began long before the dawn of civilization , has continued without cessation to the present time, and will continue, no doubt, as long as the human race endures.** ... We commonly think of ourselves as the lords and conquerers of nature, but the insects had thoroughly mastered the world and taken full possession of it long before man began the attempt. They had, consequently, all the advantage of a possession of the field when the contest began, and they have disputed every step of our invasion of their original domain so persistently and so successfully that we can even yet scarcely flatter ourselves that we gained any very important advantage over them. ... **If they want our crops they still help themselves to them. If they wish the blood of our domestic animals, they pump it out of the veins of our cattle and our horses at their leisure and before our very eyes. If they choose to take up abode with us we cannot wholly keep them out of the house we live in.** We cannot even protect our very persons from their annoying and pestiferous attacks, and since the world began, we have yet exterminated - we probably never shall exterminate - so much as a single species. **They have, in fact, inflicted upon us for ages the most serious evils without our even knowing it.**"*
>
> written in 1915 by Dr. S. A. Forbes, entomologist;
> cited in entomology text by Metcalf (1955, p xv).

> *"**The Insect Menace** (1931)"*
>
> *"**Fighting the Insects** (1933)"*
>
> **Titles of books authored by Leland O. Howard,**
> **Head, USDA Division of Entomology, 1894 - 1927 (except 1879-81).**

Table 3.4.5 (continued) - "War" Against the "Insect Problem"

the DDT era:

> *"We feel that never in the history of entomology has a chemical been discovered that offers such **promise to mankind for relief from his insect problems** as DDT."*
>
> Report of the Special Committee on DDT, with S.A. Rohwer as Chairman, in *Journal of Economic Entomology* (1945, p 144).

> *"DDT is an insecticide. It kills "bugs" of all sorts. In fact it seems destined already to take a place as **the best weapon yet discovered in man's ages-long war with a hitherto unconquerable enemy, the insects** ..."*
>
> (Leary et al, 1946, ***DDT and the Insect Problem***, p 1)

> *"When a man is brought into a court of law, we assume that he is innocent unless he is proved guilty. This is a sensible attitude for it does give greater protection to innocent people, even though, unfortunately, it also permits many of our gangsters and other public enemies to escape punishment for their crimes. But, be this as it may, **when we deal with insects, the only wise thing to do is to assume that they are guilty unless they are proved innocent.**"*
>
> (Zimmerman & Levine, 1946, ***DDT: Killer of Killers***, p 1 & 29)

> ***"Atomic Vermin Destroyer"***
>
> (DDT formulated product marketed in 1946, from *Fortune*, January 1946, p 149)

> *"**Through the centuries people have been plagued by insects and have died by the millions from diseases carried by them.** Man is gradually gaining mastery over them, but the battle is long and expensive, the burden is too heavy for the poor in many parts of the world and we still have much to learn about these agents of death."*
>
> (F.C. Bishopp of USDA-BEPQ & C.B. Philip of USPHS, in USDA (1952).

> *"Since early times, **man has waged a continuous battle** to protect and maintain himself and his food supplies in a fiercely competitive environment."*
>
> (Princi, 1952, p 44, in the trade journal *Agricultural Chemicals*)

Table 3.4.5 (continued) - "War" Against the "Insect Problem"

"Open Door to Plenty tells the story of ***man's struggle to control some of the hostile elements in the world around us.*** *These are* ***the pests which destroy our foods and our property and attack our health.*** *Research and education, the twin mainsprings of human progress, have been encouraged consistently by the National Agricultural Chemicals Association to improve* ***man's mastery over these pests.*** *"* Lea S. Hitchner, Executive Secretary of the National Agricultural Chemicals Association, in the introduction to "Open Door to Plenty" (1958), a promotional brochure published in response to the public's growing suspicion of pesticides.

"Fact of the matter is ... without products of modern chemistry, from the fertilizers to pesticides, ***nature could resume its centuries-old tyranny over man!*** *"* (from a pamphlet titled "The Day our Town Died", showing a housewife reading *Silent Spring* in a kitchen completely overrun with insects, published by the National Agricultural Chemicals Association just subsequent to the publication of Carson's book. Shown in Hayley (1983, p 36))

"New Weapons in an Ancient War" title of Chapter 2 in Whitten (1966) *"They* [pesticides] *are used against* ***creatures whose ravages have been recorded since earliest history.*** *... They* [insects] *eat, steal or destroy a large share of everything that man grows or stores."* (p 19) *"As I have tried to make plain,* ***in our fight against Communism our agriculture is perhaps our greatest asset.*** *Its scope embraces both national security and national health. ... We must not permit anyone or any group to saddle our sources of food and fiber with the burden of the unknown.* ***We must not restrict our use of our best weapons*** *against insect-borne diseases. ...* ***We must be ready with new weapons*** *and new methods; but in the meantime we must not give up those we have. ...* ***We must use all our known weapons, as we spend millions of dollars annually in our efforts to find new ones, if we are to enable man to keep that important one step ahead in his continuing contest with insects and disease, with pest and pestilence.*** *To this end we need public understanding, that we may continue to add to the years of our lives, indeed,* ***THAT WE MAY LIVE!"*** [his emphasis]. (p 214, 216)

Table 3.4.5 (continued) - "War" Against the "Insect Problem"

> ***"Since the beginning of time man was at the mercies of the elements of the environment and the pests that afflicted his crops and his person.*** *The rise of science in the last century began to provide a means by which man could alter his environment, at least to a limited extent, and control the pests that beset him."*
>
> Statement of Virgil H. Freed, Chairman, Department of Agricultural Chemistry, Oregon State University to DDT Hearing Officer, Washington State Department of Agriculture in 1969; reprinted in "Selected Statements from State of Washington DDT Hearings held in Seattle, October 14, 15, 16 1969, and Other Related Papers" compiled by Max Sobelman of Montrose Chemical Corporation

Post-DDT:

> *"**Since the dawn of civilization, insects have been plaguing human habitats** as we see from the vivid descriptions of the plagues of insects recorded in ancient literature such as the Bible. ... **In order to combat the situation**, man has come up with various methods ranging from magic and quackery to alchemy. Notwithstanding, from the early ages, **rational pest control** using crude chemical preparations has also been devised and put to use.*
>
> (Perry et al, 1998, p xvii)

> *"And what a period of transformation that fifty years was! Most fundamentally, it was **an era in which insect scourges endured since the dawn of history were brought well within acceptable limits**. But it was also an era in which **a bold - yes, courageous - industry**, building on this astonishing accomplishment, **conquered many other crop-reducing pests and opened the way to an age of agricultural plenty**."*
>
> Hayley (1983, p 3),
> official historian of the National Agricultural Chemicals Association

> *"The specific goal of insecticide research is to discover, develop and understand new products and methods for the safe and efective control of pests, thereby maximizing food production and public health. There have been successes and Golden Ages over the past six decades that met in each case the principal needs at the time. Clearly more scientifically challenging and financially rewarding horizons remain, as insects predictably circumvent attempts for control and **new pests or outbreaks of disease again threaten human welfare**. Insecticide research has led to **victories in major skirmishes**, but **insects remain our principal competitors for a limited food and fiber supply**."*
>
> (Casida & Quistad, 1998, p 15)

Table 3.4.5 (continued) - "War" Against the "Insect Problem"

American agriculture has seen more change and advancement in the current century than in all of man's history. Much of this advancement has been the product of a vigorous growth in innovative technology encouraged and funded by both government and private industry. ***To make the point,consider the agriculture of our nation in Colonial times. ... The whole farm family had to be involved in the battle for survival*** *- continuing struggle to scratch out enough food from the land just for themselves and their livestock ... During the growing season,* ***the family was in a constant battle against crop pests****: pulling or hoeing weeds from daylight to dusk, flailing at grasshoppers, picking off worms, beetles, and other insects, destroying diseased plants to keep disease from spreading. Even so, pest infestations could easily claim an entire crop. .. .The fresh fruits and vegetables they could harvest were far from the worm and pest-free quality of today's produce.*

For much of our country's existence, ***the farmer had to struggle*** *just to produce enough food for himself and his family, with some left over for others. Throughout this century, however, new technology has spurred farm productivity higher and higher. Today, on average, our U.S. farmer produces enough food not only for his family, but nearly 130 others, including some 34 people abroad in exported products.*

None of this amazing growth in agricultural production could have been possible except for the highly effective research and technology developed at land grant universities and experiment stations and by private companies in plant breeding, machinery innovations, fertilizer and pesticide developments. These crop pesticides that American laboratories have helped develop are used to protect virtually every crop that farmers grow. ***Insecticides protect crops from voracious insects****. Fungicides guard against plant diseases. Herbicides keep weed infestations from robbing crops of plant nutrients and water. In addition,* ***we depend on many of these same products to keep our schools, restaurants, hospitals and homes free of disease-carrying vermin and to make our everyday living more enjoyable and pest-free****, as well.*

Remarks by Jay J. Vroom,
President, American Crop Protection Association,
on "Technology and Agriculture - A Bounty of Food and Fiber"
to Loudon County, VA high school students, 1998 03 12.
See http://www.acpa.org.

It is interesting and important to note that the activities of insects and insect species have historically had a significant social, cultural and even spiritual dimension to them as well. In earlier societies, not only were ritual and religion engaged for pest control, but frequently insects were cast as central actors in important myths as well[43]. To the Egyptians, the beetles were sacred and symbolized eternal life[44]. In Buddhism, the cicada has been treated as a symbol of resurrection. Five insects and a spider are mentioned in the Koran, and readers of the Bible will know that there are 120 references to insects and other arthropods in the King James version. Of the 10 plagues visited upon Egypt preceding the exodus, 3 were caused by insects: lice, flies and locusts[45]

Since then, such and similar plagues have commonly been interpreted as the manifest sign of an angered God. In the United States, bountiful harvests were viewed as gifts from God meriting ceremonial giving of thanks each autumn, a ritual which endures to this day. As recently as the 1870s, State Governors in the U.S. were declaring official days of prayer and fasting in response to destructive outbreaks of insects known as hoppers[46]. This is significant for understanding the reception of modern synthetic insecticides like DDT as miraculous discoveries - "wonder bug killers"[47] and "magic insect killers"[48]. As the miracles of modern Science were applied to tame and to control Nature, God's role in insect control diminished correspondingly.

As did the role of wider Society. Historically, early agricultural practices were highly ritualized, with the function of insect control performed physically and deeply embedded in unquestioned farming routines, community norms and ceremonies[49]. "Cultural control" (this term is explained in detail below) of insects dominated. But beginning with the Industrial Revolution and continuing through the Green Revolution, as increasing

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[43] Ordish (1976)
[44] Pfadt (1962)
[45] From course notes for "Insects & Human Society" (Entomology 2004, Virginia Polytechnic Institute and State University; visit http://www.ento.vt.edu/Courses/Undergraduate/IHS/oncampus)
[46] Dunlap (1981, p 19)
[47] Standen (1946), writing in *Life* magazine.
[48] Zimmerman & Levine (1946, p 17) in the caption they wrote to accompany a photo of Paul Muller.
[49] Ordish (1976)

commercialization, standardization, and mechanization were brought to farming, this was less the case. "Chemical control" of insects came to dominate, as both Commerce and Science, with the explicit cooperation of Government, each contributed to what Polanyi (1944) would describe as the "disembedding" of economic from social activity in agriculture.

Today, modern agriculture and the wider U.S. language and culture continue to reflect this mostly conflictual history of Insect-Man relations. A perceptibly hostile attitude towards insects as the source of harm and nuisance pervades. For example, not only is it said of someone who is pestering another that he/she is "bugging" them or being a "bug", but we have even institutionalized a high-tech Information Age definition of that term: annoying computer glitches are routinely blamed on "bugs", with the "Millenium Bug" being perhaps the most famous and currently topical.

Table 3.4.6 - Important Insecticide Markets summarizes the various functions of insect control in society, which translate in a straightforward manner into different insecticide ***markets***.

Table 3.4.6 - Important Insecticide Markets

Markets	Functions of Insect Control
Agriculture	- protection of food, feed and fibre crops from direct insect damage - protection of food, feed, and fibre crops from plant disease vectors - protection of livestock, fowl from direct insect damage - protection of livestock, fowl from animal disease vectors
Home & Garden	- protection of ornamental plants, shrubs, flowers
Industry, Commercial & Government	- protection of public forests & lands from direct insect damage - protection of public forests & lands from plant, animal disease vectors - protection of industrial, commercial, public facilities - protection of fabrics - protection of human structures (i.e. wood preservatives) - protection of stored foodstuffs
Public Health	- protection of humans from disease vectors

(1) "Markets" represent the "Economic Segments" used by the EPA (see Aspelin, 1999), with the addition of public health.
(2) "Functions of Insect Control" extracted from discussion above.

3.5 Technology for Insect Control: Alternatives

Having communicated to readers a better understanding of the functions of insect control in the economy, I continue in this section with a presentation of the three broad classes of insect control mechanisms historically used to perform those functions, along with a more recent integrated approach which combines elements of each of them[50].

3.5.1 Cultural controls

Cultural controls (sometimes referred to as physical or mechanical controls) are those techniques and practices wherein the physical or mechanical activities of farmers and their tools result in smaller populations of injurious insect species[51]. Table 3.5.1.1 lists

[50] The three categories of insect control are drawn from West et al (1951). Other typologies do exist, but they differ only slightly; usually this involves the subdivision one of these three to create further categories (for example, "cultural" controls as I have described them are sometimes split into "cultural" controls and "quarantine"controls. The contents of Pimentel (1991) generally support the categorizations used here.
[51] See Sailer (1991) for a brief summary of cultural controls.

examples of agricultural practices and activities that can be considered as cultural or physical controls on insect populations.

Table 3.5.1.1 - Some Examples of Cultural Controls

1)	sanitation (destruction or utilization of crop refuse, roguing of diseased plants, etc.)
2)	tillage to destroy overwintering insects
3)	removal of alternate hosts of pathogens & insects (weeding)
4)	rotation of crops to discourage buildup of insect populations
5)	timing of planting to avoid high-damage periods
6)	use of insect-free and pathogen-free seeds and seedlings
7)	use of trap crops
8)	pruning and defoliation
9)	isolation from other crops
10)	management of water and fertilizers

• list is drawn from Smith, Apple & Bottrell (1976)

Some of these activities are primarily aimed at other purposes but nevertheless do affect insect populations. So, for example, the ploughing of fields can destroy the habitat of soil insects as well as expose them to the predation activities of natural predators, hence limiting their populations. Or consider crop rotation, which effectively starves out insects in fields left fallow, withholding from them the nutrition they need from host plants. Farmers can also manipulate the timing of crop plantings in order to avoid high pest incidence periods or to ensure that their plants are sufficiently developed at the time of infestations to withstand attack. In addition, farm and orchard sanitation activities such as the destruction of prunings and other unused plant matter by fire can reduce insects' available habitat and food sources so as to shrink their populations. And of course another important but labour intensive cultural technique of insect control is the simple manual picking or removal of insects.

A more coercive form of cultural insect control in society is possible as well, achieved through legal and regulatory means. For example, it is common practice in most countries to implement plant "quarantine" laws, which apply to the importation of new plants to a region and are aimed at ensuring that vegetation does not carry on it injurious insect species or diseases.

Historically, prior to the mid-1800's, cultural controls were the dominant "technology" used for the function of insect control, which was highly embedded in social norms and agricultural practices and activities.

3.5.2 Chemical Controls

Chemical controls are those techniques, practices and activities with which readers will be most familiar, as they have dominated the function of insect control in this century[52]. Indeed, the chemical control of insects has become almost *synonymous* with "insect control". Chemical control of insect pest species involves the direct application of a substance which is toxic and designed to kill them: an insecticide, in other words. It also includes the use of chemical substances which affect insect populations without directly killing them, such as attractants, repellents and chemosterilants, listed above in Table 3.2.2.

Killing insects can be accomplished in different ways with a chemical substance. In general, insecticides can be classed into two broad categories of poisons according to their "mode of action": "stomach poisons" and "contact poisons". The former are meant to be ingested by the insect while the latter are absorbed through the insects' bodies. Another term that comes up often is "systemic", which is contrasted with "non-systemic" insecticides. A systemic insecticide is one which can be translocated by the plant being protected. That is, it becomes dissolved in the plant liquids and can be transported to other parts of the plant. In order to facilitate this, systemic insecticides tend to have high water solubility. Systemic insecticides have two major advantages. First, treatment of only a part of the plant, even the roots, can mean that the whole surface of the plant becomes lethal to insects feeding on it. Second, it is possible for only insects actually

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[52] This discussion of chemical controls has benefited greatly from West et al (1951), Ware (1994), Casida & Quistad (1998) and Perry et al (1998) from which it has been synthesized.

feeding on the plant to become poisoned while other potentially beneficial insects merely sheltering in the plants' leaves are spared (although predators of plant-eating species may be subject to poison passed on through their prey if the insecticide does not break down quickly).

Besides their mode of action, substances used as chemical controls can also be divided into three broad categories based upon their chemical makeup and origin: (1) botanicals, (2) inorganic compounds and (3) organic compounds.

3.5.2.1 Botanicals

The first group of chemical controls, botanicals, are, as their name hints, derived from plants. The earliest chemical controls were naturally occurring substances derived from plants, so this group includes some of the oldest insecticidal compounds known to Man, like nicotine from the tobacco plant as well as pyrethrum and rotenone. Pyrethrum, prepared from the flowers of a type of chrysanthemum which grows in tropical climates, was the most widely used botanical insecticide historically and is known for its remarkably rapid "knock-down" (which means that, once applied, it kills insects very quickly) as well as its broad spectrum of activity (which means that it kills a wide variety of species of insects). Rotenone is an active ingredient for insecticides derived from the root of the tropical plant Derris elliptica. Merely grinding up the root of that plant yields the substance "Derris". Not toxic to Man, it was often used against human lice. Other insecticidal botanical compounds include sabadilla, ryania and limonene. Varying widely in their acute toxicity to mammals, the biggest drawbacks of botanicals are that they lack photostability (which means they decay rapidly in sunlight) and that they are expensive to extract from plant tissues.

3.5.2.2 Inorganics

The second group of chemical controls is comprised of inorganic substances, important among them, in terms of economic significance, are those compounds containing arsenic and known as "arsenicals", including Paris Green, lead arsenate and calcium arsenate. Besides these, other inorganic substances which achieved commercial significance included: borax and boric acid; bordeaux (the name of compounds formed by reacting dilute solutions of copper sulphate with calcium hydroxide suspensions); flourine compounds like cryolite; selenium compounds (which because of their toxicity to man and animals were not recommended for use on crops intended for human or animal consumption); mercury compounds like mercuric chloride ($HgCl_2$) and mercurous chloride (HgCl), along with elemental sulphur and other sulphur-based compounds. Of these, sulphur continues to be of importance today, especially within Integrated Pest Management (also known as "IPM", and described below) programs where its specificity towards mites and its fungicidal qualities are appreciated. The biggest drawback of inorganic chemical controls, especially the arsenicals, is their acute toxicity to mammals (including Man). Ingesting a relatively small dose of arsenic quickly brings on classic symptoms of poisoning.

3.5.2.3 Organics

The third group of chemical controls is comprised of organic compounds, and it is here where the adjective "synthetic" applies in most cases. "Organic" chemistry is the chemistry of carbon, hence organic compounds are those containing this element, which is the basis for life. The adjective "synthetic" refers to chemicals that are man-made and that do not occur in abundance in nature. Early organic insecticides include: carbon disulphide; p-dichlorobenzene; napthalene (used since the turn of this century to make moth balls); carbon tetrachloride; ethylene dichloride; propylene dichloride; ethylene dibromide; methyl bromide; chloropicrin; dichloroethyl ether; thiocyanates; phenothiazine; azobenzene, and even hydrogen cyanide, a highly poisonous gas that was used in the fumigation of citrus trees. DDT is probably the most (in)famous organic compound used as an insecticide. It belongs to a family of substances known as organochlorines (OC), introduced into the economy just subsequent to WWII. Other important families of insecticides are the organophosphates (OP), the carbamates (Carb) and the synthetic pyrethroids (SP).

3.5.2.3.1 Organochlorines

Also known as "the chlorinated insecticides", "chlorinated hydrocarbons", "chlorinated organics", or "chlorinated synthetics", the organochlorines (OCs) were the first synthetic organic chemicals to be brought to market and to achieve widespread adoption[53]. DDT is by far the most famous molecule within this product family. All the substances in this family contain carbon, chlorine and hydrogen. Most are composed solely of these three elements, while a few are derivatives of such molecules but which contain the elements oxygen or sulphur bound into functional groups common in organic chemistry: alcohols, ethers, esters, ketones, etc. This family of insecticides can actually be divided into four distinct sub-families, each based on different chemical synthesis routes and having different features to their chemical structure: (1) the DDT group; (2) the cyclodienes; (3) hexachlorocyclohexane; and (4) the polychloroterpenes.

With the significant caveat that each molecule has its own specific properties and hence exceptions exist for almost all claims made at the product family level, a few generalizations can be made nonetheless as the organochlorines as a family are characterized by common features. Most are toxic to many insect species and hence are used for **broad spectrum** insect control. Most are **both stomach and contact poisons.** Interestingly, to this day the mode of action (i.e. how it kills) of DDT has "*never been clearly worked out*"[54]. Many of these molecules are highly **persistent** which means that they do not readily nor quickly biodegrade in either soil or sunlight once released into the environment. In addition, they are slow to metabolize once they enter organisms. Most are hydrophobic, meaning that they are **insoluble in water**, but lipophilic, meaning that they are readily **soluble in fats and oils**. They have relatively **low acute oral and dermal toxicities** to mammals, including Man. Along the various measures of chronic toxicity - oncogenicity, teratogenicity, mutagenicity, etc. - it is difficult and unwise to make general statements. The insecticidal qualities of DDT were discovered in 1939, and

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[53] In addition to West et al (1951), Ware (1994), Casida & Quistad (1998) and Perry et al (1998), other important sources of information on organochlorines are: Brooks (1974, Vol I & Vol II), Brooks (1977), and Cremlyn (1991, Chapter 5).

[54] Ware (1994, p 42)

the median year of introduction of commercially significant organochlorine insecticides was 1947.

3.5.2.3.1.1 DDT group

This group contains DDT and its analogues, including DDD, methoxychlor, and dicofol among others. Each of these molecules has a structure highly similar to DDT, reflecting the fact that they were discovered through "local" search triggered by the discovery of DDT's insecticidal properties. DDD has merely one fewer chlorine atom, while dicofol is an alcohol product obtained by substituting just a single hydrogen atom on the DDT molecule which is its raw material. Insecticides in this group are, most of them, broad spectrum stomach and contact poisons. Significantly, as we will see, both DDT and DDD are much more persistent than either methoxychlor or dicofol. In addition, acute and chronic toxicities to mammals vary. Those molecules in this group which resemble DDT in that they have two phenyl rings but which have sulphur as their central atom are also known as the "organosulphurs". Of low toxicity to insects, they are much better acaracides, being highly toxic to mites. They are usually ovicidal and are used for selective mite control.

3.5.2.3.1.2 Cyclodienes

Also known as the "diene-organochlorines", this family includes polycyclic molecules formed from the reactant hexachlorocyclopentadiene through either self-condensation or the Diels-Alder reaction. Commercially significant molecules in this family include aldrin, dieldrin, endrin, chlordane, heptachlor, endosulfan, chlordecone and mirex. Most are broad-spectrum insecticides which, like DDT, are highly persistent stomach and contact poisons and do not dissolve readily in water but do dissolve in fats. Acute and chronic toxicities vary. Because of their stability, they make excellent soil insecticides and also provide for effective long term termite control. Wooden structures protected by these substances can retain their protection from termites for over forty years.

3.5.2.3.1.3 Hexachlorocyclohexane (HCH)

Also known as benzenehexachloride (BHC), this substance is made by chlorinating benzene and is composed of several isomers. The gamma isomer, making up just a tiny fraction of the technical HCH mixture, is the only one with insecticidal qualities and these it has against a broad spectrum of pests through stomach and contact poisonous activity. When isolated to a state of 99% purity, the gamma isomer is referred to as "lindane". The inert isomers of HCH are more persistent than lindane, which is less persistent than DDT or the cyclodienes, but still relatively persistent compared to other families of pesticides like the organophosphates. Lindane is highly volatile but odourless, whereas technical grade HCH has the undesirable property of bearing a distinct musty odour and imparting a "taint" or "off-flavour" to foods.

3.5.2.3.1.4 Polychloroterpenes:

This family includes only two substances, toxaphene which is also known as "camphechlor", and strobane, with the former achieving much more commercial significance. Toxaphene is a mixture of more than 177 polychlorinated derivatives formed from the chlorination of camphene, a substance obtained from pine trees. It became the most used insecticide in United States history. It is both a stomach and contact insecticide with some acaracidal action. Though persistent, it is more easily metabolized by birds and mammals.

3.5.2.3.2 Organophosphates:

The organophosphate (OP) family of insecticides contains all those substances which contain the element phosphorous. They are also known as "organic phosphates", "phosphorous insecticides", "phosphates", "phosphate insecticides", "phosphorous esters" or "phosphorous acid esters", and "nerve gas relatives", with this last term betraying a bit of the history of their development, which is in chemical warfare and genocidal research of WWII Germany. OPs achieve their toxicity by inhibiting important enzymes of the nervous system, cholinesterases.

The family as a whole can be divided into three sub-families, the names of which signal important aspects of their molecular composition to those familiar with the nuances of organic chemistry nomenclature: the aliphatic derivatives; the phenyl derivatives; and the heterocylic derivatives. Before saying a few words about each of these sub-families, we can summarize those properties that, in general, characterize the organophosphate family. First, most have a **broad spectrum of insecticidal activity**, but are chemically unstable and hence **not persistent**. They decay rapidly in soil and sunlight, especially compared to organochlorines. Second, although toxicity varies between molecules, in general they are **more acutely toxic to mammals and other vertebrates** than organochlorines. The ingestion of small quantities causes inhibition of important cholinesterase enzymes of the nervous system, bringing on rapid twitching of muscles and eventually paralysis. These toxic effects are unsurprising if one considers the origins of these substances in nerve gas research. The earliest introduction of organophosphate molecules into the economy occurred just subsequent to WWII, with research continuing to yield commercially viable substances for many years following. The median entry year for major organophosphate insecticides was 1965.

3.5.2.3.2.1 Aliphatic OP derivatives

This sub-family includes those insecticides which are simple phosphoric acid derivatives bearing short carbon chains. Tetraethylpyrophosphate (TEPP) was the first OP introduced into agriculture, in 1946 in the U.S., then soon after that came malathion which went on to become the most heavily used aliphatic OP. With a very low acute toxicity to mammals, this broad spectrum insecticide was also used extensively around the home. A number of the aliphatic OPs are soluble in water and hence plant juices, making them useful as systemic controls against sucking insects. Besides malathion, some other important aliphatic OPs include dichlorvos, mevinphos, monocrotophos, and trichlorfon, a chlorinated OP.

3.5.2.3.2.2 Phenyl OP derivatives

Phenyl OPs are phosphate-based molecules containing a benzene ring. In general they are more stable than aliphatic OPs, though much less persistent than OCs. By far, the two most familiar and commonly used phenyl OPs are ethyl parathion and methyl parathion. The first was introduced into agriculture in 1947 and is also known as "parathion" while the second, which always carries its prefix, was introduced in 1949. Both of these are contact and stomach poisons which are very acutely toxic to mammals.

3.5.2.3.2.3 Heterocyclic OP derivatives

The least utilized of the three sub-families, these are OPs which contain ring structures for which at least one carbon atom has been replaced by oxygen, nitrogen or sulphur. The first insecticide of this type to enter into the economy was diazinon, in 1952. Other important members of this sub-family include: azinphosmethyl and chlorpyrifos. In general, these molecules have longer lasting residues than either the aliphatic or phenyl derivatives.

3.5.2.3.3 Carbamates

These insecticides are derivatives of carbamic acid which, like the OPs, achieve their toxicity by inhibiting the enzyme cholinesterase. First introduced in 1951, this first generation of carbamates (isolan, dimetan, pyramat, and pyrolan) were expensive and ineffective. The first of this family to achieve significant success was carbaryl, introduced in 1956, and more of it has been used worldwide than all the other carbamate insecticides combined. It has a **broad spectrum of activity** and a **very low oral and dermal acute toxicity to mammals** (with the notable exception of aldicarb, the most acutely toxic insecticide of commercial significance). Other important carbamates include: aldicarb, carbofuran and methomyl. Like the OPs, the carbamates are also **much less persistent** than the organochlorines. The median entry year for major carbamates was 1969.

3.5.2.3.4 Synthetic Pyrethroids

Also known as "pyrethroids", these molecules were developed to imitate the insecticidal effects of the natural botanical insecticide pyrethrum but to be much more stable in sunlight. The median year of entry for pyrethroids was 1979. Their history can be divided into four generations, with the first generation containing just one substance, allethrin, introduced in 1949. Almost a synthetic equivalent of one of the active ingredients in pyrethrum, its synthesis was particularly complicated (an unheard of 22 chemical reactions) and hence expensive. The second generation included tetramethrin, bioresmethrin, and bioallethrin but these too decomposed rapidly upon exposure to air and sunlight. It is with the third generation that the desired combination of the properties of photostability and exceptional insecticidal activity was achieved with fenvalerate and permethrin. The fourth generation, still being developed, combines those desired qualities of the third but requiring only one tenth the application rate to crops. The synthetic pyrethroids share the same mode of action as DDT, but are **much less persistent** and have a **higher selectivity** in their toxicities to insect species (i.e. they tend to affect a more narrow spectrum of insect species once applied). Another important advantage of the synthetic pyrethroids over OPs and carbamate insecticides relates to their **incredible insecticidal activity**. For instance, with the fourth generation, acceptable insect control can be achieved through the application of just 0.01 lbs of active ingredient per acre (even the third generation required just 0.1 lbs), as compared to application rates of 1.0 to 2.0 lbs of active ingredient per acre for OCs, OPs and carbamates. These low application rates, combined with their already **very low toxicities to mammals**, make the synthetic pyrethroids *"truly exciting"*[55] to contemporary economic entomologists.

3.5.2.3.5 Other Conventional Organic Insecticides

Besides those chemical families outlined above, a number of other distinct chemical families of insecticides which are more recent in terms of their introduction into the economy and/or which have never or not yet captured much market share and hence do not figured prominently in the history of DDT include: formamadines (ex. chlordimeform, amitraz); thiocyanates (ex. lethane, thanite); dinitrophenols (ex. dinitrocresol (DNOC, introduced in 1892) and dinoseb); organotins (ex. cyhexatin), and acylureas. The properties of this diverse set of molecules varies widely and cannot be collapsed into general statements, although it can be stated that none of these substances is without its own particular problems: chlordimeform was removed from the US market

[55] Ware (1994, p 63)

in 1976 because of its oncogenicity, for example, while the dinitrophenols are, in general, highly toxic to mammals.

3.5.2.4 Non-conventional chemical controls

Into this class of substances can be put a set of substances that have insecticidal properties and which were commercialized as insecticides, but which are produced primarily for other purposes. Used in the United States as far back as 1868, this category of substances includes: soaps, coal tar, creosotes, kerosene, crude petroleum, lubricating oil, and other petroleum oils. Besides having some insecticidal activity on their own, they are often used in the formulation of conventional insecticidal compounds, like the botanical pyrethrum or even DDT for example, as "carriers" to facilitate delivery of these latter compounds to the desired target. Though, technically, these are in fact organic chemicals with insect killing power, they have not traditionally been accounted for in that category of insecticidal substances. In terms of physical volumes (i.e. annual sales in lbs.), these substances are still important today, but this is ironically due to their low toxicity to insects. The high phytotoxicity of these substances - their toxicity towards the plants they are supposed to protect - is another factor that has severely limited their use. In terms of their commercial value (i.e. annual sales in dollars), they pale in comparison to the other classes of chemical controls presented above which are known as "conventional" insecticides.

3.5.2.5 Summary - Chemical Controls

Table 3.5.2.5.1 contains a summary of some of the more important synthetic organic insecticidal chemicals introduced over the lifetime of DDT[56], indicating when they were patented and/or put on the market and by whom[57]. Table 3.5.2.5.2 summarizes the major

[56] This list is not exahaustive by any means, but does include the best-selling substances from each chemical family. It also includes ALL substances specifically mentioned in this dissertation as SUBSTITUTES for DDT in some market.

[57] All data is from Thomson's (1994) *Agricultural Chemicals, Book I - Insecticides*, except fenvalerate, HCH, and TEPP where information was missing. See Ware (1994) and Hurst et al (1991). Whenever

differences between the different families of substances, already discussed above. The first Table demonstrates the shift away from organochlorines over time, towards organophosphates and carbamates and then to synthetic pyrethroids more recently. Note that even though the synthetic pyrethroids represent the newest family of insecticidal molecules, they have not yet risen to marketplace dominance. Indeed, since DDT, in general it has been quite difficult for newer molecules to displace older incumbent products *except* due to some problem-driven ban, as was the case for DDT. Even as late as 1998, one half of the top 20 insecticides from the standpoint of sales were organophosphates and one fifth were carbamates[58].

discrepancies arose between dates of discovery of insecticidal action, patent and first use, the earliest was selected.

[58] Casida & Quistad (1998, p 6)

Table 3.5.2.5.1 - Synthetic Organic Chemical Insect Controls

Year	Organochlorines	Organophosphate	Carbamates	Synthetic Pyrethroids
1939	DDT (Geigy)			
1940				
1941				
1942	HCH (Solvay, ICI)			
1943				
1944	methoxychlor (Geigy) DDD (Rohm & Haas)			
1945	chlordane (Velsicol) lindane (Chevron)			
1946		TEPP (I.G. Farben)		
1947		parathion (Bayer)		
1948	aldrin (Shell) dieldrin (Shell) heptachlor (Velsicol) toxaphene (Hercules)			
1949		EPN (DuPont)		
1950	endrin (J. Hyman)	malathion (Am. Cyan)		
1951				
1952		methyl parathion (Bayer)		
1953		diazinon (Geigy) mevinphos (Shell)		
1954		Azinphosmethyl (Bayer)		
1955		dichlorvos (Geigy)		
1956	endosulfan (Hoechst)		carbaryl (Union Carbide)	
1957	dicofol (Rohm & Haas)	trichlorfon (Bayer)		
1958				
1960				
1961				
1962				
1963				
1964				
1965		monocrotophos (Geigy, Shell) dicrotophos (Geigy, Shell)	aldicarb (Union Carbide)	
1966		chlorpyrifos (Dow) tetrachlorvinphos (Shell)		
1967			methomyl (Shell)	
1968				
1969			carbofuran (FMC)	
1970		propaphos (Nippon Kayaku)		
1971		tirazophos (Hoechst)	bendiocarb (Fisons)	
1972			oxamyl (DuPont)	fenvalerate * (Sumitomo)
1973				
1974				permethrin (NRC)

* This was the first commercially viable synthetic pyrethroid. Earlier molecules include: allethrin (Sumitomo, 1949); bioallethrin (Sumitomo, 1949); and tetramethrin (Sumitomo, 1965).

Table 3.5.2.5.2 - Properties of Chemical Families of Organic Insecticides

	Organochlorines	Organophosphates	Carbamates	Synthetic Pyrethroids
(1) year of first product:	1939	1946	1956	1972 (first viable product for agriculture; first molecule was 1949)
(2) median year of introduction:	1947	1965	1969	1979
(3) first product:	DDT	TEPP	carbaryl	fenvalerate (1972; 1st viable) allethrin (1949, 1st ever)
(4) other products:	aldrin, chlordane, DDD, dicofol, dieldrin, endosulfan HCH, heptachlor, lindane methoxychlor, toxaphene	chlorpyrifos, EPN, malathion, methyl parathion, parathion,	aldicarb, carbofuran, methomyl	bioallethrin, permethrin
(5) toxicity to insects:	2.6	2.0	2.8	0.45
(6) toxicity to mammals:	230	67	45	2000
(7) relative safety [ratio of (6)/(5)]:	91	33	16	4500
(8) average use rate:	3.0	1.8	1.6	0.07
(9) some products with systemic action?	no	yes	yes	no
(10) spectrum of activity:	broad	broad	broad	more narrow
(11) persistent?	yes	no	no	no

(1) from Ware (1994)
(2) from Casida & Quistad (1998)
(3) from Ware (1994)
(4) from Ware (1994)
(5) from Elliott (1977); LD50 in mg/kg (average for 4 different insect species)
(6) from Elliott (1977); LD50 in mg/kg (rats)
(7) from Elliott (1977)
(8) from Casida & Quistad (1998); in kg active ingredient/hectare
(9) from Elliott (1977) & Ware (1994)
(10) from Casida & Quistad (1998)
(11) from Ware (1994)

3.5.3 Biological Controls

Biological controls are those techniques, practices and activities involving the "natural" restraint placed on the increase in insect populations by biotic factors such as predators and parasites[59]. Table 3.5.3.1 lists examples of practices and activities that result in the biological control of insect of insect populations.

Table 3.5.3.1 - Some Examples of Biological Controls

1)	use of target species predators (other insects, birds)
2)	use of target species parasites (other insects)
3)	use of target species pathogens (fungi, protozoa, bacteria)
4)	introduction of sterile males into target species populations
5)	introduction of exotic predator species (especially if the target pest species is itself non-native to ecosystem)

* list drawn from Hagen & Franz (1973)

Farmers can attempt to control the populations of injurious species of insects by introducing bacterial and fungal diseases of insects or by introducing predators and parasites. For example, farmers producing organically-grown foods who shun chemical controls have long relied upon a bacteria known as Bt (*bacillus thuringiensis*) which they introduce into agro-ecosystems to manage pest populations. Predator insect populations can be artificially increased through systematic breeding or the implementation of hibernation programs, for example. The introduction of foreign or exotic species into an ecosystem is also an option, particularly if the pest species is itself an exotic species that is controlled by that predator in its natural environment.

Biological controls have been used against insects in a systematic way at least since the 1700s. Larger predators, such as birds and certain beetles, were the first to be appreciated as natural control agents and as a result became subject to local transfers to curb insect

[59] For an introduction to biological controls, see Volume II of Pimentel (1991).

outbreaks. International transport of predators is believed to have begun prior to 1800 as well. But it was not until the late 1800s and early 1900s that applied biological controls were implemented with significant success. California served, and continues to serve, as the centre for biological control research in the United States. It was there at the turn of the century that techniques of mass culture of predacious insect species and their periodic colonization in the field were developed.

But although they have been researched scientifically for a long time, biological controls have remained, for the most part, in the periphery of insect control research and unimplemented in the field for much of this century.

> *"Through the late 1940s into the 1960s chemical control of insect pests with persistent organic insecticides was so spectacular and successful that the biological control approach received little support. In fact, it was considered passe except for a few research centers."*
>
> (Hagen & Franz, 1973, p 435)

Biological controls were considered by the majority of mainstream economic entomologists to be inherently inferior to chemical controls because they could not be used to achieve what was considered by them to be the ultimate goal of insect control, eradication.

> *"It should be emphasized, however, that because the relation of the insect pest to its enemies is always in the nature of a balance, whether it be favourable to the one or the other, there can be no question of complete elimination of pests by this method* [biological controls]. "
>
> (West, Hardy & Ford, 1951, p 25)

Entomologists favouring biological over chemical controls recall being ridiculed as a "*lunatic fringe*" within their discipline[60]. However, with the identification, discussion and resolution of various problems linked to the chemical control of insects, which are presented in this thesis, biological control has come to occupy a much more prominent

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[60] Doutt & Smith (1971, p 5)

position in the portfolio of insect control methods in use[61]. Within the discipline of economic entomology, it was proponents of biological controls who came to be some of the most vocal critics of DDT and the dominance of the *"magic bullet"* paradigm of chemical controls embraced and promoted by *"nozzle heads"*[62] and *"squirt-gun entomologists"*[63]. More recently, the implementation of Integrated Pest Management (IPM) has contributed substantially to an increased emphasis on biological controls.

3.5.4 Integrated Pest Management

Integrated Pest Management (IPM)[64], sometimes (but decreasingly) referred to as "integrated control", is often defined as follows:

> *"a pest management system that, in the context of the associated environment and population dynamics of the pest species, utilizes all suitable techniques and methods in an as compatible a manner as possible and maintains the pest population at levels below those causing economic injury."*
>
> (FAO, 1975)

IPM, in other words, combines and integrates cultural, biological and chemical controls into a single insect control approach:

> *"IPM is a decision support system for the selection and use of pest control tactics, singly or harmoniously coordinated into a management strategy, based on cost/benefit analyses that take into account the interests of and impacts on producers, society and the environment."*
>
> (Kogan, 1998, p 249)

Largely as a result of the problems of relying solely on chemical insect control methods, with these being brought to light by society's experience with DDT and described later in

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[61] It merits almost a complete volume (II) in Pimentel's (ed.) *CRC Handbook of Pest Management in Agriculture* (1991).

[62] This term turned up more than once. Currently it can be found at the home page of Cornell University, Department of Entomology, New York State Agricultural Station in Geneva, NY, in their profile of Professor Ed Glass (who was actively involved in the promotion of IPM and was *not* a "nozzle head").

[63] This term is used in Henkin et al (1971, p 5) to describe an entomologist who appeared at the Wisconsin DDT Trial as a strong supporter of DDT. It undoubtedly has earlier origins.

this Chapter, IPM - an acronym unknown to the entomological and agricultural communities 35 years ago - has become the dominant paradigm for insect control today.

IPM differs significantly from the linear, *"magic bullet"* approach of chemical controls in terms of its conception of both the means and ends of insect control. With respect to the former, IPM applies knowledge founded on systemic thinking and ecological models, rather than simple considerations of molecules' toxicity to various injurious insect species. Chemical controls remain a very important part of IPM, but they are applied more selectively and much less liberally. With respect to the ends of insect control, not only does IPM reject the goals of "eradication" and even "control" of insect populations for the humbler objective of "management", it also incorporates objectives other than those solely of farmers, as evidenced by the reference to society and the environment in the definition above.

It is important to note that IPM did not appear out of nowhere. Rather, it incorporates and embodies concepts and practices long promoted by entomologists who questioned the dominant paradigm of chemical control of insects, and who favoured instead biological controls and the application of ecosystem models to agriculture. These "dissident" entomologists were largely marginalized in their discipline during the period when DDT was the dominant insect control technology and, as we will see later in this Chapter, actively fought against the use of DDT and other organochlorine insecticides. Not coincidentally, at about the same time as the final fate of DDT was being hotly contested at hearings in 1972 in Washington which ultimately resulted in its ban in the United States, IPM began to receive special funding from the U.S. Congress with the creation and implementation of the "Federal IPM Thrust" as the program came to be called[65]. In addition, the rise of IPM also coincided with the transfer of responsibility for pesticide regulation from the farm-oriented USDA to the then newly formed environment-oriented EPA.

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[64] For introductions to IPM, see Burn, Coaker & Jepson (eds.; 1988); Dent (1995); and Kogan (1998)

IPM continues to be popular. In September of 1993, the Clinton Administration declared that the implementation of IPM practices on 75% of the nation's crop acres by the year 2000 was a national goal[66]. Although IPM is most widely implemented for the function of insect control in agriculture, it is notable that similar programs such as Integrated Vector Management (IVM) and Integrated Disease Management (IDM) are currently being aggressively promoted for insect control activities related to public health, especially for malaria campaigns, and that this is motivated to a large extent by a desire to speed the exit of DDT from the global economy[67].

3.6 Technology for Insect Control: Evolution

In this section I present how insect control technologies have evolved over time, in order to establish an appropriate context for recounting the full story of the rise and fall of DDT a bit later. The context I establish here is both past and future referential from the perspective of DDT, anchoring the story of that molecule within a particular pre-DDT *and* post-DDT history. In other words, my biography of DDT will not be completely linear. Rather I reveal, here, salient details from the life of that molecule that facilitate the early introduction of analysis and arguments, in order to frame and focus readers' attention.

3.6.1 Technology Eras and Substitution Processes

As has been hinted at in the discussion above, the development and deployment of various technologies for achieving control of insect populations occurred at different points in time. And despite overlaps in the timing of developments at the individual product level within the chemical families (i.e. not *all* OCs were discovered before the

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[65] Kogan (1998, p 251)
[66] Kogan (1998, p 253)
[67] See the World Wildlife Fund's (1998) report *Resolving the DDT Dilemma*, for instance.

first OP; not *all* OPs were discovered before the first carbamate; etc.), the major insecticide categories can be, relatively neatly, ordered chronologically according to their appearance in the economy.

Doing so yields identifiable periods in which different insect control technologies were dominant in agriculture, displayed in Table 3.6.1.1 - Evolution of Technology for Insect Control. These distinct "eras" are well accepted among insecticide scientists, manufacturers, users as well as historians, although precise beginning and end dates vary slightly by author according to their interest and the coarseness of grain by which they measure time[68]. Because the emphasis is on insecticide ***products*** and processes of ***substitution***, I demarcate eras using dates of discovery of molecules' insecticidal properties, where possible.

[68] See, for example: West, Hardy & Ford (1951); Fronk (1962); Jones (1973); Ordish (1976); Perkins (1980).

<u>Table 3.6.1.1 - Evolution of Technology for Insect Control</u>

Trigger	Insect Control Technology Era
	(1) ***prior to 1867***, an older era of **cultural controls**, where farmers carried out their own insect control activities by physical and mechanical means embedded in farming norms (some writers further segment this era by distinguishing between (a) insect control prior to Baconism and the rise of the scientific method in the eighteenth century, and (b) increasingly science-informed insect control from Bacon to 1867) ;
Paris Green, the first arsenical (1867)	
	(2) ***1867 - 1939***, a transitional era of early **chemical controls,** spurred on by the commercialization, specialization, scientificization and mechanization of farming, as farmers began contracting with firms who supplied substances dominated by ***botanicals*** and ***inorganics***, especially the arsenicals, and when "chemical control" became almost synonymous with "insect control";
DDT, the first organochlorine (1939)	
	(3) ***1939 - 1962***, a second era of **chemical controls**, but with this one focused on ***synthetic organic*** chemistry and characterized by intense R&D activities and highly successful innovation that resulted in, along with the **rise of DDT**, a proliferation of other organochlorines, organophosphates, carbamates and early synthetic pyrethroid products;
Silent Spring (1962)	
	(4) ***1962 - present***, the **post-Silent Spring** era of **IPM** in which **chemical controls** are still very important, but they are used within a context of the **revalorization of cultural and biological control methods.** Just as the rise of DDT symbolizes the previous era, **the fall of DDT** and its ban in the United States symbolize this one.

Just as the discovery of the insecticidal properties and subsequent marketing of the arsenicals triggered the transition from (1) to (2) in 1867, the discovery of the insecticidal properties of DDT in 1939 triggered that from (2) to (3). As presented in table 3.6.1.1, the rise of DDT and the process of substitution of DDT for the incumbent arsenicals is pivotal to the history of insect control technology.

But the onset of era (4), on the other hand, is more complicated. That the transition from (3) to (4) has occurred, users, manufacturers and historians of insect control technologies agree. And although it does coincide with the fall of DDT, this transition cannot be accounted for by the sudden invention and commercialization of a new insecticidal technology in the form of a particular substance or molecule. Rather, IPM represents more of a conceptual and philosophic innovation. It combines and synthesizes elements from the various long available insect control technologies - cultural, biological and chemical - with more ecological and systemic thinking about the means of insect control as well as a reconceptualization of its goals. In addition, IPM does not preclude chemical control, the use of which remains quite significant in terms of both physical volume and dollar value.

As a result, the precise timing of the transition from (3) to (4) is blurred even in retrospect. Although it is relatively straightforward to look back and to pinpoint the precise dates of such events as a particular molecule's first synthesis, first demonstration of insecticidal properties, first experimental field use, first registration and commercial sale - as well as the precise date of any subsequent ban on the product - the genesis and demise of ideas are much tougher to nail down with precision. For example, historians of entomology trace the intellectual roots of IPM to a time long before that concept was enunciated as such[69]. As early as 1939, some scientists were writing and presenting papers that made "*Recommendations for a more discriminating use of insecticides*"[70], with the IPM precursory concepts of "*integrated control*" and "*pest management*" appearing first in 1952 and 1961 respectively[71]. "*Integrated pest population management* was first used in 1967[72], with the shortened expression and acronym appearing in 1972. This, not coincidentally, was the same year that DDT was banned in

[69] See Kogan (1998); Perkins (1982).
[70] Hoskins (1939), cited in Kogan (1998)
[71] Michelbacher & Bacon (1952); Geier (1961), both cited in Kogan (1998)

the United States and only a few years after the EPA took over responsibility for pesticide regulation from the USDA.

Despite the multiple and ambiguous roots of the most recent era, the vast majority of official and unofficial historical accounts of insect control technology encountered during this research do give much credit for both the transition from (3) to (4) and the demise of DDT to Rachel Carson and her book *Silent Spring*[73], a moving exposition and critique of the problems of relying solely on chemical technologies for insect control.

> *"Present approaches to IPM are to optimize, not eliminate, chemicals. Rachel Carson set in motion a philosophy to use all tools in controlling pests, not to rely exclusively on chemicals."*
>
> (Marco, Hollingworth, & Durham, 1987, p 198)

> *"Unquestionably, the impression caused by the publication of Silent Spring accelerated acceptance of the integrated control concept."*
>
> (Kogan, 1998, p 245)

Consider the following titles of books concerned with pesticides and/or pesticides policy, past, present and future, and the way they have periodicized history:

Before Silent Spring (Whorton, 1974)

Since Silent Spring (Graham, 1970)

Silent Spring Revisited (Marco, Hollingworth & Durham, 1987)

The Recurring Silent Spring (Hynes, 1989)

Beyond Silent Spring: Integrated Pest Management & Chemical Safety (van Emden & Peakall, 1996)

Insecticide users also view Carson's book as pivotal. In 1994, readers of the trade publication *Farm Chemicals* voted on the *"Top Ten events, products people, and regulations which have had the greatest industry influence"* for its special 100th

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[72] Smith & van den Bosch (1967), cited in Kogan (1998)

anniversary edition. Given that DDT ranked amongst the top ten products, it is perhaps unsurprising that (a) the publication of *Silent Spring* by (b) Rachel Carson and (c) the banning of DDT by (d) William Ruckelshaus each appeared in the lists of most significant events and people[74].

Ruckelshaus, the Administrator of the EPA who ultimately banned DDT, explicitly paid tribute to Carson in his 1972 decision, writing:

> *"Public concern over the widespread use of pesticides was stirred by Rachel Carson's book, "Silent Spring", and a natural outgrowth was the investigation of this popular and widely sprayed chemical."*
>
> (Ruckelshaus, 1972)

Certainly within the pesticides industry itself, as well as in politics and government, the publication of Silent Spring signified the dawn of a new era:

> *"[In 1962] The NACA headquarters was moved to more prestigious quarters in The Madison Building and the associated began new efforts to impress Congressional leaders, especailly those in the agricultural field, with the importance and safety of pesticides. Just in time, because* ***the industry was about to enter the era of Silent Spring, an era which in many ways is still with us.*** *"*
>
> Hayley (1983, p 35)
> official historian of the National Agricultural Chemicals Association

> *"Writing about* Silent Spring *is a humbling experience for an elected official, because Rachel Carson's landmark book offers undeniable proof that* ***the power of an idea*** *can be far greater than the power of politicians.*
>
> ...
>
> *"And except for a few scattered entries in largely inaccessible scientific journals, there was virtually no public dialogue about the growing, invisible dangers of DDT and other pesticides.* ***Silent Spring came as a cry in the wilderness, a deeply felt, thoroughly researched and brilliantly written argument that changed the course of history.*** *Without this book,*

---

[73] Carson (1962); reprinted numerous times, including a 1994 edition that I drew upon.
[74] *Agricultural Chemicals*, September 1994, p D-14

the environmental movement might have been long delayed or never have developed at all ...

"Rachel Carson's influence reaches beyond the specific concerns in Silent Spring. *She brought us back to a fundamental idea lost to an amazing degree in modern civilization: the interconnection of human beings and the natural environment.* ***This book was a shaft of light that for the first time illuminated what is arguably the most important issue of our era.*** *In* Silent Spring*'s final pages, Carson described the choice before us in terms of Robert Frost's famous poem about the road "less traveled". Others have taken that road; few have taken the world along with them, as Carson did.* ***Her work, the truth she brought to light, the science and research she inspired, stand not only as powerful arguments for limiting pesticides but as powerful proof of the difference that one individual can make."***

(Al Gore, Vice President of the United States of America, writing in the Introduction to a 1994 edition of *Silent Spring*)

It is safe to say that the publication of Carson's *Silent Spring* is almost universally viewed by scientists, government officials, pesticide producers and pesticide users as a turning point in the history of insect control technology. This is dramatically underlined in Table 3.6.1.2 - Agricultural Entomology in an Evolutionary Context which is an actual summary of events with evolutionary significance in the history of agricultural entomology, extracted from an edited volume entitled *History of Entomology* that was co-published by none other than the Entomological Society of America in 1973:

Table 3.6.1.2 - Agricultural Entomology in an Evolutionary Context

Significant event	Years ago (from1972)	Date
First land plants	$400X10^6$	
First insects	$350X10^6$	
First angiosperms	$100X10^6$	
First hominids	$15X10^6$	
First *Homo sapiens*	$250X10^3$	
Fist records of insects in human society	$14X10^3$	12,000 B.C.
Beginnings of agriculture	$10X10^3$	8000 B.C.
First record of insecticides	450X10	2500 B.C.
First descriptions of insect pests	350X10	1500 B.C.
Burgeoning of descriptions	20X10	18th, 19th centuries
DDT and beginning of insecticide era	3X10	1939
Rachel Carson's *Silent Spring*	1X10	1962

(1) Table from Jones (1973, p 307).

One entomological expert even divides the history of man's relations with "*The Constant Pest*" into just two "epochs": BC (Before Carson) and AC (After Carson)[75].

The fate of DDT was tightly linked to this turning point. As the dominant and best known insect control technology at the time of Carson's writing, it figuring prominently in her book. A simple analysis of the index at the back of *Silent Spring* shows DDT to be by far the most referenced active ingredient. All the other significant organochlorines are there as well - chlordane, dieldrin, endrin, heptachlor, etc. - while only two organophosphates are mentioned specifically, malathion and parathion.

> *"Silent Spring is, essentially, a book about organochlorine pesticides."*
> (van Emden & Peakall, 1996, p 17)

> *"Rachel Carson's Silent Spring led to banning DDT and other pesticides."*
> (U.S. EPA, History Office, "Pesticides and Public Health", http://www.epa.gov/history/publications/formative6.htm)

[75] Ordish (1976)

Although it was not formally banned until 1972, a full 10 years after *Silent Spring*, the use volumes of DDT declined dramatically in the wake of its publication and the problems of pesticides it publicized. On the other hand, it is important to note that, specifically because of some of the problems Carson described and the ideas she was promoting, DDT had *already* begun to be substituted in certain markets prior to her book. But, undoubtedly, its publication accelerated its exit from the economy. When the U.S. government finally formally banned it, DDT had but only one remaining significant crop use, on cotton, having been substituted by alternative substances in other markets already.

All in all, when it comes to characterizing the evolution of insect control technology, it is impossible to ignore the appearance and **rise of DDT**, when DDT substituted for the arsenicals in the economy. In addition, it is difficult to disentangle the publication of *Silent Spring*, the problems of pesticides it publicized, the popularization and institutionalization of the concept of IPM, and **the fall of DDT**, when DDT was substituted for by other compounds in the economy. So the story researched and told here, of the rise and fall of DDT - the story of those processes of substitution in which DDT figured prominently as either the supplanting alternative or the supplanted incumbent product - is simultaneously the story of the evolution of insect control technology.

3.6.2 Substitution Triggering Events

Prior to *Silent Spring*, new-era-triggering events were simultaneously substitution-triggering events and were standard "technological discontinuities", as that term is understood in the organizational literature. Paris Green, the first arsenical, and DDT, the first organochlorine, were new material technologies (i.e. molecules) with significantly higher performance relative to their costs when compared with incumbent products at the time they were "invented" (or "discovered") and commercialized.

But how did a mere book so dramatically affect the technological trajectory of insect control? Through the realm of ideas.

Composed of powerful, precise and poetic prose penned by an award-winning science writer, *Silent Spring* explained the numerous problems and dangers associated with DDT and other pesticides in general. The book, meticulously documented with over 50 pages of endnotes, became a bestseller almost instantly and triggered a massive public reaction along with a flurry of activity by bureaucrats, politicians and scientists. Covering an incredible range of scientific material (entomology, wildlife biology, ecology, as well as various disciplines within medicine) it pulled together "facts" that - once assembled, organized, juxtaposed and interpreted in her manner - indicted industry, science and government, especially the USDA. Counter to a common misconception, Miss Carson did not call for an end to all pesticide use; she did challenge the accepted wisdom for achieving insect control:

> *"The chemical pesticides are a bright new toy. They sometimes work in a spectacular way, giving those who wield them a giddy sense of power over nature, and as for the failures and the long-range undesirable effects, these are dismissed as the baseless imaginings of pessimists. Disregarding the whole record of contamination and death, we continue to spray, and to spray indiscriminately.* ***We proceed as if there were no alternative, even though there are alternatives****, such as biological controls and selective spraying, which has been effective in many places. As Dr. C.J. Briejer, a Dutch scientist of rare understanding, has put it,* ***'We are walking in nature like an elephant in the china cabinet.' "***
>
> (from "A Reporter at Large - Silent Spring I",
> by Rachel Carson, June 16, 1962,
> The New Yorker, 35-99)

> ***"My contention is not that moderate chemical controls should never be used under any circumstances but, rather, that we must reduce their use to a minimum and must as rapidly as possible develop and strengthen biological controls.*** *I contend that we have put poisonous and biologically potent chemicals indiscriminately into the hands of persons who are largely or wholly ignorant of the harm they can do. There is still a very limited awareness of the nature of the threat. This is an era of specialists, each of whom sees his own problem and is unaware of or*

indifferent to the larger frame into which it fits. It is also an era dominated by industry, in which the right to make money, at whatever cost to others, is seldom challenged. We shall have no relief from this poisoning of the environment until our officials have the courage and integrity to declare that the public welfare is more important than dollars, and to enforce this point of view in the face of all pressures and all protests, even from the public itself. On those occasions when the public, confronted with some obvious evidence of the damaging results of pesticide applications have ventured to question the use of poisonous chemicals, it has been fed little tranquillizing pills of half truth. We urgently need to put an end to these false assurances. ***It is the public that is being asked to assume the risks that the insect controllers calculate. The public must decide whether it wishes to continue on the present road, and it can do so only when it is in full possession of the facts.*** *In the words of the French biologist Jean Rostand, "The obligation to endure gives us the right to know."*

(from "A Reporter at Large - Silent Spring III",
by Rachel Carson,
June 30, 1962, The New Yorker, 33-67)

Explaining to her readers the problems inherent to chemical intensive agriculture, like insect resistance and the death of beneficial insect species when spraying against a particular target injurious species, Miss Carson challenged the accepted view of the **efficiency** of DDT and other pesticides. Collating and synthesizing a myriad of scientific studies of harm done to man and the environment., Miss Carson challenged the accepted **truth** about DDT and other pesticides. Pointing to risks borne by innocent citizens - ignorant of, and far from, pesticide decision-making - Miss Carson challenged the **justice** of continued and unchanged usage of DDT and other pesticides. And throughout *Silent Spring*, as highlighted above, she argued for the wider adoption of safer and more ecologically sound **substitutes**, like biological controls.

Although it took some time to become fully apparent, Miss Carson successfully transformed the function and technology of insect control. She did so, not immediately, and not by her own actions really, but rather by *reorienting* the actions of others in the pesticide domain - policy-makers, NGOs, scientists, manufacturers and users. Miss Carson redefined, reframed and certainly reprioritized the *problems* on the agendas of those actors who I in this thesis call insecticide "artifact-makers" (industry: builders and promoters of particular technological artifacts or "tools"), fact-makers (scientists:

conceptors and promoters of particular beliefs), and rule-makers (politicians, NGOs, government, concerned citizens and others in the public arena: conceptors and promoters of particular values and preferences for outcomes).

These sets of actors can all, for simplicity's sake, be viewed as "problem-solvers", and what happened next can be seen as them searching for solutions to what they, prodded by Miss Carson, perceived to be problematic. Within science, more and more "facts" about DDT (and other insecticides) got made, few of which helped that molecule's reputation. The scientific discipline of "environmental health" came into its own, as did "ecotoxicology", two fields in which it is difficult to imagine "fact-making" about DDT that could be beneficial from chemical manufacturers' perspective. The monopoly of economic entomologists on pesticide discourse in science quickly eroded. In the public domain, citizens, NGOs and allied politicians attempted to have their values invoked during insect control decision-making and to remake the rules and regulations governing pesticide use. The monopoly on pesticide discourse in politics, once firmly held by the USDA and allied politicians from farm states who dominated agricultural committees, was also eroded. And in commerce, research monies shrunk because as more conflicting evaluation criteria from a larger and more diverse set of stakeholders began to be applied to the screening of molecules, the probability of R&D success diminished. Those funds remaining were allocated to discovering molecules with dramatically different performance properties than DDT, the now so discredited but one-time *"ideal insecticide"*[76].

New physical technologies arise out of processes of problem-driven search that can be characterized in terms of both quantity (ex. How many resources are being allocated to R&D? How urgent is the artifact-making project?) and quality (ex. In the incredibly large space of all possible technological artifacts, in which particular technological neighbourhood are firms conducting R&D? From where are they starting, in which direction, and how local is their search? Given the locus and direction of search, do its

[76] Mellanby (1992)

results promise to be competence-enhancing or competence-destroying for incumbents?). If necessity is the mother of invention, then imagination is the father and resources are also required to nourish the process.

As it is with ideas.

Efforts to bring new facts and new rules into existence can also be characterized in terms of quantity and quality. With *Silent Spring*, Miss Carson captured the *attention* and stirred the *imagination* of scientists, politicians, NGOs and citizens. She imparted a sense of *necessity* to those with the intellectual, political and financial *resources* to make new facts and new rules applicable to DDT and other insecticides. As will be shown in the case study, in the scientific arena, once widely-accepted Truths about DDT were successfully contested. Old "facts" melted away as *beliefs* counter to them became widespread and "crystallized" or "hardened" into new "facts". In the public arena, the Justice of the continued usage of DDT was successfully contested by those seeking to assert their rights over those of insecticide manufacturers and users. Old "rules" and regulations disappeared as the promoters of particular *values* and *rights* successfully institutionalized their preferences into new rules.

The focal process of substitution resulted; DDT left the U.S. domestic economy. In a world of new beliefs (or, more strongly, "facts") and values (or, more strongly, "rules"), the continued use of this insecticidal "tool" could no longer be justified. The "arguments" that were complementary and necessary for the "artifact" DDT had disappeared. In other words, Rachel Carson's Silent Spring triggered fact-making activity in the scientific arena and rule-making activity in the public arena that can only be described as "competence-destroying" from the perspective of the manufacturers of DDT and other organochlorine insecticides. These facts and rules that got made devalued producers' resources and competences - their patents, specialized plant and equipment, and expertise in chlorine chemistry, for example. In addition, new "facts" and new "rules can trigger substitution processes as well, and this is demonstrated in this dissertation.

By changing the *trajectory* and fueling the *pace* of fact-making and rule-making, Rachel Carson succeeded ultimately in altering the trajectory and pace of artifact-making as well. The rate and direction of search for new technologies for the function of insect control were both significantly altered. Innovation in the insecticide industry slowed, and the chemical insect controls introduced subsequent to *Silent Spring* amid the rise of IPM differed dramatically from DDT in terms of their properties. Indeed, today molecules are routinely *rejected* in insecticide R&D if they are "persistent", a quality of DDT considered "ideal" by the discoverer of DDT's insecticidal action.

In other words, a technological trajectory was dramatically changed through the power of ideas.

3.7 Technology for Insect Control: "Performance", "Problems", and "Properties of an Ideal Insecticide"

Rachel Carson dramatically changed the technological trajectory of insect control, through the power of ideas. But ideas about what, specifically?

Many argue, quite convincingly, that hers was a voice that ushered in a new philosophical era, one informed by ecology and environmentalism. The image of Man that had guided science for much of this century - outside of, apart from, and able to dominate Nature - would from that point on be seriously challenged by a view that saw Man as inside and very much a part of Nature. I believe that these arguments have much merit, but they deal with themes too grand for this document.

For the purposes of this dissertation, the analysis and interpretation of *Silent Spring* remains a bit more mundane; it is anchored and guided by the goal of adequately explaining the process of substitution of insect control technologies. From this perspective, the important ideas in Rachel Carson's book were her *descriptive* and *normative* claims as to the consequences of using different insect control technologies.

Rachel Carson *problematized*, in a very public way, both the *ends* and *means* of the function of insect control.

Rachel Carson's *Silent Spring* challenged existing *descriptive* claims as to the *reality* of particular outcomes of using pesticides, as well as existing *normative* claims as to the *desirability* of particular outcomes of using pesticides. Miss Carson raised some very tough questions. What were *all* the consequences - impacts, benefits, costs, risks, etc. - of pesticide use? What constitutes acceptable pesticide *performance*? What constitutes an unacceptable pesticide *problem*? And from whose perspective should these questions be asked? Who should be involved in answering such questions? By doing so, Miss Carson forced those traditionally included in the pesticides domain, *and* those who had until then been excluded from that domain, to *reopen*, to *converse* with each other about, and ultimately to *settle* fundamental questions about both the *ends* and *means* of insect control: (a) what *are* and what *should be* the criteria along which insect control technologies are evaluated; (b) what *is* and what *should be* considered desirable/acceptable or undesirable/unacceptable outcomes on these dimensions; and (c) how *do* individual products and their substitutes actually measure up?

In other words, *Silent Spring* triggered conversations that led ultimately to changed perceptions of *reality as it is*, drawing attention to particular consequences of insecticide use that had largely been ignored, and also to changed perceptions of *reality as it should be*, transforming the very definition of those insecticide properties considered to be "ideal".

3.7.1 Insecticide Performance and Problems

Decision-making about "the insect problem" is far from simple, especially in agriculture. Different crops have their own idiosyncratic needs, and many need to be protected against more than one insect species, each with their own particular requirements. So, for example: control of insect pests of food crops is different from control of insect pests of crops grown for feed or fibre; control of soil insects is different from control of plant-dwelling insects; control of sucking insects is different from control of chewing insects; control of species whose larvae are injurious is different from control of species whose adults are injurious; and so on. Moreover, comparisons of competing insecticides are complicated by the fact that, besides their varying toxicities to different insect species, different insecticides are typically applied at different rates of active ingredient per acre, according to different spraying schedule frequencies, and in different formulations. This means that, although an insecticide may appear to be lower cost in terms of its purchase price per pound, if more of it must be applied to achieve insect control on a given acreage, or if it must be applied more often, or if it must be mixed with other costly substances to facilitate spraying, its total cost may be greater than alternatives.

But besides the obvious criteria of toxicity to targeted injurious species and cost, insecticides are evaluated by taking many other factors into consideration. Some of these have come up in the discussion so far, but they merit being summarized here again. Table 3.7.1.1 lists different *reasons* given for users' preference for one insecticidal substance over another that have been extracted from case study data, clustered and synthesized into a few general categories[77]. Two basic and unsurprising dimensions emerge from this analysis - efficacy and safety. Both of these have always been desirable properties but, as indicated in the Table (and as will be presented in detail in later Chapters), the ways that these concepts have been operationalized have changed greatly over time. Statements like "DDT is effective" and "DDT is safe", quite simply, have had different *meanings* at different points in time.

[77] Simple content analysis on Brooks (1974, vol I & II) & Ware (1994, Chapter 4). Normative/evaluative claims made about any insecticide (not just DDT) were extracted, from which the "property" in question was identified along with what was considered desirable for that property. This was done very early in the research, and the results were generally confirmed by later data gathering efforts, including interviews.

Table 3.7.1.1 - Dimensions of Insecticide "Performance"

Dimension	Evaluation
EFFICACY	
1) formulation considerations	
- physico-chemical characteristics relevant for formulation (volatility, melting point, solubility in water, solubility in oils, etc.)	depends upon specific insect/crop combination
- mode of action (contact vs. stomach poison)	depends upon specific insect/crop combination
- mode of action (systemic vs. nonsystemic)	depends upon specific insect/crop combination
- compatibility/synergism with other insecticide active ingredients	typically desirable
- synergism with inert ingredients of formulations	typically desirable
2) effects on plants	
- phytotoxicity, acute &/or chronic	always undesirable
- residues left on food	always undesirable
3) effects on insects	
- toxicity to target insect species	always desirable, BUT PROBLEMS of RESISTANCE mean that this property is not a "constant" as was assumed earlier this century
- toxicity to beneficial insect species	always undesirable, BUT operationalized earlier this century to reflect a preoccupation with "honey bees"; the list of beneficial insects has grown since, as an ecosystemic view has been adopted, due to PROBLEMS of SECONDARY PESTS and RESURGENCE
- spectrum of activity (wide vs. narrow)	wide/broad spectrum control was once strongly desirable BUT is now much less desirable (see PROBLEMS in point above)
- residual effect / persistence (high vs. low)	persistence was once strongly desirable, BUT is now strongly undesirable as it extends in both time and space any PROBLEMS of SAFETY to HUMANS as well as to FISH, BIRDS, & WILDLIFE
- quick "knock-down" effect	typically desirable

Table 3.7.1.1 (continued) - Dimensions of Insecticide "Performance"

Dimension	Evaluation
SAFETY	
1) safety of formulation & application, to human users - absence of problems of acute toxicity to humans	always desirable, BUT the regulation mandating safety of insecticides *"when used as directed"* was established only in 1947 (FIFRA) with its requirement to register all insecticides and their labels
2) safety of application, to fish, birds, & wildlife - absence of problems of acute toxicity to fish, birds, & wildlife	always desirable, BUT fish and bird kills due to acute toxicity were generally tolerated until *Silent Spring* - USDI received mandate to research effects of insecticides on wildlife only in 1958, but with no regulatory powers
3) safety of residues on food, to humans - absence of problems of acute & chronic toxicity to humans	always desirable, BUT the regulation formalizing the setting of legal maximum tolerance levels was established only in 1954 (Miller amendment)
4) safety of residues in environment, to fish, birds, wildlife and humans - absence of problems of chronic toxicity to fish, birds, wildlife, and humans; no problem of "bioaccumulation"; and an understood and accounted for "environmental fate"	always desirable, BUT essentially ignored until *Silent Spring* - degradation studies (i.e. persistence of insecticides in soil) first required for registration of *new* molecules only in 1965 - monitoring of environment for residues routinized only in 1967 when Pesticides Monitoring Journal established (USDA, HEW, USDI)

*NOTE: When I say that certain effects were "tolerated" or "ignored", I am referring to and characterizing the entire pesticides domain in general; certainly there were actors - some inside and some outside the domain - who did not tolerate/ignore these effects. Indeed, it was only through their activities that the domain became transformed.

As can be seen in the Table, many of those features which make up insecticide "performance" (as in "performance/price ratio", introduced in the review of the literature) are not desired functionality, per se, but refer to the avoidance or minimization of certain insecticide "dysfunctionalities" or "problems". Solving the "insect problem" often led to new "insecticide problems"[78]. Table 3.7.1.2 lists **problems** associated with insecticide use extracted from case study data, clustered and synthesized into a few general categories[79].

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[78] This expression was routinely used. See for example Knipling's (1953) "The Greater Hazard - Insects or Insecticides" in *Journal of Economic Entomology*, 46, 3, p 1; also Rudd's (1959) "Pesticides - the REAL Peril" in *The Nation*, Nov. 28, p 399; also Moore's (1967) "A Synopsis of the Pesticide Problem" in *Advanced Ecological Research*, 4, p75.

[79] Simple content analysis on two sources: (1) United Nations' *Consolidated List of Products Whose Consumption &/or Sale Have Been Banned, Withdrawn, Severely Restricted or Not Approved by Governments* (1994) for regulators' perspective; and (2) Brooks (1974, vol I & II) for users' perspective. Instances of exit of pesticides from markets were extracted and the stated reasons given for these were identified and related to "problems". This was done very early in the research, and the results were generally confirmed by later data gathering efforts, including interviews, although a few additional "problems" were added subsequently. Names and explanations for the problems were refined by refering to textbooks of toxicology (Chengelis, Holson & Gad, 1995) and pest management (Pimentel, 1991).

Table 3.7.1.2 - Insecticide "Problems"

Problem	Explanation (with DDT examples, where applicable)
PROBLEMS RELATED TO EFFICACY	
1) resistance	This problem refers to the development over time through evolution, in an insect species, of an ability to tolerate doses of insecticides which would prove lethal to the majority of individuals in a "normal" population. Repeated exposure to insecticides "selects" for hardy individuals who, with their peers dead, reproduce easily to become a larger portion of the population. DDT resistance was documented as early as 1946.
2) secondary pests	This problem occurs when the use of an insecticide kills the targeted primary insect species as desired, but in so doing it raises the status of what was once considered a secondary or "nuisance" species to full pest status. This is especially the case if the insecticide is not toxic to the nuisance species but is toxic to its predators, parasites and competitors. If this occurs, the unaffected species' population increases, filling the biological void left by the killing power of the insecticide. DDT led to problems of secondary pests.
3) resurgence	This problems occurs not because different species are differentially affected by the active ingredients' killing power but rather because the targeted pest species is able to rebuild its population faster than its predators, parasites and competitors and hence quickly refills the biological void. In other words, farmers' initial pest infestation problems return quickly and with more severity. This is also called "flare-back", and was a problem associated with DDT.
PROBLEMS RELATED TO HUMAN SAFETY	
1) acute toxicity - oral (swallowing) - dermal (through skin) - inhalation (breathed in)	Health effects (Irritation, organ dysfunction or even death) resulting from a single exposure, of short duration, to a chemical.
2) chronic toxicity	Health effects resulting from exposure to chemicals (usually in the diet) over a large portion of an organism's lifetime.
- oncogenicity	- ability of a chemical to cause cancer
- teratogenicity	- ability of chemical to cause effects in the fetus following exposure to the maternal system during major periods of organ development
- reproductive effects	- ability of a chemical to effect such things as estrous cycles, mating behaviour, as well as number, weight, survival and growth of offspring over multiple generations

3) mutagenicity Effects that involve changes to the genetic material in cells. Changes in reproductive cells (i.e. egg, sperm) can retard fetal development or lead to congenital abnormalities while changes to somatic cells can lead to cancer.

PROBLEMS RELATED TO NON-HUMAN SPECIES' SAFETY

1) acute toxicity Death to nontarget organisms immediately following spraying. Dramatic and obviously connected to insecticide spraying because they occur immediately, "fish kills" and "dead robins on suburban lawns" were two such problems of DDT that received wide attention.

2) chronic toxicity *"It is possible for DDT to wipe out an entire species of bird without killing even one individual"* explained Dr. Charles Wurster Jr., testifying at the Wisconsin DT hearings, by having reproductive effects analogous to those in humans. Chemicals can interrupt reproductive processes via a number of mechanisms, but the most celebrated with respect to DDT was its causal connection to eggshell thinning in birds (especially the peregrine falcon) such that parent birds crushed the eggs when they nested.

3) ecosystem effects Disruptions to the populations of certain species within an ecosystem can perturb the entire system and affect its "ecosystem health".

FACTORS AGGRAVATING SAFETY PROBLEMS

1) persistence This is not a problem per se but does tend to multiply in time and space the toxicological effects of chemicals.

2) bioaccumulation This problem, also called "bioconcentration" occurs when molecules are soluble in fats and oils and not easily metabolized by organisms. Residues dissolve, are stored in, and over time concentrate in an organism's fat tissue. When that organism is preyed upon and eaten by something higher up the food chain, the predator takes up and stores all the bioaccumulated material. See Figure 3.7.1.1 for a graphical illustration.

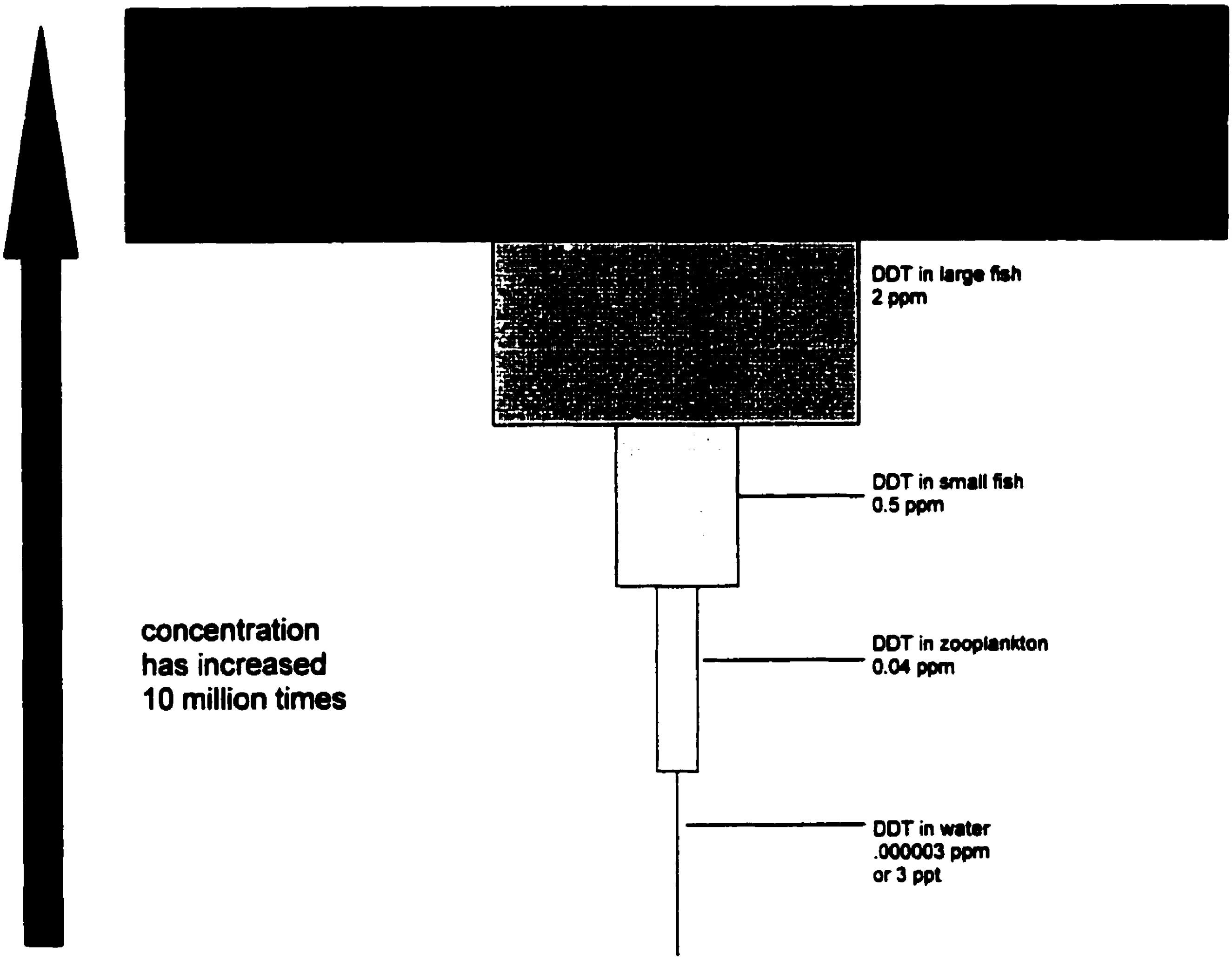
OTHER PROBLEMS

1) contaminants Sometimes it is not the active ingredient which is responsible for human and non-human safety problems, but contaminants. These are usually unreacted reactants (ex. DDT found in dicofol) and unwanted byproducts (ex. dioxins) of chemical synthesis.

2) regulatory and trade problems Sometimes products exited markets (a) in order to achieve regulatory homogeneity within a trading block, or (b) in order for a crop exporting country to be able to meet the pesticide tolerance requirements of crop importing countries.

Figure 3.7.1.1 - The Problem of Bioaccumulation

The concentration of DDT was magnified approximately 10 million times in the food chain of Long Island Sound.



* This Figure appears in Rogers (1976, p. 25).

To illustrate how the notion of insecticide safety vis a vis humans has evolved, consider Tables 3.7.1.3 and 3.7.1.4. The former shows the minimum information requirements (in terms of specific studies) for registration of new insecticides, while the latter shows the tests that were required of manufacturers in order to establish maximum tolerance levels for residues. These Tables also show how both the time and the cost of bringing new insecticides to market has increased along with the shifting definition and operationalization of safety.

Table 3.7.1.3 - Human Safety Evaluation: Minimum Registration Requirements

1947	1960	1970	1973	Mean Average Cost 1970
Acute toxicity	Acute toxicity	Acute toxicity	Acute toxicity	$18,405
		Subacute dermal	Subacute dermal	6,940
		Subacute inhalation	Subacute inhalation	6,120
30-90 day, rat	90 day, rat	90 day, rat	90 day, rat	12,765
	90 day, dog	90 day, dog	90 day, dog	17,381
	2 year, rat	2 year, rat	2 year, rat	30,000
	1 year, dog	2 year, dog		
		Reproduction, 3 gen., rat	Reproduction, 3 gen., rat	35,410
		Teratogenesis, rodent	Teratogenesis, rodent	10,420
			Mutagenesis	8,170

• Cost figures taken from Statement of R. E. Naegele, Manager, Agricultural Department, The Dow Chemical Company, before The House Committee on Agriculture, March 8, 1971.
•• Table is adapted from that of Blodgett (1974, p 248)

Table 3.7.1.4 - Tests Required for Establishing Tolerances

	Tests	Date Established	Cost (estimated dollars)	Time Implication (months)
1.	Toxicology			
	- Acute (rat and non-rodent)	1954	5,000	1
	- Subacute (rat and dog)	1954	50,000	6
	- Chronic, 2 year (rat and dog)	1954	160,000	28
2.	Reproduction (rat)	1960	35,000	20
3.	Teratogenesis	1970	10,000	2
4.	Mutagenesis	1972	10,000	2
5.	Metabolism			
	- Plant	1954	50,000	6
	- Animal	Before 1960	25,000	3
6.	Analytical Methodology			
	- Crops, Meat, Milk, Poultry, Eggs	1954 1965 (Poultry)	100,000	4-6
7.	Field Residue Data			
	- Crop, Feed, Meat, Milk, Poultry, Eggs	Before 1960 1965 (Poultry)	100,000	12

* Table is adapted from that of Blodgett (1974, p 247)

Notice also that "safety", over time, came to refer to different constituencies, some not even human. Earliest safety concerns arose when arsenicals were first introduced and these were concerns for *farmers and pesticide applicators*, although no formal legislation related to their safety was implemented until 1947. Then, the problem that pesticide residues could pose for *consumers* emerged as a public issue near the turn of the century (see Chapter 4), but it was not until 1954 when the FDA was granted meaningful authority to legislate maximum tolerance levels (see Chapter 5). The safety of insecticides to *fish, birds and wildlife* emerged as a public issue in the late 1950s, but it was only in the 1960s after the publication of *Silent Spring* that data began to be gathered systematically on the effects of insecticidal molecules on fish, birds and wildlife using standardized tests, as summarized in Table 3.7.1.5. This information proved critical to the substitution of DDT (see Chapter 6).

<u>**Table 3.7.1.5 - Fish & Wildlife Safety Tests**</u>

	Criterion	Date Established			Cost (estimated dollars)	Time Implication
		1947-62	63-70	71-73		
1.	Fish (2 species), Acute LD_{50}		X		600-800	Less than 1 month
2.	Birds (2 species), Acute Oral LD_{50}		X		600-800	•
3.	Crustacean, Acute		X		1,000	•
4.	Mollusc, Acute		X		1,000	•
5.	Simulated Field Testing, Birds and Mammals		X		Highly variable (More than 6,000)	•
6.	Birds (2 species), Subacute Feeding			X	800-1,200	•
7.	Special Testing					
	(a) Field monitoring of effects on wildlife populations		X		Highly variable	Less than 1 year
	(b) Aquatic ecosystems (laboratory)			X	Highly variable	3-9 months
	(c) Aquatic invertebrates (laboratory)			X	Highly variable	1-12 months
	(d) Other				Highly variable	
				X		Less than 1 year
8.	Reproduction Studies, Fish, Birds, Mammals			X	Greater than 10,000	6-12 months
9.	Residue, Fish, Birds, Mammals		X		Unknown	Less than 6 months

• Table is adapted from Blodgett (1974, p 249)

As the notion of safety expanded to cover a longer period of time and a wider set of potential victims, what became known as the "environmental fate" of insecticidal molecules emerged as a concern. It became obligatory for firms seeking to register new molecules to undertake even more studies and tests to determine just where all the tons of active ingredients that they were hoping would be applied in insecticide markets would ultimately end up. Table 3.7.1.6 summarizes just the *basic* tests that were required of manufacturers seeking to register products over the years, in addition to the tests of human safety summarized in Table 3.7.1.3.

Table 3.7.1.6 - Basic Tests Required for Pesticides Registration

	Tests	Date Established	Cost (estimated dollars)	Time Implication
1.	Chemical and Physical Properties (such as solubility, vapor pressure, flash point)	1947	5,000-15,000	
2.	Degradation Studies		$100,000 - 250,000 (for Degradation, Mobility, Residue, & Microbiological all combined)	
	- Persistence (soil)	1965		6-24 months
	- Persistence (water and sediment)	1970		Less than 1 year
	- Photochemical	1970		2-6 months
3.	Mobility Studies			
	- Runoff	1970		Less than 6 months
	- Leaching	1970		Less than 3 months
4.	Residue Studies			
	- Fish	1970		2-6 months
	- Birds	1970		2-6 months
	- Mammals	1970		2-6 months
	- Lower tropic levels of food chains	1972		6-9 months
5.	Microbiological Studies	1970		Less than 3 months

* NOTE: Much of the data generated by these tests is utilized in studies of human, fish, and wildlife safety.
** Table is from Blodgett (1974, p 246)

That what constitutes acceptable "performance" of an insecticide has changed is evidenced by Table 3.5.2.5.2 - Properties of Chemical Families of Organic Insecticides, presented above. Notice the differences between the *"truly exciting"* synthetic pyrethroids and the *"persistent organic pollutant"* organochlorines:

(1) Average use rates (pounds of active ingredient per hectare necessary to achieve control) are much, much lower, reflecting concerns about all the problems associated with insecticide use.

(2) Relative safety ratios (toxicity to mammals/toxicity to insects) are much higher, reflecting concerns about problems of acute toxicity. The abandonment of organochlorines for organophosphates actually increased acute toxicity problems back towards those of the days of the arsenicals.

(3) Wide spectrum control is a less desired feature, reflecting the ecosystemic principles embodied by IPM.

(4) Persistence is no longer a valued feature, reflecting concerns about bioaccumulation.

3.7.2 Performance and Problems of Insecticides: Evolving Definitions and Measurements

As noted above, the outcomes of insecticide use labeled as undesirable "problems" and desirable "performance" have changed dramatically over time. Another good way to illustrate this, before we get into the details of the case study, is simply to juxtapose the actual words of two of the most significant actors in the biography of DDT, Paul Muller of Geigy who discovered its insecticidal properties in 1939 and William D. Ruckelshaus of the EPA who banned it in the United States in 1972. These particular texts of theirs are especially precise about desirable and undesirable properties of insecticides.

Table 3.7.2.1 contains selections from the 1972 "findings" of Ruckelshaus about DDT, extracted from his *Opinion and Order of the Administrator*. Table 3.7.2.2 contains extracts from the speech given by Muller upon accepting his Nobel prize in 1948.

Table 3.7.2.1 - Selected Findings from Ruckelshaus' Decision to Ban DDT
(June 14, 1972)

Chemical properties of DDT
1) DDT can persist in soil for years and even decades.
2) DDT can persist in aquatic ecosystems.
3) Because of persistence, DDT is subject to transport from sites of application.
   a) DDT can be transported by drift during aerial application.
   b) DDT can vapourize from crops and soils.
   c) DDT can be attached to eroding soil particles.
4) DDT is a contaminant of fresh waters, estuaries, and the open ocean and it is difficult to prevent DDT from reaching aquatic areas and topography adjacent and remote from the site of application.

=> *The above factors constitute a risk to the environment.*

Activity in Food Chain and Impact on Organisms
1) DDT is concentrated in organisms and transferred through food webs.
   a) DDT is concentrated in and transferred through terrestrial invertebrates, mammals, amphibians, reptiles and birds.
   b) DDT can be concentrated and transferred in freshwater and marine plankton, insects, molluscs, other invertebrates, and fish.
2) The accumulation in the food chain and crop residues results in human exposure.
3) Human beings store DDT.

=> *The above factors constitute an unknown, unquantifiable risk to man and lower organisms.*

Toxicological Effects
1) DDT affects phytoplankton species composition and the natural balance in aquatic systems.
2) DDT is lethal to many beneficial agricultural insects.
3) DDT can have lethal and sublethal effects on useful aquatic freshwater invertebrates, including arthropods and molluscs.
4) DDT is toxic to fish.
5) DDT can affect the reproductive success of fish.
6) DDT can have a variety of sublethal physiological and behavioural effects on fish.
7) Birds can mobilize lethal amounts of DDT residues.
8) DDT can cause thinning of bird eggshells and thus impair reproductive success.
9) DDT is a potential human carcinogen.
   a) Experiments indicate that DDT causes tumours in laboratory animals.
   b) There is some indication of metastasis of tumours attributed to exposure of animals to DDT in the laboratory.
   c) Responsible scientists believe tumour induction in mice is a valid warning of possible carcinogenic properties.
   d) There are no adequate negative experimental studies in other mammalian species.
   e) There is no adequate epidemiological data on the carcinogenicity of DDT, nor is it likely that it can be obtained.
   f) Not all chemicals show the same tumourigenic properties in laboratory tests on animals.

=> *DDT presents a carcinogenic risk.*

* Source: Environmental Protection Agency (1972), *Consolidated DDT Hearings - Opinion and Order of the Administrator*, issued June 14, 1972; printed in the Federal Register, vol. 37, no. 131, July 7, 1972, pp.13369 - 13376

Table 3.7.2.2 - Selected Extracts from Muller's Nobel Lecture
(December 11, 1948)

Ladies and gentlemen, ...

"When, in about 1935 and on behalf of my Company, J.R. Geigy A.G. in Basel, I began to study the field of insecticides, and in particular those insecticides of importance to agriculture, the situation looked desperate indeed. Already an immense amount of literature existed on the subject and a flood of patents had been taken out. Yet of the many patented pesticides were practically none on the market and my own investigations showed that they were not comparable with known insecticides such as the arsenates, pyrethrum or rotenone.

"This gave me courage to press on. In other respects too, the chances were worse than poor: only a particularly cheap or remarkably effective insecticide had any prospects of being used in agriculture, since the demands put upon an agricultural insecticide must necessarily be strict. I relied upon my determination and powers of observation. I considered what my ideal insecticide should look like, and the properties it should possess.

"I soon realized that a contact or 'touch' insecticide would possess very much better prospects than an oral poison. The properties of this ideal insecticide should be as follows:

(1) Great insect toxicity.

(2) Rapid onset of toxic action.

(3) Little or no mammalian or plant toxicity.

(4) No irritant effect and no, or only a faint, odour (in any case not an unpleasant one).

(5) The range of action should be as wide as possible, and cover as many Arthropods as possible.

(6) Long, persistent action, i.e. good chemical stability

(7) Low price (= economic application).

"Known insecticides can be grouped as follows under these seven headings:

Insecticides	Satisfies the following requirements:	Does not satisfy the following requirements:
Nicotine	1, 2, 5, 7	3, 4, 6
Rotenone	1, 3, 4, 5	2, 6, 7
Pyrethrum	1, 2, 3, 4, 5	6, 7
Thiocyanate (Aliphatic)	1, 2, 5, 7	3, 4, 6
Phenothiazine	1, 3, 4, 7	2, 5, 6

"First of all, a substance had to be found with greater contact insecticidal properties and this was obviously not so easy ...

"After the fruitless testing of hundreds of various substances I must admit that it was not easy to discover a good contact insecticide ...

"This compound [DDT] ... now showed a strong insecticidal contact action such as I had to date never observed in any substance. My fly cage was to toxic after a short period that even after very thorough cleaning of the cage, untreated flies, on touching the walls, fell to the floor. I could carry on my trials only after dismantling the cage, having it thoroughly cleaned and after leaving it for one month in the open air ...

"Later the material was tested on other insects such as aphids, gnats (Culex) and finally cockchafers, Colorado beetles, etc. In all cases the new compound acted, although it often killed only in a matter of hours or days. This is also the reason why biologists were not very interested in the substance; pyrethrum and rotenone had accustomed them to expect very rapid knockdown and they did not understand that long residual activity far outweighed the slow toxic process. ...

Insecticides	Satisfies the following requirements:	Does not satisfy the following requirements:
DDT	1, 3, 4, 5, 6, 7	2

"DDT insecticides have now been introduced into all possible fields of insect control, for instance in hygiene, textile protection, storage and plant protection. ...

" ... The field of pest control is immense, and many problems impatiently await a solution. A new territory has opened up for the synthetic chemist, a territory which is still unexplored and difficult, but which holds out the hope that in time further progress will be made.

"I am grateful and glad that I have been permitted to lay a first foundation stone in this puzzling and apparently endless domain."

Source: The Nobel Foundation (1949). Speech was "Dichlorodiphenyltrichloroethane and Newer Insecticides", and is shown here translated from the German. Reproduced in Mellanby (1992, p 97).

Juxtaposed with Ruckelshaus' decision to ban DDT, the Nobel Lecture delivered by Muller in 1948, and especially his elaboration of what would constitute an *"ideal"* insecticide and how DDT measures up, is striking. Very different evaluation criteria and beliefs were invoked by each.

Consider their beliefs about the safety of DDT to humans: Muller found *"little or no mammalian toxicity"* while Ruckelshaus found that *"DDT is a potential human carcinogen"* and that it *"causes tumours in laboratory animals."* As will be demonstrated, each was operationalizing the criteria of safety in a different manner. At the time of DDT's introduction, a product's safety refereed to an absence of *acute toxicity* and it was not until later that *chronic toxicity* concerns significantly affected the evaluation of pesticides. Or consider the evaluation criteria that each employed. Certainly, Ruckelshaus used more dimensions to evaluate DDT; the safety of DDT with respect to birds, ultimately of determining importance since DDT's causal connection to *eggshell thinning* led to its ban in the U.S., was not even on Muller's list. As will be demonstrated, it was only through the relentless efforts of concerned individuals and organizations that this and other environmental criteria eventually became standard for evaluating pesticides. Note also that even when they invoked the same evaluation criteria, they had very different ideas about what constituted desirable performance. Of particular significance, the *persistence* of DDT, considered one of its greatest strengths when the substance was introduced, is now one of its greatest weaknesses.

Indeed, the major points to be made in this dissertation can be summarized and foreshadowed with reference to Muller's Nobel Lecture. After setting the stage and establishing the context for DDT's entry into the economy in Chapter 4, the Chapters which follow provide a detailed description of the rise and fall of DDT, drawing attention to instances of substitution which I categorize as belonging to one of three "ideal types". Each of these can be related back to Muller's characterization, in his list of insecticide properties (1) through (7), of an ideal insecticide:

> In Chapter 5, I describe the rise of DDT. I focus on its enthusiastic acceptance into many different markets in the economy and how it substituted for the incumbent arsenical and botanical products. As Muller explains above in his speech outlining what guided his search for better tools for insect control, **this process of substitution occured because DDT was perceived to have: (1) great insect toxicity; (3) little or no mammalian or plant toxicity; (4) no irritant effect and no, or only a faint, odour; (5) a very broad range of action, covering many insect species; (6) long, persistent action; and (7) a low price.** Some insecticide users, homeowners for example who liked to see their insecticide working before their eyes, did have reservations about DDT and its poor performance on Muller's criteria (2), rapid onset of toxic action. The "knockdown" potential of DDT - it demonstrated its efficacy by killing insects only after a few hours - was indeed low, but this was easily overcome by mixing DDT with a substance with quick knockdown like pyrethrum. But in the vast majority of markets, DDT's measures on all the other important dimensions far outweighed this shortcoming such that, from the perspective of actors in the pesticide domain at that time, DDT was the insecticide closest to "ideal". Its performance/price ratio - notice Muller's criteria (7) - was highest amongst available products, making it the insecticidal tool scoring best on the test of efficiency. Hence, its appearance on the choice menus of actors triggered the decline of the incumbent products as users switched to the newly-available alternative. In other words, as a result of the work of Muller and his firm Geigy aimed at bringing new insecticidal tools into existence, **the tools**

changed and one supplanted another. This is an example of what I call **substitution as a consequence of tool-making.**

In Chapter 6, I describe the fall of DDT. I focus on the series of events leading up to and culminating in DDT's final exit from the economy. Readers will see how, over time and due to the efforts of actors formerly outside of the pesticide domain ("new entrants" so to speak), the desirability of certain of the characteristics of DDT - its persistence in particular - would be successfully challenged. Events in the pesticide domain led **to a complete reversal of positions as to the desirability of Muller's criteria (6).** By the end of the 1960s, to be labelled "persistent" was the beginning of the end for an insecticide. Combined with their toxicological properties, this quality of persistence made it unlikely that insecticideal substances could be used without infringing upon the rights of others to a safe and healthy environment. Thus these tools failed the test of justice. Persistent pesticides like DDT were banned, forcing insecticide users to switch to long-available alternatives. In other words, as a result of the work of concerned citizens, NGOs, certain politicians and other government officials aimed at bringing new regulations into existence, **the rules changed** and one product supplanted another. This is an example of what I call **substitution as a consequence of rule-making.**

Finally, in Chapter 7, I describe other instances where DDT was substituted by alternative products which occured before its ultimate ban and in a manner different from those substitutions outlined in Chapters 5 and 6. Note the connection between those two: in Chapter 5, the evaluation criteria against which products are measured are given and the trigger for substitution is the appearance of a new insecticidal product which changes the choice menu confronting users; in Chapter 6, the products available to users' and on their choice menus are given and it is a change to the evaluation criteria invoked which triggers substitution. In Chapter 7, a third processs of substitution is described where neither products nor evaluation criteria change; what triggers and drives substitution are changes to actors' perceptions of how available products score along the given criteria. Readers will see that, over time, due to the problem of insecticide resistance, **the claim that DDT met Muller's criteria (1) came to be falsified.** That DDT had "great insect toxicity" was no longer true for certain insect control markets, making DDT far from "ideal" and causing actors to switch to long-available alternatives. In other words, as a result of the work of scientists aimed at bringing knowledge into existence, **the facts changed** and one product supplanted another. This is an example of what I call **substitution as a consequence of fact-making.**

4 Pre-DDT: The Rise of Chemical Controls

4.1 Introduction

Cultural control of insects was by far the dominant technology for accomplishing the function of insect control in the United States prior to the mid-1800's, a time generally acknowledged as the dawn of the era of chemical controls[1]. Nevertheless, a handful of substances, mostly botanicals, were in use earlier. Take nicotine for example. As early the 1700's the smoke from heated tobacco was blown by farmers onto infested plants to kill insects, or water in which tobacco leaves had been allowed to soak was sprayed by them onto fruit trees[2]

Indeed, although it may come as a surprise to many who conceive of insect control only in terms of modern synthetic chemical compounds, the use of pesticide-like substances can actually be traced back far into Man's history. One of the earliest records of a substance being used as a pesticide is attributed to Homer, the Greek poet, who described in 1000 BC the burning of sulphur to fumigate homes. It is also believed that as early as 900 AD the Chinese were using arsenic to control garden insects[3].

But *"not until the mid-nineteenth century were pests controlled to any degree of success with chemicals."* writes one author[4] in a value judgement probably reflecting today's standards of *"success"* but nonetheless drawing attention to the significant technological changes which took place at about that time and which were accompanied by very significant changes in social organization, including the emergence of: a new industry (insecticides); a new scientific discipline (economic entomology); new government agencies and regulations (the Bureau of Entomology within the USDA, and the Insecticide Act of 1910); and new problem domains (residues). The coevolution of these

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[1] West el al (1951); Ware (1994)
[2] West et al (1951, p 48); Ware (1994, p 58)
[3] Ware (1994, p 4)
[4] Ware (1994, p 11)

three spheres of society with the problem domain and with insect control technology is presented here.

4.2 Solving the Insect Problem: The Rise of Arsenicals

It is not surprising that events in the United States have come to have such significant influence upon the practice of insect control around the world. This may very well have been the case even if that country did not have the economic and military power that it has historically enjoyed, for the agricultural interests in the US faced very serious and particular insect challenges that spurred them to be creative[5]. Necessity is, after all, the mother of invention.

In opening up and settling the continental United States, as more and more immigrants moved west, much ecological disruption occurred and this strained agricultural activity. Some of this is linked to problems inherent in the opening up of new frontiers and settling of new lands. Other stresses on agriculture are directly related to both the *quantity* and *quality* of farming practiced in the United States.

Settling new lands is risky, from the point of view of Insect-Man relations, because alien species are routinely introduced into ecosystems, hitching rides on wagons or in stored grains, for example. Without natural predators, their populations can increase quickly to levels of economic significance. The populations of local insect species can also become problematic if the plants that communities choose as "crops" happen to be those that allow them to feed and flourish. More dense transportation links between regions and communities increased these invasion and infestation risks. Generally, in quantitative terms, as agricultural production increases, so does *demand* for the function of insect control. Inevitabiy, as the scope and scale of agricultural production in the United States

[5] This discussion has benefited greatly from the following works: Shepard (1951); Whorton (1971); Jones (1973); Whorton (1974); Ordish (1976); Dunlap (1978a); Dunlap (1981); Perkins (1982); Boardman (1986).

grew, more and more investment became at risk of insect damage so more and more became at stake every growing season when it came to insect control.

But the qualitative nature of U.S. agriculture also increased demand for the function of insect control. Mechanization and the commercialization of farming further increased what was at stake each growing season: more capital had to be serviced with returns and larger loans had to be repaid. Downstream customers, themselves becoming increasingly industrialized, demanded predictable quantities of produce of a predictable quality. The natural rhythms of nature had to be damped and farms came to be run more and more like machines, where control was paramount. Even today, preferential access to bank loans and crop insurance can be made contingent upon using pesticides to minimize risks. Also, very important in terms of increasing demand for insect control, commercialized agriculture combined with increased farm and regional specialization dramatically simplified ecosystems. Suddenly, vast continuous and well-maintained tracts of food and habitat were available for insect species. In simplified monoculture-based farming, infestations are more difficult to contain spatially. Simplified agro-ecosystems are less resilient and much more vulnerable to what might otherwise be minor fluctuations in pest populations, as these perturbances or stresses on the system can become amplified across vast spatial scales.

These changes set the stage for innovation in accomplishing the function of insect control. Enter the inorganics.

> *"The real history of chemical control began in the middle nineteenth century when anxious farmers in the United States were faced with the invasion of the Colorado beetle (Leptinotarsa decemlineata) into cultivated potato lands and took the unprecedented step of applying arsenical poisons onto crops which were destined for human consumption; the arsenicals proved effective as a beetle control while the prophesized human mortality did not occur, and from that time onwards the development of control by insecticides has made steady progress. With the realization that insect attack could be suppressed, at least below the level of economic importance, came the need for the close study of the living insect in the field and today applied entomology is a science in which the entomologist and chemist bear equal responsibility."*
>
> (West, Hardy & Ford, 1951, p 25)

The botanical pyrethrum was introduced into the United States in 1858, but it is a compound derived from arsenic, Paris Green (copper aceto-arsenite), which is credited with becoming the first insecticide in "widespread use" in the United States. Mixed with ashes or mineral oil, it was initially used against the Colorado potato beetle. Experimenting against insects with this material, a dye, might seem odd but it was not much of a conceptual leap - it was common knowledge among farmers and the general public that arsenic was a deadly poison. Faced with a particularly severe and potentially costly infestation, farmers had little to lose by experimenting with this substance. Soon after this initial success in 1867, the use of Paris Green spread to other crops and pests. Other substances were also applied to crops and experimented with to test their insecticidal value. Historical accounts of entomology list almost 40 different pesticidal materials (mostly insecticides, but a few fungicides, nematicides and herbicides as well) introduced and used as chemical controls between 1867 and the beginning of WWII[6]. Compared with cultural controls - like the use of widely-spaced rows of plants, the periodic flooding of fields, or the removal and destruction of plants after harvesting, all of which aim at limiting insect populations by disrupting their reproduction, food supply and vectors of migration - chemical controls give immediate and visible results.

Along with Paris Green, which never reached usage levels of more than 5 million pounds annually[7], two other arsenicals that came to dominate the insecticide market in pre-DDT America were lead arsenate and calcium arsenate. The first actually refers to two different preparations, acid lead arsenate and basic lead arsenate, both of which are white powders with the desirable property of being less likely to burn plants than other arsenicals. The potential of an insecticide to damage or kill plants is known as its "phytotoxicity". Low phytotoxicity, like that of lead arsenate, is desirable.

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[6] See Ware (1994, p 12).
[7] Shepard (1951, p 15)

First used in Massachusetts in 1892 against the Gypsy Moth, lead arsenate came to be widely used, especially in apple orchards[8]. By 1934, use of lead arsenate had risen to about 40 million pounds per year[9]. The other important arsenical, calcium arsenate, was first used experimentally in 1907, and is actually a mixture of several calcium arsenates. This material came to be extensively used, especially on cotton, with around 30 million pounds being used annually as of 1934[10]. Other arsenicals of less importance were derived from sodium, and still others from zinc. The success of the arsenicals - they were convenient, gave immediate obvious results, and replaced time-consuming labour-intensive cultural controls - meant that chemical controls became almost synonymous with insect control.

> *"They* [arsenical insecticides] *were, in fact, responsible for the initiation of large-scale insecticide applications eventually leading to the intensive use of fungicides and herbicides in modern agriculture."*
>
> (Ware, 1994, p 71)

As these directly-acting and convenient chemical controls became widespread and institutionalized, once standard practices, such as sanitation activities (i.e. disposal of crop residues and/or infected fruit) and crop rotation, became less common.

> *"The success of the arsenicals stimulated the chemical control of pests at the cost of the consideration of other methods."*
>
> (Ordish, 1976, p 179)

So prior to the introduction of DDT, botanicals and inorganic compounds were the dominant conventional chemical insect control technologies in use, especially in agriculture, which accounted for about 56% of the $12.4 million, $ 27.7 million, and $33.2 million in total insecticide production in each of 1931, 1935 and 1937 respectively, with the balance being for the household market. In agriculture, the leading arsenical, lead arsenate, on its own accounted for 29% of the total in 1931, 27% in 1935, and 30% in 1937, while calcium arsenate represented 10%, 15%, and 10%.

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[8] Shepard (1951, p 18)
[9] Roark (1935), cited in Perkins (1978)

Table 4.2.1 - Arsenicals Dominant in Agriculture in Pre-DDT United States

Chemical Control	Production 1931	Production 1935	Production 1937
Lead Arsenate:	37,974,038 lbs $ 3,674,422	52,145,851 lbs $ 4,173,462	63,291,440 lbs $ 5,540,885
Calcium Arsenate:	26,128,620 lbs $ 1,279,789	43,295,354 lbs $ 2,322,394	37,001,959 lbs $ 1,879,253

Chemical Control	% of Total Agricultural Insecticide Market ($ basis) 1931	1935	1937
Lead Arsenate:	29	27	30
Calcium Arsenate:	10	15	10

(1) Figures are calculated from data in "Chemical Facts and Figures" (1940), published by the Manufacturing Chemists Association.
(2) Exports were a small percentage of production at this time, so production volumes approximate sales volumes.
(3) Pyrethrum was accounted for as a "household insecticide" during this period, so has been excluded from the Table. In 1937, 7,100,682 lbs with a value of $2,021,751 were produced.

It is not by accident that we have mentioned apples and cotton in our account of the rise of arsenicals. Prior to the introduction of DDT, insecticide use was confined to low acreage, high value field crops like cotton or tobacco or hops, fruit orchards like those of apples, and glasshouse produce[11]. For instance, in 1941 over 50% of lead arsenate used was applied to apple orchards[12]. For high acreage, low value field crops, like corn or soybeans for example, treatment with an insecticide was simply too expensive.

[10] Roark (1935), cited in Perkins (1978)
[11] Ordish (1976, p 187)
[12] Shepard (1951, p 18)

4.3 Chemical controls and industrial organization

With the commercialization and specialization of agriculture came opportunities for commercialization and specialization of the function of insect control. In essence, the "boundary of the farm" was redefined such that the function of insect control came to be performed through increased reliance upon chemicals produced by others rather than upon cultural controls implemented by farmers themselves. At first farmers purchased active ingredients to be formulated and applied by themselves, but later these activities came to be performed by others and a whole industry in its own right. Whereas agricultural and crop protection activities used to be tightly embedded in other agricultural practices on the farm, they gradually came to be performed by different specialized actors.

New industries were born. Inorganic and organic chemical manufacturers produced active ingredients, while formulators and applicators increasingly took on the jobs of final formulation and subsequent spraying or dusting of crops. Specialization led to economies of scale, making insecticide products even more affordable. For example, calcium arsenate, which had but one producer in 1918 when only 50,000 lbs per year were being used[13] was being manufactured at a rate of 10,000,000 lbs annually by 20 producers in 1920[14], a rate which had quadrupled by 1935[15] and which ultimately peaked in 1942 when 84 million pounds were produced[16].

New complementary technologies appeared for application, and spraying equipment got more sophisticated. The first use of an airplane for spreading an insecticide occurred in 1921 and records indicate that, by 1927, at least one company had formed specifically to dust cotton[17]. With production worth more than $ 36 million of active ingredients[18]

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[13] Dunlap (1981, p 30)
[14] Dunlap (1981, p 30)
[15] Shepard (1951, p 23)
[16] Shepard (1951, p 23)
[17] Dunlap (1981, p 30)
[18] Manufacturing Chemists' Association *Chemical Facts & Figures* (1940, p 88)

which was formulated into applicable pesticides with a retail value of more than $70 million in 1937[19], the sector had grown to an appreciable size by WWII.

As the insecticide industry grew and firms therein began to recognize themselves as such, efforts were made to organize the sector. The industry association is currently called the American Crop Protection Association (ACPA), and it was formerly known as the National Agricultural Chemicals Association (NACA), with this most recent name change coming in the 1990's. The predecessor to NACA was created in 1924 and was called the Agricultural Insecticides and Fungicides Manufacturers' Association (AIFMA). Its stated purpose was "*to stabilize the industry through the development of wider markets for agricultural insecticides and fungicides, to conduct a campaign of public education in the benefits of proper use of these products, to develop more economical more efficient means of production, and to foster closer cooperation between producers and dealers.*" according to official NACA history[20]. This entity, ineffective due to a lack of resources, merged with the larger and stronger Manufacturing Chemists Association (CMA)[21] in 1932 to become the CMA's "Insecticide Committee", but hopes of a dedicated lobbying tool for insecticide manufacturers remained. In 1933, an organizational meeting was held which led to the creation of a new organization, in 1934, located in New York City, and called the Agricultural Insecticide and Fungicide Association (AIF). With many members from the CMA continuing their involvement, AIF was stronger and more attractive to potential members than AIFMA, and it increased its membership from 14 to 23 companies in its first year of operation[22].

By 1942, membership had reached 45 companies which represented 85% of the US production of insecticides and fungicides[23]. In 1949, the organization changed its name to the National Agricultural Chemicals Association and moved its offices to Washington,

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[19] Manufacturing Chemists' Association *Chemical Facts & Figures* (1940, p 60); See Hitchner (1952, p 452) as well for a similar estimate.
[20] Hayley (1983, p 10)
[21] This organization was renamed the Chemical Manufacturers' Association (CMA) in 1979. See Hayley (1983, p 11).
[22] Hayley (1983, p 12)
[23] Hayley (1983, p 17)

DC. This name change and physical relocation reflected both the growing importance of regulatory and government issues as well as the broadening spectrum of available crop protection products and activities, as membership was extended beyond manufacturers to formulators, remixers and suppliers of diluents, clays, and surfactants[24]. By 1950, NACA had 121 members who manufactured 85% of basic pesticide chemicals used in the United States. The industry as a whole was producing 1 billion pounds of active ingredients annually, valued at $146 million by this point in time[25].

4.4 Chemical controls and the organization of science and government

Along with this process of commercial development and the rise to dominance of chemical methods of insect control were parallel developments in the organization and priorities of those concerned with insects in both government and science. Indeed, it is very difficult to separate government and science when recounting the history of the rise of chemical insect controls in the United States, for *"America is pre-eminently the home of the science* [economic entomology]*"* and *"the history of the science is largely the history of the State and Government entomologists"*[26].

The year 1862 was an important one. In that year, President Abraham Lincoln signed the law establishing the Department of Agriculture (USDA), which would come to have jurisdiction over the majority of regulations concerning pesticides through most of this century, and he also approved the Morrill Land-Grant College Act[27]. This Act established State agricultural colleges and universities, in every state, which would come to work very closely with the State experimental stations and extension services. These latter were government units which *"helped the American farmer adapt scientific advances to his own circumstances"* through highly localized applied research and a steady flow of communications providing education to farmers as well as concrete

[24] Hayley (1983, p 24)
[25] Hayley (1983, p 24)
[26] Folsom (1914, p 332)
[27] USDA (1963)

recommendations for action[28]. Among the sciences, chemistry was viewed as vital to agricultural interests, as evidenced in this report by Isaac Newton, at that time the Commissioner of Agriculture:

> *"The field open for chemical science was never so great as the present time. Chemistry being indeed the life and soul of an intelligent, rational agriculture, the governments of Europe - Germany taking the lead - impressed with this unquestionable fact, have established experimental stations, consisting of an experimental garden and complete analytic laboratory. The chemist, provided with assistants, institutes on the spot such original experiments, and tests such theoretical problems in reference to agriculture as seem most prolific of benefit to the farming community and the world at large. ... Thus every one may gradually be prepared to receive and profit by the rich stores of science open to every intelligent farmer."*
>
> (Commissioner's Report, 1865, p 7)

A steady stream of funding supported these new institutions. The Hatch Experiment Station Act of 1887 provided Federal grants to States for agricultural experimentation, much of which involved the use of novel substances against particularly significant pests[29]. Official recommendations about insecticide use - which substance, in which quantities, at which time, against which pest for which crop - that flowed from these stations carried much weight with farmers.

At the USDA, the Division of Entomology was established in 1863 [30]. From 1878 until 1894 (except 1879-81), it was headed until his retirement by Charles V. Riley. From that point, until 1927, the division, which achieved full Bureau status in 1904, was led by Leland O. Howard[31]. By 1914, the Bureau of Entomology employed no fewer than 600 people[32]. The organizational structure of the new Bureau of Entomology reflected its practical orientation: work was organized around important insects to specific crops. The individuals leading and working in this government unit played central roles in the

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[28] USDA (1963)
[29] USDA (1963)
[30] USDA (1963)
[31] USDA (1963)
[32] Folsom (1914, p 336)

establishment of economic entomology as a profession and branch of science. Largely through their initiative, "economic entomology" came to have a defined public mission recognized by its practitioners and the public, with its own standards, training, and entry requirements[33].

> *"This chapter* ["Insects in Relation to Man"] *would be incomplete without some mention of the progress of economic entomology in this country, especially since America is pre-eminently the home of the science. The history of the science is largely the history of the State and Government entomologists ... "*
>
> (Folsom, 1914, p 332)

Through the USDA periodical *Insect Life*, it was suggested that a professional organization of *government* entomologists be formed. Howard, working with James Fletcher, a Dominion of Canada entomologist, hammered out the constitution of a new organization which limited its membership to those working in government or at agricultural research stations, a policy quickly dropped but which nevertheless ensured that the priorities of government entomologists dominated. An organization meeting was held at a convention of the American Association for the Advancement of Science, and from that the "Association of Official Economic Entomologists" was born, which by 1893 had become the "American Association of Economic Entomologists" (AAEE) to reflect the change towards a more open membership policy. It was headed initially by Howard's predecessor at the USDA Division of Entomology, Riley, and its proceedings were published at first in the USDA's *Insect Life* and then later in other official USDA bulletins. This continued until 1908, when the first issue of the *Journal of Economic Entomology* appeared. This scientific peer-reviewed journal continues to be one of the leading journals of applied entomology today.

This professionalization of economic entomology was accompanied by an increase in its size and greater specialization. Whereas the earlier entrants to the entomological profession had been interested in insects, nature and ecology, later generations of

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[33] This point, and those in the two paragraphs following it, are from material in: Folsom (1914, Chapter XIII); Whorton (1974, Part I); Dunlap (1981, Chapter 1)

economic entomologists trained at land-grant colleges became more like technicians in that they demonstrated a preoccupation with achieving direct and immediate results - dead insects - through chemical controls. Consider the poem in Figure 4.4.1, a *"paean to poison"*[34], which appeared in a 1906 volume of the periodical *Entomological News.*

Figure 4.4.1 - A Paean to Poison

Spray, O Spray
by E.G. Packard

Spray, farmers, spray with care,
Spray the apple, peach and pear;
Spray for scab, and spray for blight,
Spray, O spray, and do it right.

Spray the scale that's hiding there,
Give the insects all a share;
Let your fruit be smooth and bright,
Spray, O spray, and do it right.

Spray your grapes, spray them well,
Make first class what you've to sell,
The very best is none too good,
You can have it, if you would.

Spray your roses, for the slug,
Spray the fat potato bug;
Spray your cantaloupes, spray them thin,
You must fight if you would win.

Spray for blight, and spray for rot.
Take good care of what you've got;
Spray, farmers, spray with care,
Spray, O spray the buglets there.

(1) Packard, E.G., 1906, "Spray, O Spray", *Entomological News*, 17, 256

[34] Whorton (1974, p 91)

This even became cause for concern amongst certain leaders who feared that their discipline was becoming little more than applied chemistry, as noted in a retirement speech of the outgoing AAEE president in 1924:

> *"The use of insecticides has led to a side issue that has assumed enormous proportions. Many of the later entomologists even before thoroughly studying the life of the insect begin experimenting with insecticides for the control of the insect in question. It is not well for the entomologist to lose sight of the insect."*
>
> (Ruggles, 1924, "Pioneering in Entomology" speech; cited in Dunlap, 1981, p 36)

Back in government, the Division of Chemistry, established in 1862, also achieved full Bureau status, becoming the Bureau of Chemistry on July 1, 1901[35]. Research on insecticides was given greater recognition when an Insecticide and Fungicide laboratory was established by special order of the Secretary of Agriculture in 1908. It was data from this laboratory, along with that from the Bureau of Entomology, that was used in the approval of the Insecticide and Fungicide Act of 1910 (sometimes referred to as only the Insecticide Act)[36]. Later, this laboratory performed much of the analytical work on insecticide samples. The laboratory symbolized, in a very concrete way, the progressive commitment of the Bureau of Entomology and of economic entomologists in general to chemical controls. The visible, immediate results of economic poisons made them ideal for satisfying farmers with particular insect problems, an outcome necessary to justify continuation of their work and funding.

> *"By 1916, the metamorphosis of the Bureau of Entomology into a new scientific agency was virtually complete, and it was proving its worth so regularly that its position in government was not only secure but taken for granted."*
>
> (Dupree, 1957, p 159).

The Insecticide Act was an important piece of legislation designed to protect farmers, not from toxic substances, ironically, but from non-toxic ones. It prohibited the interstate shipment for sale of any adulterated or misbranded insecticide or fungicide (rodenticides

[35] USDA (1963)

were added only in 1947, and nematicides, plant regulators, defoliants, and desiccants in 1959), and it was enforced by the Insecticide and Fungicide Board, first appointed Dec. 22, 1910. The Act was aimed at stemming some of the fraud that had begun to take place as the number of insecticide manufacturers increased and incidents of farmers buying useless substances with little insect killing power proliferated. It acted as a post-market control; if fraud was revealed, products were removed from commerce. It was also intended to avoid a fragmented regulatory environment for economic poisons across the United States, coming just after individual states began regulating these substances themselves outside of any framework obliging or even encouraging harmony and uniformity: New York (1898); Oregon and Texas (1899); California, Louisiana, and Washington (1901)[37]. Given its thrust and intent, the law was put under the administration of the USDA.

In 1912, the Plant Quarantine Act was passed, a piece of federal legislation, promoted by Howard, that regulated the importation of foreign plant materials. The Act created the Federal Horticultural Board and was designed to supplement a collection of varying state laws[38]. Ultimately, the administration of these quarantine regulations was combined with other Bureau of Entomology activities in 1934, and the new agency became known as the Bureau of Entomology and Plant Quarantine (BEPQ)[39].

Economic entomologists saw their work as vital and sensed the growing dependence (though they did not use this term) of farmers on chemical controls.

> *"To mitigate the tremendous damage done by insects,* ***the individual cultivator is almost helpless without expert advice,*** *and the immense agricultural interests of this country have necessitated the development of the economic entomologists, the value of whose services is universally appreciated by the intelligent."*
>
> (Folsom, 1914, p 329)

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[36] USDA (1963)
[37] Pesticide Handbook - Entoma (1972, p 71)
[38] USDA (1963)

A very tight system of cooperation between industry, science and government had emerged to serve these *"almost helpless"* farmers.

4.5 Chemical controls and a new problem: residues

Chemical controls came along with their own new problem: residues[40]. The application of chemical substances to plants in order to protect them meant that there was the possibility that traces of the toxin would remain upon food that reached consumers or upon feed that reached livestock. The safety of each had to be assured.

As arsenicals became increasingly popular, government entomologists reassured farmers and the public that they were safe[41]. Lead arsenate, the leading insecticide and intensively applied especially by apple growers, was of particular concern: *both* lead and arsenic are poisons. The insecticides quickly weathered off, entomologists argued, and the minuteness of any amounts of poison that might remain on fruit and vegetables was stressed. Comparisons were drawn between the "amount of residue" and the "amount necessary to produce illness or death"[42], thus placing the criteria of acute toxicity front and centre in discussions of the residue problem.

In 1906, Congress passed the Food and Drugs Act and placed responsibility for this new legislation within that Department that concerned itself most with food: the USDA. It was also where one of the biggest champions of the bill, Harvey Wiley, worked; he was chief of the Bureau of Chemistry[43]. This meant that the USDA, with responsibilities towards both agricultural production and now public health would eventually find itself in a situation of conflict of interest, and public policy towards pesticide residues was developed within this context of conflicting priorities. Charged with keeping food "unadulterated", the Bureau of Chemistry established informal tolerance levels for

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[39] USDA (1963)
[40] This discussion has benefited greatly from the following works: Whorton (1971); Whorton (1974)
[41] Whorton (1971)
[42] Dunlap (1981, p 41)

insecticidal compounds it felt were dangerous. Following the lead of a British Royal Commission, with Britain being an export market for U.S. apples, these maximum levels of residue were set at levels *"liable to be dangerous"* and which were also *"capable of exclusion, with relative ease, by the careful manufacturer"*[44]. In other words, tolerable levels of insecticide residues were determined not by considerations of what was *safe* only, but also by what was *achievable.*

> *"Heretofore, the Secretary of Agriculture, in recognition of the needs of the fruit industry and appreciating that a drastic enforcement of the 0.01 grain tolerance* [1 grain/pound = 143 ppm] *would result in disaster to the industry, has assumed the risk of stultifying himself before the consuming public by observing an informal tolerance considerably more liberal than is justified by the physiological facts."*
> (W.G. Campbell of the Bureau of Chemistry, in speech given in 1927; cited in Whorton, 1971, p 236)

In addition, technically, these levels had no legal standing; they were administrative guidelines to food inspectors to direct them to seize food with residues that exceeded them. This meant that, in the case of a seizure challenged by growers, the Bureau would be forced to demonstrate the wisdom of these levels to a jury of laypeople. Given the state of toxicological knowledge at the time - to this day, it is a field of much contestation and few certainties - it was repeatedly frustrated in its efforts to convince such juries that so minute quantities of substances could be so harmful[45].

This system continued until 1925 when, after a British chemist traced incidents of poisoning to arsenic-sprayed apples imported from the United States, the Bureau of Chemistry was forced to act. It implemented a certification program whereby it checked shipments of apples bound for England and initiated washing of the apples if residues exceeded the informal tolerance level they had set[46]. But this situation was unsustainable politically: a maximum acceptable level for exported produce but none for domestically consumed food. In 1927, a conference of toxicological and physiological chemists was

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[43] USDA (1963; see also Whorton (1974, p 99)
[44] Whorton (1974, p 111)
[45] Whorton (1974, p 111)

called with Dr. Reid Hunt of Harvard University serving as chairman (it was called the Hunt Committee)[47]. Concerned also about chronic as well as acute poisoning problems, in part because the chronic toxicity of lead was receiving scientific attention at that time, the committee recommended that more research be undertaken and recommended specific tolerances for both lead and arsenic. The long term effects of these substances concerned the toxicologists who wrote urgently in their report:

> *"The conferees consider it to be a matter of fundamental economic as well as social and health importance to the food industry, ...* ***that researches be pushed vigourously*** *through the resources of the Government* ***in order to discover a substitute for lead arsenate*** *as an insecticide and fungicide for fruits and vegetables."*
>
> (Hunt Commission report, 1927; cited in Whorton, 1974, p 212)

Their suggestions were too ambitious for the USDA which preferred instead to set a tolerance for arsenic higher than the suggested one, and none at all for lead. Not until 1933 was the recommended tolerance for lead implemented and enforced[48]. The USDA was once again focusing on what was *achievable*. Testing for lead residues was slow and difficult at the time so it might have held up shipments and, in general, they wanted tolerances that industry could achieve without radically changing its washing and handling practices and hence its economics. They consistently pointed to the absence of cases of acute poisoning that could be scientifically traced to residues on fruit or vegetables. Nevertheless, the arsenic tolerance was lowered bit by bit over a five year period, and it did eventually reach that used in the UK, which was known as the "world tolerance". Throughout this period, public awareness of the tolerance issue was minimal; the USDA knew that any controversy might hurt the interests of fruit and vegetable farmers, and the discussions were occurring in little-read scientific journals, medical reports and government documents.

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[46] Whorton (1971)
[47] Whorton (1974, p 155)
[48] Whorton (1971)

The arsenic and lead tolerances set by the Bureau of Chemistry, which had become the new Food, Drug and Insecticide Administration in 1927[49], were consistently fought by industry and it was not until the American Medical Association took a position that pesticide residues might become a serious health hazard in 1935, reiterated in 1937, that the situation began to change. The publication of the book *100,000,000 Guinea Pigs* by Arthur Kallett and F.J. Schlink in 1933 (it was ultimately reprinted more than 30 times subsequently) was also influential. Sensationalistic, it has been described as the *Uncle Tom's Cabin* of the consumer movement, detailing as it did allegedly harmful foods, drugs and cosmetic products and calling, specifically, for consumers to *organize* themselves[50]. But only in 1938, with the passage of amendments to the Food and Drug Act, did the new Food and Drug Administration finally get the right to set once and for all maximum tolerance levels for residues, but only after a long series of public hearings. In the process of developing this amendment, growers successfully negotiated the right to appeal the FDA's tolerances to U.S. circuit courts[51].

But in order to set defendable tolerances, the FDA would need evidence of hazards or threats to safety, the gathering of which would not be easy, at least if those who viewed themselves as protectors of farmers' interests, like Congressman Clarence Cannon of Missouri, could help it. After becoming chairman of the agricultural appropriations subcommittee in 1937, he ensured that the next appropriations act contained a clause stating *"that no part of the funds appropriated by this act shall be used for laboratory investigations to determine the possible harmful effects on human beings of spray insecticides on fruits and vegetables."*[52]. Thus it fell to yet another agency, the Public Health Service, to produce data needed to understand the risks of pesticide residues. At the time, this agency was working with a criteria of safety developed around notions of acute, and not chronic, toxicity and had undertaken studies among populations exposed to

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[49] USDA (1963)
[50] Whorton (1974, p 190)
[51] Dunlap (1981, p 51)
[52] U.S. Statutes at Large, v 50, p 396; cited in Whorton (1974, p 230)

pesticides looking for classic symptoms of lead and arsenic poisoning, which it found, unsurprisingly, to be rare[53].

The USDA's conflict of interest (protecting the public by policing residues, yet promoting agricultural and farmers' interests) was remedied finally in July of 1940, when the FDA was transferred to the Federal Security Administration, the predecessor of the Department of Health, Education and Welfare (HEW)[54].

4.6 The search for new chemical controls: from inorganic to synthetic organic chemicals

Table 4.6.1 - Early Chemical Insect Controls shows the history of introduction of various chemical controls in the United States prior to WWII. It clearly demonstrates the shift over time away from botanicals and inorganics, towards synthetic organic molecules.

[53] Dunlap (1981, p 54)
[54] USDA (1963)

Table 4.6.1 - Early Chemical Insect Controls

Period		Botanicals	Inorganics	Organics
< 1855		nicotine (1773)		
1856	1860	pyrethrum (1858)		
1861	1865			
1866	1870		Paris Green (1867)	
1871	1875			
1876	1880		London purple (1878) lime-sulphur (1880)	hydrogen cyanide (1877)
1881	1885		Bordeaux mixture (1883)	napthalene (1882)
1886	1890			
1891	1895		lead arsenate (1892)	DNOC (1892)
1896	1900			
1901	1905			
1906	1910		calcium arsenate (1907)	
1911	1915		zinc arsenite (1912)	p-dichlorobenzene (1912)
1916	1920			
1921	1925	rotenone/Derris (1924)	selenium compounds (1925)	
1926	1930		cryolite (1929)	ethylene dichloride (1927) ethylene oxide (1927) alkyl phthalates (1929) n-butyl carbitol thiocyanate (1929)
1931	1935			methyl bromide (1932)
1936	1940			pentachlorophenol (1936)
1941	1945			DDT (1939) HCH (1942) DDD (1944) methoxychlor (1944) chlordane (1945) lindane (1945)

• adapted from Ware, 1994, Table 1-9, and Thomson (1994)

Note that although in 1945, the time of DDT's entry into the civilian economy, the most widely produced and used insecticides were still the inorganic arsenicals, industry's research efforts, on the other hand, had been directed at organic molecules for some time. The shift towards organic chemistry as the hunting ground for insecticidal molecules meant that very well-funded, very well-organized, and systematic R&D efforts of industrial chemists became focused on the "insect problem", and the possibility of finding solutions to it that avoided the "residue problem". These research efforts were, for the most part, orchestrated inside large chemical firms where competencies and expertise in organic chemistry resided like Geigy and DuPont for example. Here, the application of these competencies resulted in the creation of an incredible number (tens of thousands) of new synthetic molecules that firms hoped would be useful and patentable for *something*:

> *"Industry had many compounds of unknown biological activity but lacked methods to recognize which ones were of interest. Screens were developed for several easily reared pest species to find insecticidal compounds, and the biological test methods were standardized for precise determination of structural changes on activity, which allowed optimization of potency and useful properties. The system of synthesis and screening became well established and opened a new era or rapid advances that led to the current balance of insecticides."*
>
> (Casida & Quistad, 1998, p 3)

Active search for inorganic compounds with insect killing power did take place, but the serious and systematic insecticide R&D push came from those with an interest in organic molecules. There were a number of reasons for this. First, the chemistry of the carbon atom is unique, with almost endless opportunities for the synthesis and preparation of new molecules with potential commercial value and eligible for patent protection. Second, the feedstocks (i.e. raw materials) for preparing organic molecules, at first coal then later petroleum, were readily available in industrial quantities, facilitating quick scale-up in the production of molecules found to have commercial significance. Third, it was within the particular industrial, scientific and regulatory contexts described above that research and development of new insecticides took place: desirable insecticide *performance* was understood to refer to **insect killing power** at a **low cost**, while the undesirable insecticide *problems* that preoccupied researchers were those of **residues** and their potential **acute toxicity to humans**. On this latter point, it was felt that "*The prospects of finding insecticides of low toxicity to man are much better in the organic than in the inorganic field*" as stated a USDA chemist in 1935[55].

[55] Roark (1935), cited in Perkins (1978)

That the problem of acute toxicity to humans oriented research and development efforts is confirmed in the preface to the third edition of an introductory text on *Applied Entomology*:

> *"The last ten years have seen great advances in our knowledge of insects and how to control them. ...and the problems of spray residues has led to a search for new chemicals to use against them [pests]. ...* ***Organic chemistry has been explored*** *to quite an extent* ***in the hope of finding insecticides not dangerous to man*** *and the discovery of many poisonous gases has been made a basis for their use against insects. Altogether over 50 new materials have been tested as insecticides and a number of promising ones have been found ..."*
>
> (Fernald, 1935, p vii)

Ultimately, this intensification of R&D efforts focusing on organic chemistry heralded the dawn of a new era, with the discovery of the insecticidal properties of DDT.

5 The Rise of DDT: Substitution as a Consequence of Tool-Making

5.1 Introduction

In this Chapter, I describe the rise of DDT, from its first synthesis in Europe, to its entry into the United States economy and its enthusiastic adoption by farmers and other insecticide users, to its dominant position as the most widely applied insecticide in the United States, an honour it maintained until the 1960s. The processes of substitution in which DDT was involved during this phase of its life are described and analyzed. In various markets, DDT substituted for such controls as calcium arsenate, lead arsenate, biological and cultural insect controls because of its demonstrated superior performance/price ratio. Simply put, DDT better solved users' insect control "problems". It killed *more numbers* of a *wider spectrum* of insect species *for a longer time*, was *less poisonous* to humans than arsenic, and was *much less costly* to boot.

I argue that these instances of substitution are relatively pure examples of the phenomena which I term *substitution as a consequence of "tool-making"* (or, equivalently "artifact-making"), a process whose dynamic is dominated by activities in the commercial or industrial arena of society. Substitution as a result of this mechanism is relatively well-understood in the business strategy and economics literature, as compared to the other types of substitution described in this document. The story recounted here, although it is intriguing and has its own twists and turns, can be distilled to one which is very familiar: commercial markets in which particular incumbent products (i.e. the arsenicals) are dominant in terms of market share are contested by new competing products (i.e. DDT) from firms who had previously undertaken R&D specifically to discover or bring them into the world and to these markets. Actors (i.e. firms) attempt to understand and to satisfy demand for products and technologies with particular functionalities (i.e. which deliver certain outcomes or levels of performance) at the lowest price possible. In the artifact-making arena, actors (agrichemical firms in the case of DDT) search for, develop or "make" products and technologies with potential for becoming adopted, then they bring these to organized structures of exchange (i.e. to "markets") where they demonstrate their superiority in terms of performance/price ratio. The fate and status of firms is closely linked to that of the products they propose and promote. In this process, new artifacts *substitute* for older incumbent ones. The monopoly or quasi-monopoly of incumbent tools is challenged and contested, essentially, with appeals to and demonstrations of the challenger tools' "**Efficiency**".

In other words, this Chapter describes instances where products, insecticidal molecules in this case, were outcompeted through what many would call "normal" marketplace competition, subsequent to the appearance of new alternative products (i.e. DDT). Both customers (i.e. farmers) and gatekeeping regulators (i.e. USDA, FDA) of these insecticidal products - although each had their own distinct view of what constituted acceptable and superior performance - were satisfied with the new substances. DDT, the new challenger product, reached and surpassed the performance level of incumbent products when evaluated by the "evaluation constituencies" who used the decision rules and criteria in place at the time.

Stated in terms of the conceptual language we are advocating, the dominance of incumbent "tools" was overturned subsequent to the appearance of a challenger tool, through the application of existing decision "rules" and without falsifying any "facts" as they stood at the time. New facts about the safety and efficacy of DDT did get made, and were certainly important in insecticide users' decisions, but these did not falsify users' beliefs about incumbent products. They were complements to rather than substitutes for the existing set of facts. Contestation continued until the use of DDT was so commonplace and widespread, one could say that it had become *institutionalized*; DDT and other organochlorines became the "dominant design" for chemical insect control technology.

5.2 DDT - A New Insect Control Tool from Problem-Solving Search

DDT, whose basic properties are described in Chapter 3, was first synthesized in 1874 by Othman Zeidler, an Austrian chemist pursuing doctoral studies who was not trying to invent an insecticide but who was merely following his interest in the chemistry of aromatic hydrocarbons[1]. It was Dr. Paul Muller, a chemist at Geigy (Switzerland) who was working on a major research project initiated in 1932 and specifically aimed at developing a new moth-proofing agent, who discovered the insecticidal properties of DDT in 1939[2].

It had been noticed that a Geigy dye molecule (Eriochrome Cyanine R) had structural similarities to IG Farbenindustrie's new moth-proofing agent known as *Eulan New*, and hence might be a promising starting point for new molecules toxic to insects[3]. Both these molecules have structural similarities to DDT, and eventually, among many other similar molecules, DDT was tested for its insecticidal properties.

This is a common way in which new useful chemical products are invented or discovered. Different chemical "structures" (configurations of atoms on a molecule known as "groups") participate in particular chemical reactions with relatively specific structures on other molecules. These structures are referred to as "functional groups" as it is as if particular configurations of atoms have "functions". The "functionality" of these groups means that they also tend to correlate with various chemical properties as well, such as solubility in water, solubility in oil, etc. If researchers are searching for a molecule with particular properties (for example, researchers may be concerned with "water solubility", if it is foreseen that water will be the delivery mechanism for getting the insecticide from user to insect) and which will participate in particular chemical reactions (for example, researchers may be attempting to find a molecule that will

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[1] This discussion has benefited greatly from the following works: West & Campbell (1950); Brooks (1974, vol I); Perkins (1978); Dunlap (1981); Mellanby (1992).
[2] West & Campbell (1950, p 2)
[3] West & Campbell (1950, p 12)

interfere with or inhibit a specific biochemical reaction in insects' nervous systems), then, if they feel they have a good understanding of the relevant chemical structure-function relationships, they can limit their search to molecules with a particular structure. This approach, highly sophisticated nowadays, is known as "rational design". The other way to find new useful chemical products is one of brute force and numbers wherein a large number, often thousands, of substances of known chemical structure and composition but unknown function are tested or screened against important evaluation criteria. A sophisticated derivative of this technique is known today as "combinatorial chemistry". In the past it was common that any new molecules synthesized in a chemical company would be, as part of company policy, routed to the appropriate laboratory to be tested for insect toxicity.

In the particular Geigy project leading to DDT, the desired qualities researchers sought in a molecule were: stability in light, good larvicidal activity as a stomach poison, and water solubility. They tested over 6,000 chemicals, including DDT, and finally settled on Mitin FF. Having poor water solubility, DDT was disqualified as a moth-proofing agent being sought, but researchers were also aware of the need for a lipophilic (i.e. soluble in oils and fats) contact poison for agricultural use[4].

The wide range of DDT's insecticidal properties was quickly established and a Swiss patent application was made early in 1940[5]. Muller prepared various formulations - solutions, emulsions and dust - at 5 and 10% active ingredient, and completed successful agricultural tests against a series of injurious species of insects: the raspberry beetle, apple blossom weevil, apple sawfly, cabbage moth, cabbage flea beetle, carrot fly, and the Colorado potato beetle. In terms of public health, DDT was tested against houseflies, cockroaches and mosquitoes. Other researchers soon tested it against body lice and fleas, and quickly established the link between DDT and the control of diseases like typhus.

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[4] Brooks (1974, p 7)
[5] West & Campbell (1950, p 1)

Geigy, in collaboration with the Red Cross, field tested DDT in the Balkans in 1942, and DDT was adopted by the Swiss army beginning in 1943[6]. In parallel to this testing of insecticidal activity, study of the Gesarol and Neocid mixtures at the pharmacological laboratories of Basle yielded no evidence of hazard to man or other warm-blooded species[7]. DDT did undergo significant toxicological testing during its development, although not all of this testing occurred prior to its first incorporation into various insect control activities[8]. It is important to note that the notion of product safety that oriented and guided this testing was one associated with low acute oral and dermal toxicity to mammals. DDT could be handled by farmworkers - mixed, applied and generally splashed about - safely. Even eating it in small quantities did not bring on serious effects, and this stunt was known to be used by economic entomologists in their classrooms, and then later by DDT proponents attempting to demonstrate its safety. Experience with the highly poisonous arsenicals in agriculture had focused attention on this particular interpretation and operationalization of insecticide safety.

DDT's physical and chemical properties were such that it quickly became incorporated into a number of products available in Switzerland aimed at different insect control problems. J.R Geigy introduced the first DDT formulations in 1942 under the trade marks Gesarol® and Gesapon® (ultimately used in the United States and continental Europe), or Guesarol® and Guesapon® (used in England), for use in agriculture, but DDT-containing substances M-1850 and M-1859 were marketed as early as 1941. Neocid® was made available for public hygiene (i.e. for body lice), and in 1943 Trix® powders, sprays and emulsions could be acquired to protect fabrics from insect attack. Gesafid® was developed for control of insects harmful to ornamental plants, and a liquid emulsion, Geigy-33, was produced to treat the walls of warehouses, sheds and silos used to store grains. As a wood preservative, DDT was incorporated into Bosan® to kill insects, a product that also contained a fungicidal active ingredient to counter dry rot[9].

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[6] Mooser (1944), cited in West & Campbell (1950, p 3)
[7] Brooks (1974, p 11)
[8] See Chapter IV in West & Campbell (1950) entitled *Toxic Manifestations*.

It was 1941 when the American subsidiary of Geigy learned of DDT and its successful use against an outbreak of Colorado beetle in Switzerland. But this information was less significant to them than one might expect, apparently because lead arsenate was being successfully used in the US against that pest[10]. Meanwhile, the American military obtained samples of Neocid and the USDA isolated its active ingredient, DDT, at its laboratories in Beltsville, Maryland and Orlando, Florida[11]. Under different and more urgent pressures, the military and the USDA quickly came to realize the potential importance of this new substance. Its effectiveness as a lice powder and its safety were quickly established.

> *"Our chief worry was 'can the chemical be used safely on man?' the Food and Drug Administration was attempting to determine the answer to this question. After several months of intensive study, they concluded that in dust form **DDT was entirely safe to use**. By May, 1943, DDT was recommended to the armed services as a **safe** and **effective** louse powder."*
>
> (Knipling, 1948).

By the end of 1944, extensive testing of DDT against a long list of injurious insect species had been completed, uses established, and DDT products formulated by American researchers, including oil sprays for the control of flies, mosquitoes and bedbugs; a DDT larvicide spray for mosquitoes; DDT-impregnated clothing; and DDT aerosols for mosquito control in industrial plants[12].

Across the ocean, DDT was brought to the attention of the British subsidiary of Geigy at a time almost perfectly designed to ensure that it caught their attention: substitutes for natural pyrethrum and derris, the supply channels of which had been upset by the war, were needed to control the vectors of malaria and typhus. I present here a few details from the situation in the UK, a WWII ally of the United States at this time, because *"There was the closest cooperation throughout between the British and American*

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[9] See Brooks (1974) for an excellent history of organochlorine molecules and their early trade names.
[10] Brooks (1974, p 11)
[11] Perkins (1978)
[12] Perkins (1978)

scientists, and development went forward rapidly along parallel lines."[13]. In Britain, an Insecticide Panel of Experts led by Sir Ian Heilbron had even been established after Japan's entry in the war had cut off supplies of these from the British and Dutch East Indies just as Britain and other Allied countries were deploying troops in areas where disease-carrying insects were common[14]. Early in 1943, the efficacy of DDT against lice was confirmed and its manufacture became *"a national priority of the highest order"* says a British entomologist who was involved with DDT during that period[15]:

> *"Plans were made to ensure the most effective use of the existing insecticides to protect our troops, and though things would probably have been better than during the 1914 - 1918 war, the situation was far from satisfactory. Then DDT arrived on the scene. We on the Entomology Committee obtained the first information. We were sworn to secrecy and this secrecy was maintained almost until the end of the war. ... **The whole force of the Ministry of Production was mobilized to expedite the manufacture of the new insecticide**"*
>
> (Mellanby, 1992, p 18).

The need to overcome technical challenges related to production and formulation as well as toxicological testing resulted in the widespread and *"unprecedented"*[16] involvement of scientists and technologists.

5.3 The Military's *"Magic"* Insect Killer

DDT was first used on a large scale by Allied forces to arrest a typhus epidemic in Naples, Italy, in December of 1943 and into 1944[17]. It was here that it earned its reputation as a *"miracle"*[18] insecticide. By the end of the epidemic, some 3,000,000 individuals, both local citizens and Allied troops, had been dusted one by one. A squirt

[13] Wigglesworth (1945), writing in the *Atlantic Monthly*.
[14] Mellanby (1992, p 19)
[15] Mellanby (1992, p 18)
[16] Brooks (1974, p 11)
[17] British Government press release, 1944 08 02, reprinted in West & Campbell (1950, p 7)
[18] United Kingdom Medical Services' official History of the Second World War, cited in Mellanby (1992, p 23) addresses the reputation of DDT as a *"wonder drug"* and the *"almost miraculous powers"* ascribed to it.

gun forced DDT powder, most of it coming from the United States, into subjects' sleeves, waistband, collar pants' cuff, hair and hat. Note that this technique substituted for a complicated system of baking people's clothes, shaving them all over and applying an ovicide[19]. At peak operation, 72,000 people were dusted on one day[20]. Later it became standard for many Allied troops to wear DDT-impregnated shirts

In addition, the first prophylactic use of DDT also occurred during WWII, in 1944 in Dakar, West Africa where a successful campaign against fleas, vectors for the bubonic plague, took place. Concerned about malaria in certain theatres of war, like at Guadalcanal and other Pacific islands, Allied troops also began the practice of spraying regions with DDT *before* they landed.[21]

As military experience with DDT accumulated, news of this "*miracle*", "*magic*", and "*wonder*" product began to leak out. These unofficial reports were eventually confirmed by official government statements which read like glowing product endorsements, reassuring the public that industry, science and government were coordinating their activities to ensure *"a steady flow of this life-saving compound."* Besides public health, the potential of DDT in agricultural and household uses was also explicitly addressed, as evidenced by these extracts of a press release issued on August 2, 1944 by the British Government which came with the title *"Synthetic Insecticide which stopped a Typhus Epidemic"*, portions of which are contained (with my emphasis) in Figure 5.3.1:

[19] Dunlap (1981, p 62)
[20] British Government press release, 1944 08 02, reprinted in West & Campbell (1950, p 7)
[21] Mellanby (1992, p 22)

Figure 5.3.1 - "A Synthetic Insecticide which Stopped a Typhus Epidemic"

"The full story can now be told of what has been described as one of the greatest scientific discoveries of the last decade, a synthetic multi-purpose insecticide which has already stopped a typhus epidemic, threatens the existence of the malaria-carrying mosquito and household insect pests, and is capable of controlling many of the insects which now do untold damage to food crops.

"It is 'p : p'-dichloro-diphenyl-1, 1, 1,-trichloroethane'--DDT for short. DDT is lethal to the body louse which transmits typhus fever to man and is capable of killing mosquitoes, thus helping to control the spread of malaria. Dysentery, enteric, and cholera will be capable of better control than heretofore, as DDT is deadly towards the various species of flies, whilst it has already been used successfully to destroy bugs, fleas, cockroaches, beetles, cabbage worms, apple-codling moths, and aphids. Its efficacy is almost unique, as on insects it acts both as a contact and as a stomach poison, although it is non-toxic to man and other warm-blooded animals in the concentration normally used. It also has the remarkable property of being effective for many weeks after application. For instance, when sprayed on walls, it kills any fly alighting thereon, in some cases for as long as three months afterwards; a bed sprayed with DDT is deadly to bed-bugs for 3 to 6 months; clothing impregnated with it is safe from lice for a month, even after several launderings; whilst a swamp properly treated may be freed from breeding mosquitoes for a considerable period. ....

"Before an insecticide can be used on a large scale, however, particularly as a hygiene measure, a great deal has to be known not only about its power to kill insects and its methods of application and the strength in which it should be applied, but even more important, the degree of risk to health which may attend its use. The early laboratory tests carried out in England by groups of chemists, entomologists, and other scientists concentrated the work of several years into a slightly higher number of weeks, and the faith of these research workers was justified, as DDT was soon shown to be a unique compound, with properties superiors to those of any insecticide yet made. It thus had obviously immense military possibilities. Pilot-scale production was immediately commenced and in collaboration with the British Geigy Colour Company, plans for larger scale production were entered into. Its full potentialities and methods of application were simultaneously worked out by teams of Government, university, and industrial scientists, in collaboration with experts from the three Services. Close liaison was established with American and Dominion scientists, who were already working on similar lines, and now many hundreds of workers are collaborating in developing all aspects of its use and application. ...

"In the United Kingdom and the U.S.A., big manufacturing projects are in train and a steady flow of this life-saving compound is now ensured. In the United Kingdom all production is under the direct control of the Ministry of Supply, which has already set up a number of factories for the purpose and which has greatly simplified the task of production by pooling the ideas and experience of all the separate manufacturers. All the output is at present reserved for Service uses."

• The press release from which the above extracts are taken is reproduced in full in West & Campbell (1951, p 7)

Not long thereafter, British Prime Minister Winston Churchill also trumpeted the virtues of *"the excellent DDT powder"* against *"insects of all kinds, from lice to mosquitoes and back again"*, stating that it had *"been fully experimented with and found to yield astonishing results"*[22].

This official enthusiasm mirrored the enthusiasm of those scientists working with DDT. They had already begun to envision and discuss the vast potential of DDT against agricultural pests, as recalled by one of the first entomologists to be involved with DDT:

"DDT appeared to be ***the ideal insecticide****, very toxic to most pest insects and relatively harmless to man. It retained its toxicity for a considerable period, so repeated applications were not required. It could be made in the factory in unlimited quantities, and it was cheap to produce."*

(Mellanby, 1992, p 1)

"The reaction of those concerned with the new insecticide was one of euphoria. We seemed to have ***the perfect weapon against harmful insects****, and one which was* ***harmless to man and his livestock****. It was so potent that entomologists thought that they would soon be out of a job. It certainly revolutionized the whole field of insect control, and made many people think that most pests would soon be permanently wiped out. It made the idea of actually totally eliminating dangerous pests, like some of the mosquitoes which carried malaria, and the Colorado potato beetle, from whole continents seem practicable. We thought that the whole literature of agricultural and medical entomology would have to be rewritten. I myself scrapped, before publication, the text of a book on economic entomology on which I had been working for several years, as it seemed to be largely out of date because of the use of DDT."*

(Mellanby, 1992, p 37)

U.S. government officials and economic entomologists, many of them working in government or tightly affiliated with it through the land-grant universities' experimental agriculture stations were equally enthusiastic. In December of 1944, a Special Committee on DDT of the American Association of Economic Entomologists, which was chaired by Sievert A. Rohwer of the BEPQ in the USDA, issued a statement on the promise of DDT in agriculture and household use as well as public health, from a meeting of the Entomological Society of America and the American Association of Economic Entomology in New York. It began, as most discussions of DDT by economic entomologists did at that time, by underlining the historic nature of this insect control technology:

"We feel that ***never in the history of entomology has a chemical been discovered that offers such promise to mankind for relief from his insect problems as DDT.*** *There are limitation and qualifications, however.*

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[22] From a radio broadcast of 1944 09 28, transcribed in West & Campbell (1950, p 11).

Subject to these, ***this promise covers three chief fields: public health, household comfort and agriculture.*** *As public health we include control of the insects which carry diseases which have scourged humanity, such as malaria, typhus and yellow fever. Household comfort is taken to cover such things as flies, fleas, bedbugs and mosquitoes. Agriculture includes not only farms, gardens and orchards, but forests, livestock and poultry."*

(Report of the Special Committee on DDT, with S.A. Rohwer as Chairman, in *Journal of Economic Entomology*, 1945, v38, p 144)

Belief in the superiority of DDT over incumbent insecticides was spreading quickly in science and government. Propelled by endorsements from authorities, this belief was also spreading amongst the general public. DDT's superiority was established by pointing to its insecticidal efficacy, its safety - interpreted in terms of acute toxicity - and its low cost, with this latter attribute due in part to the long residual killing effect that users could achieve because of the molecule's incredible persistence and chemical stability.

So even before it became available for civilian use, talk of DDT, most of it positive, was everywhere. Between May, 1944 and October 1945, one news clipping service compiled a list of 20,762 items on DDT which were *"mostly wildly enthusiastic"*[23]. *"The publicity given DDT might well be envied by any Hollywood movie star."*[24] recalled one food company official.

Without doubt, the coincidence of DDT's discovery with WWII certainly contributed to the enthusiasm and speed with which this new chemical was received. For not only were the short supplies of older botanical insecticides placing *substitution* front and centre in insecticide users' minds, but the war substantially increased overall *demand* in the public health market. Prior to WWII, it was a generally accepted truth that more people died in war due to diseases such as typhus rather than due to bullet wounds or bombs, and official wartime praise for DDT reiterated this. By summarizing the death tolls due to disease in previous wars, government officials suggested that DDT had saved literally millions of lives and explicitly raised the possibility that it could save millions more in

[23] Fortune (January 1946, p 149)

public health uses around the world[25]. Its performance in the extraordinary conditions of a world war helped DDT to achieve the status of a hero. Eventually, use of this molecule in the more mundane setting of rural America would become routine in the local but never-ending war against insects.

5.4 The *"Atomic Vermin Destroyer"* enters the Civilian Economy: Tension between Caution and Continued Enthusiasm

Initial production of DDT was allocated almost exclusively to military uses. Only limited supplies were sent to researchers at experiment stations. Initial agricultural experimental work was done during growing season of 1943, with results published in the February issue of the *Journal of Economic Entomology* in 1944[26].

During the period of 1943 - 1944, the USDA tested the effects of DDT on 170 different insect species, contrasting its efficacy with the incumbent chemical control agents in use against those pests in order to classify DDT as "more effective", "equally effective" and "without effect". The first of these categories easily contained the longest list of insect pests[27]. In the fall of 1944, the WPB informed the DDT Producers Industry Advisory Committee that DDT could not be recommended for use on crops because important questions remained to be resolved related to specific concentrations of DDT to be used and residue safety[28]. Despite their enthusiasm, scientists were still being cautious, devoting time and resources to gathering more information about DDT. In 1944, a memo to researchers at experimental stations came from BEPQ entitled *"Information on DDT and Suggestions for Experimental Work for Agricultural Purposes"*[29] that stressed this:

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[24] Britten (1950), cited in Dunlap (1981, p 61)
[25] British Government press release, 1944 08 02, reprinted in West & Campbell (1950, p 7)
[26] Perkins (1978)
[27] Brooks (1974, p 28)
[28] Perkins (1978)
[29] cited in Perkins (1978)

"When the lack of definite information on the agricultural use of DDT is considered, both as to its efficiency against insects under field conditions and as to its effect on plants and plant growths, it is evident that even if the material were available for use against crop insect pests it could not be recommended at this time."

The sorts of questions still unanswered, under investigation and subject to debate among economic entomologists were also described in the statement issued from the 1944 New York meeting of their professional associations, mentioned above:

"In agriculture, it [DDT] *is promising against a wide variety of destructive pests. These include most potato insects, many orchard and vineyard pests, numerous vegetable insects, as well as the chief insect enemies of vitally important seed crops. It appears to be effective against the pink bollworm and outstanding against the Japanese beetle, two of our worst imported pests. It promises also a more practical control of the pests which ravage thousands of square miles of forest, and against many of those which harass livestock.*

"DDT will not kill all the important insect pests. ***It will kill many beneficial insects which are allies of mankind*** *against the destructive species.* ***Because of its toxicity to a wide variety of insects, its large-scale use might create problems which do not now exist.*** *To illustrate, it is a superior insecticide for control of codling moth on apples, but in some sections at least* ***will kill certain natural enemies and thus release other insects which may then become major problems.***

"The research reports emphasize that we have not had time to develop entirely satisfactory mixtures and dosages of DDT insecticides, nor the methods and timing of application for may possible uses. Modern agricultural pest control often requires mixing several materials in combination treatments, and we know little of DDT's compatibility with many of these others. Researches thus far were made with a material which was produced under pressure for military needs, and which is not necessarily the best form for agriculture.

*"****We do not know enough about effects on plants, animals and soils.*** *While most plants were not harmed by DDT insecticides in the experiment, injury to squash, corn, tomatoes, and possibly fruit trees was reported. DDT is toxic to animal life when large amounts are taken internally or absorbed through the skin from oil solutions, but reports indicated a reasonable margin of safety. In the light of our present knowledge, heavy deposits on edible parts or plants should be avoided.* ***Reports show***

definite toxicity to cold-blooded animal life including fish and frogs. *There has not been time to learn the possible cumulative effects on soils.*

*"**More and larger-scale experimentation is needed.** Enough DDT for such research in 1945 should be provided."*

So in addition to identifying the superiority of DDT over incumbent products along what were at the time primary dimensions of efficacy (i.e. toxicity to insect species) and safety (acute oral and dermal toxicity to humans), scientists were also identifying and debating potential problems of DDT as well.

What is interesting about the communications of scientists during this period of intense research is that, although questions were in short time answered, issues closed and concerns allayed, many of these *exact* same questions, issues and concerns would come to reappear and be reopened years later. Beliefs about efficacy and safety would be successfully re-challenged and re-contested, issues re-opened and questions pushed back onto the research agendas as "problems" of DDT appeared, were identified and labeled as such. These were frequently propelled by dissident researchers who had never bought into what had become orthodoxy for the majority in their field, like those economic entomologists who favoured biological over chemical controls. For instance, consider DDT's efficacy as an insecticide. The 1944 statement above points to DDT's wide spectrum of activity and how DDT can *"kill certain natural enemies and thus release other insects which may then become major problems."*. Concerns that the solution of one insect problem could create an even bigger insect problem, which stem from an ecosystemic and ecological view of insect control rather than a "magic bullet" perspective, were marginalized (along with the proponents of biological controls who promoted them) in the years immediately following DDT's enthusiastic acceptance into the economy. They reappeared however, were taken more seriously, and ultimately caused DDT to be substituted for in certain markets. This "secondary pests" problem which lowered the overall efficacy of DDT and caused it to be supplanted by alternatives is described in Chapter 7.

In February of 1945 came the announcement by the War Production Board (WPB) that DDT would be available in limited amounts to encourage commercial development of insecticides[30]. In other words, experimenters from industry could obtain it without authorization from WPB. The USDA continued to communicate its enthusiasm, but was not yet prepared to recommend DDT, as noted in the popular press:

> *"The U.S. Department of Agriculture, summing up two years of intensive, nationwide testing, last fortnight reported: **(1) DDT is unquestioningly the most promising insecticide ever developed; but (2) it is not yet safe for general use."***
>
> (*Time*, April 16, 1945, pp. 91 - 92)

Finally, in August of 1945 came the revoking of WPB's control over supplies of DDT which meant that the substance became available for commerce[31], although the regulations applicable to all economic poisons would still apply. Almost immediately, it entered the civilian economy where in little time formulations containing DDT, with names such as "*Atomic Vermin Destroyer*"[32], began to appear. DDT was embraced for a wide variety of agricultural and non-agricultural uses, including public health, where wartime success was followed up by ambitious disease eradication efforts around the globe. DDT quickly became ubiquitous in use. At least three complete books were published in 1946 devoted to this single molecule, two targeted at the general public.

The book of West & Campbell, *DDT: The Synthetic Insecticide*, was a scholarly effort published in 1946 with an expanded second edition, *DDT & Newer Persistent Insecticides*, appearing in 1950. In this second edition, besides inserting short chapters which presented benzene hexachloride (BHC, which is also called hexachlorocyclohexane or HCH[33]), chlordane, toxaphene and a few other substances, they also added more than 1400 additional academic citations for just the three years

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[30] Perkins (1978)
[31] Perkins (1978)
[32] Fortune (January 1946, p 149)
[33] Ware (1994, p 44)

1945 - 1948 to those they already had. The book was published in Britain, but drew extensively upon U.S. scientific literature and government documents.

A review of its contents gives one an idea of the multitude of uses for DDT that were being researched and quickly becoming reality. Consider that, after presenting the history of DDT's development, this 632 page book then featured complete chapters, meticulously referenced to the scientific literature, with titles as they appear in Table 5.4.1, which also lists specific products containing DDT.

Table 5.4.1 - DDT Use Becomes Ubiquitous

"DDT & Newer Persistent Insecticides" - Chapter Titles

(V) DDT in paints and miscellaneous materials
- paints, varnishes, wax polishes, linoleum, rubber

(VI) DDT in textiles and paper
- clothing, hats, bedding, oilcloth, food covers, furniture fabric, carpets, rugs, jute sacking for storage of flour and grains, finished paper, wallpaper, insect-proof paper bags containing food products

(VII) DDT against human lice
- impregnated underwear, powders and dusts for use against head lice, body lice and crab lice

(IX) DDT against mosquitoes
- dusts, oil mixtures, impregnated sawdust, sprays

(X) DDT against household pests
- dusts, sprays, aerosols for use against some 16 different insects, including houseflies, ants, carpet beetles, bedbugs

(XI) DDT against other pests affecting man and animals
- soaps, sprays, dusts, dips for use against some 37 different insects, mostly flies (black flies, horn flies, midge flies, deer flies, etc.), ticks, and lice (chicken lice, dog lice, goat lice, horse lice, cattle lice, etc.)

(XII) DDT against plant pests.
- dusts, sprays, emulsions, solutions
- ***This last chapter, addressing agricultural uses, was the longest and made reference to more than 150 different insect species.***

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* These are Chapter Titles from "DDT & Newer Persistent Insecticides" (West & Campbell, 1950).

The other two books, published in the United States and less scholarly, were aimed at the general public. Their titles are revealing of just how DDT was framed at that time by its promoters: *DDT & the Insect Problem*, and *DDT: Killer of Killers*. Insects were a "*problem*", if not the full-fledged "*killers*" they had been during the war, and DDT solved that problem.

The first, written by two journalists and a Chicago epidemiologist, was *"only the first installment of the story of DDT, but its publication at this time seems necessary because of the tremendous interest in the subject"* and was prepared *"with the needs of the user in mind"*[34]. In chapters such as *"Man's Health and Comfort"*, *"Agriculture"*, and *"Forest, Shade, and Fruit Trees"*, it reported on the research to date, explained which specific formulations could be used against which pests, and included helpful photos illustrating application techniques. The second, written by two Professors of chemical engineering, also explained which formulations should be used when, and it too included photos. Both works employ the discourse of war. For example, Zimmerman & Levine's first and fifth chapters were titled *"Man's Mortal Enemies"* and *"Common Insect Enemies"*. This sort of talk was characteristic of descriptions of Man-Insect relations by almost everyone concerned with insect control at that time (with the exception of the minority of economic entomologists who favoured biological controls). It permeated these books and other presentations of DDT aimed at the lay public:

> *"DDT is an insecticide. It kills "bugs" of all sorts. In fact it seems destined already to take a place as **the best weapon yet discovered in man's ages-long war with a hitherto unconquerable enemy,** the insects."*
> (Leary et al, 1946, p 1)

> *"The **struggle between man and insects** began long before the dawn of civilization, has continued without cessation to the present time and will continue, no doubt, as long as the human race endures."*
> (from an entomology textbook by Metcalf & Flint, 1932, cited in Leary et al, 1946, p 1)

> *" ... the development of DDT was the greatest contribution to the field of insecticides since that day in 1969 when man first began to use poisons in*

[34] Leary et al (1946, p vi)

*his fight against his eternal enemies - **the enemies that fly, that crawl, and that hop; and yet are so small that it is hard for us to believe that some day they may, if we weaken our guard, inherit the earth.**"*

(Zimmerman & Levine, 1946, p 146)

*"With such a product [DDT] to stimulate additional research, **mankind has new weapons** promising eventual **freedom** from disease-bearing insects such as lice, fleas, flies, mosquitoes, and ticks; from household pests such as moths, cockroaches and bedbugs; and from the insects which frequently kill crops, orchards and shade trees."*

(Business Week, November 25, 1944, p 67)

By the end of 1945, the U.S. public was *"hungry for DDT"*[35], said Fortune magazine. This same article also stated, with confidence, that there had been substantial progress in answering questions, resolving issues and addressing concerns about the molecule:

*"A startling amount of information has been uncovered about DDT in three years by federal, state, and private agencies. Certain aspects remain unsettled, but **out of the initial confusion a considerable body of fact has emerged.**"*

(Fortune, January, 1946),

Such was the promise of DDT, that it was even tried, incredibly in retrospect, against polio:

"A scientific expedition headed by Yale's Dr. John R. Paul sprayed DDT on the polio-ridden city of Rockford Ill (147 cases, 17 deaths since July 1 [reported on Aug 27, 1945]*), to find out whether killing all the flies would prevent the spread of infantile paralysis."*

(Time, Aug 27, 1945)

The photographs contained in these books and in the popular press of the time are revealing of just how common DDT was becoming, showing it being applied liberally in the home and on the farm, not to mention entire communities. In the home, DDT was applied to rooms via aerosol; to beds; to floors and rugs; to curtains; under the sink; on screen doors; inside garbage cans; an even directly to the family dog. On the farm, DDT

[35] Fortune (January 1946, p 149)

was applied of course to crops, but in addition, directly onto pigs, sheep, cattle, and fowl. It was sprayed onto public beaches by large trucks and onto suburbs by small airplanes.

Advertisements, an important element in the creation of a market for DDT[36], began to appear soon after its release into civilian use, and not only in farming or rural publications, but in the mainstream publications targeted at a general urban public as well. One by the Penn-Salt Company appeared in Time magazine in 1947 and featured a sketch of a housewife, a cow, a dog, a chicken, an apple and a potato, all dancing together and singing *"DDT is good for me-e-e ! "*.[37]

But not all talk of DDT was positive. The January, 1946 article in Fortune did describe the *"circulation of anti-DDT talk"*, saying *"there has been a lot of that"*, but also concluded that it was *"mostly unfounded in fact."* But what was this *"anti-DDT talk"*? During these early years the public was made at least partially aware of some of the scientific questions unanswered, issues unresolved, and concerns unallayed with respect to DDT. Although the majority of DDT's press was positive, the general public was audience to a small but unofficial debate about DDT's potential problems as well as its potential benefits. This is interesting because a number of these problems, described in subsequent Chapters, reappear in the domain later as real concrete problems that ultimately lead to the substitution of DDT: its toxicity to beneficial species; its persistence; and its acute toxicity to birds, fish and wildlife, for example. So even upon its entry into the economy, DDT the war-heroic "Killer of Killers" was also regularly referred to as a *"two-edged sword"*, as captured in Table 5.4.2.

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[36] Perkins (1978)
[37] *Time*, 1947 06 30

Table 5.4.2 - DDT: A Two-Edged Sword?

"The more entomologists study DDT, the new wonder insecticide, the more convinced they are that ***it may be a two-edged sword that harms as well as helps."***

(Time, April 16, 1945, pp. 91 - 92)

"It is obvious enough that DDT is a two-edged sword. *We can see how seriously it may upset the balance locally between insect enemies and friends"*

(Atlantic Monthly, 1945, 176, 107-113)

"On May 23, 1945, the sun shone warmly on a large oak forest near the village of Moscow, Pennsylvania. Bird calls and songs rang through the woodland as the birds flew about feeding hungry young ones. But the forest will ill; its leaves were covered with millions of devouring gypsy-moth caterpillars. Though birds ate vast numbers of the caterpillars and carried them to their newly hatched young, the horde was beyond their control.

"Early the next morning, an airplane droned over the forest, dropping a fine spray of DDT in an oil solution at the rate of five pounds an acre. The effect was instantaneous. The destructive caterpillars, caught in the deadly rain, died by the thousands. On May 25, the sun arose on a forest of great silence--the silence of total death. Not a bird call broke the ominous quiet.

"The symptoms of poisoning were always the same: the birds were first barely able to fly, arising a few feet with a weak motion of the wings, then falling back to the ground. As the poison overcame them, they staggered, pitched forward and died, fluttering their wings violently. During the eight days that followed, at least 4,000 birds succumbed. They had been sacrificed to a practical experiment to see how much DDT birds could withstand.

"This test arouses more than compassion for the birds. ***There is the cold significance of a chill wind in the potential power of DDT.*** *Birds, along with beneficial insects and weather, are a steady curb on the destructive insects which threaten to consume all of man's green food supplies. If we removed the birds and helpful insects from large areas of the earth, we might soon know a great famine. ...*

(The New Republic, March 25, 1946, 415-416)

Table 5.4.2 (continued) - DDT: A Two-Edged Sword?

*"DDT's greatest defect for use of out-of-doors is its non-selective killing power. Even in experienced hands, **its use may be likened to firing a broadside at a throng of people in which we have both enemies and friends**. ...* ***Unfortunately, DDT and the new and powerful British insecticide, 666*** **[HCH]**, ***are two-edged swords. ...*** *In a recent test, rats were killed by feeding them milk from goats receiving small daily doses of DDT. Scientists conducting the experiment are worried that **cow's milk might become impregnated with DDT** if dairy cattle are allowed to graze on areas sprayed or dusted with the insecticide.* (The New Republic, March 25, 1946, 415-416)

There were worries about its widespread use, as noted by the New Yorker on May 26, 1945 just after WPB announced the release of limited amounts of DDT for civilian use:

> *"An amateur naturalist we know, who is currently skipper of a landing barge in the South Pacific, wrote us a letter a few weeks ago describing the effect of DDT, the deadly military insecticide sprayed from airplanes before invasions. 'It kills every insect' he informed us. **'The Lord knows what's going to happen if they start using it promiscuously in the States'.**"*
>
> (The New Yorker, May 26, 1945, p 18)

This same New Yorker article goes on to quote the former president of the Entomological Society of America, Edwin Teale, who expressed serious concerns about DDT's effect on non-target insect species. Similarly, the National Audubon Society was also *"definitely alarmed over the possibilities of DDT"* suggesting that it might *"conceivably eliminate all insect-eating birds"* by killing their food supply.

In their attempts to compete with DDT, manufacturers of incumbent products did not hesitate to draw upon DDT's potential problems. They pointed to and underlined them in their communications, attempting to exploit the confusion and absence of what they felt were solid facts about DDT, although their opinion as to what constituted and what were the "facts" differed from those of others.

> *"There has been speculation and, in advertisements of some manufacturers of old-time insecticides (who seem to fear that DDT will hit them as hard as it does insect life), a definite charge that the new formula will 'under certain circumstances' act as a poison. The fact is that, while DDT has definite toxic properties, it is probably less toxic to humans than many standard insecticides."*
>
> (Fortune, January 1946)

Opinion was lining up behind DDT, specifically because it was not burdened by what had been a "problem" of the incumbent products (i.e. arsenicals), their acute toxicity. According to the evaluation criteria and rules governing insecticide choice of the time, DDT had superior performance. Those with concerns about wildlife and birds were largely ignored because they were not considered to be what I call a "legitimate product evaluation constituency"; their values and preferences were irrelevant for product design decisions.

And so DDT was officially sanctioned for agricultural use by the USDA in a bulletin issued on March 27, 1946[38], extracts of which are presented in Table 5.4.3. It addressed the safety issue explicitly, drawing attention to DDT's low acute toxicity, contrasting it with the dominant incumbent products in use at that time, the arsenicals.

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[38] USDA bulletin 576-46-2rev., reprinted in West & Campbell (1950, p 208)

Table 5.4.3 - The USDA Cautiously Recommends DDT

"Recommended uses of DDT:

"New recommendations for use of DDT, the war-tested insecticide, have been made by the United States Department of Agriculture for the 1946 crop year. The main point to be considered is that DDT should not be applied in such a way that it will contaminate foodstuffs.

"Few recommendations have been made to date, and these are for only certain insects when the practical and safe use of DDT has been determined for them. The Bureau of Entomology and Plant Quarantine, the agency responsible for the original research in the United States and much of the developmental work on this insecticide, has not approved the general use of DDT except in the instances given below.

"Regarding the possible toxic effects of DDT on man and animals, the Bureau said: (1) No case of poisoning resulting from the use of DDT itself in an insect control operation has been called to the attention of Bureau officials. (2) The effects of DDT on higher animals are markedly less than that of many insecticides such as nicotine and the arsenicals. (3) The use of DDT powders and water-dispersible DDT material on the skin is without any irritating effect or other ill results. DDT, however, in oil solutions or emulsions is readily absorbed through the skin of man and animals. Persons using it in this form are urged to take special precautions to avoid repeated or prolonged exposures to the material in oil solutions. (4) No DDT has ever been found by Bureau chemists to be absorbed and deposited in leaves, stems, roots, or tubers of potato plants following the treatment of the plants with DDT insecticides.

"Until additional factors regarding the possible ill effects of DDT on humans and animals become better understood, the Bureau of Entomology and Plant Quarantine is making no recommendations, except as noted, for the use of DDT on crops, portions of which may become sources of human or animal food. **Reports that DDT may be stored in the fat and excreted in the milk when fed to animals in considerable quantities are disturbing and indicates the need for strict observance of rules for safe use of DDT.**

"The present recommended uses of this insecticide made by the Bureau of Entomology and Plant Quarantine are as follows:

"Household Insects. For houseflies, stableflies, mosquitoes, fleas, roaches, bedbugs, lice, ants, ticks and other insects annoying to man and animals in houses, barns and other buildings: Dusts of 10 per cent DDT in talc or pyrophylite; Suspensions or Emulsions of 21/2 per cent DDT dispensible powders in water; solutions of 5 percent DDT in kerosene or fuel oil.

"This insecticide leads all others in its effectiveness for the control for most of these insect pests. Oil solutions are usually used inside houses where white deposits of DDT powder may be objectionable. Dusts, suspensions or emulsions are used in other places.

"Under no circumstances should oil solutions be applied to animals. DDT dusts or water-dispersible suspensions should be used.

"Aerosols are not recommended for applying insecticidal residues on surfaces for killing insects such as cockroaches, bedbugs, and ants that may later come in contact with them. Aerosols containing 3 per cent DDT and a suitable amount of purified pyrethrum extract are valuable as space applications for killing household insects such as flies, sandflies, mosquitoes and moths when they are in the flying stages.

"Insect Pests of Forest and Shade Trees. For defoliating insects such as gypsy moth, elm leaf beetle, catalpa caterpillar, locust leaf miner, boxwood leaf miner, cankerworm, sawflies, evergreen bagworm, tent caterpillar, and others: Emulsions, one pound of DDT, one quart of solvent (Xylene) and one or one and one-half ounces of an emulsifying agent. For dilution to a 0.1 per cent emulsion, add 100 gallons of water. Apply with a hand knapsack or power sprayer. The surfaces of the leaves should be wetted until the spray material begins to run.

"Vegetable and Truck Crop Insects. For cabbage caterpillars: Dust of 3 per cent DDT in talc or pyrophyllite, 20 pounds per acre. No DDT should be applied for 30 days before the cabbage is to be ready for market.

"For Lygus bugs on sugar beets grown for seed: Dust of 5 per cent DDT in pyrophyllite, or talc, 30 pounds per acre, applied at the time the plants are in full bloom.

"Insects Affecting Cereal and Forage Crops. For stored seed insects: Dust of 3 per cent DDT in pyrophyllite, or talc, thoroughly mixed with the seed, one-half ounce of dust to one bushel of seed, or, 3 per cent DDT in magnesium oxide which is also a repellent, applied in the same manner. Not recommended for stored grains or cereal products to be used for food.

"For insects affecting stored grains and cereal products in grain bins, warehouses and mills: Sprays containing 5 per cent or less of DDT in refined, deodorized kerosene or in water suspensions or emulsions applied on the walls and woodwork at a rate of not more than one gallon of spray per 1,000 square feet. Avoid contamination of grains or food products.

"For weevil (bruchid) in hairy vetch grown for seed: Dust of 3 per cent DDT in talc or pyrophylite, 25 pounds per acre, one application as soon as first pods begin to appear. Livestock should not be pastured in dusted fields during the remainder of the season after harvest unless straw and chaff have been buried by ploughing.

"Cotton Insects. For cotton flea hopper and other sucking insects: Dust of 5 per cent DDT in at least 75 per cent sulphur, 12 to 15 pounds per acre, weekly intervals until flea hoppers are under control.

"For bollworm: Dust of 5 per cent DDT, 15 to 20 pounds per acre, two or more applications at 5-day intervals.

"Fruit Insects. Notwithstanding the extensive investigations which have been made, it is not considered practicable to make recommendations for the use of DDT on fruits at this time.

"DDT has shown much promise as an insecticide in the control of a number of important insect pests other than those named above including the Japanese beetle, European corn borer, codling moth, oriental fruit moth, white-fringed beetle, Colorado potato beetle, chinch bug, alfalfa weevil, pea aphid, various species of leafhoppers, flea beetles, webworms, stink bugs and others. But the yellow light is on for all of these. The green light has been given for DDT insecticides only in the stated definite recommendations above. This is not all necessarily because of the residue hazard. Additional information on plant injury and further experience with different formulas is also desired. It will require experience from at least one more season to determine the status of DDT when applied as an insecticide to fruits, vegetables, forage crops and other foods and food products."

Even here we find evidence of caution. Citing residue concerns, DDT received the *"yellow light"* for the vast majority of food crops, including apples, the fruit attacked by the codling moth mentioned in the last paragraph. Cotton, eaten by nobody except the insects, got the *"green light"*. Residues remained a concern:

> *"Experimenters have been reluctant to recommend DDT insecticides for use in agriculture, where the major quantity of insecticides have always been used, for there the host is an important consideration. No accepted method for removal of spray or dust residues of this insecticide from crops for consumption of human beings and other animals has been worked out."*
>
> (Agricultural Chemicals, January 1947, p 63)

Note that although the USDA hesitated to recommend DDT on many food crops because of residue concerns, it had no legal powers at this point to stop or to prevent DDT's use anywhere.

The residue issue was a particularly difficult one for the FDA, which had been wrestling with it as DDT's fame and reputation grew. Given DDT's prominence, the FDA was in an unenviable position. Awareness and demand were already stoked, yet the lack of a clear case against DDT on the issue of hazard to humans meant that the FDA had no legal basis for holding DDT off the market, not to mention the political harm such a move might bring to the agency. It could set provisional tolerances for residues on food, but binding tolerance levels could only be established and enforced after a long series of hearings.

The FDA knew by 1944 that there was evidence that DDT accumulated in animal fat and could also be found in mammals' milk, but the implications of this were unclear. The acute toxicity of DDT was low, but chronic toxicity data was sparse. Indeed, two years after DDT was released for civilian use, the FDA's own Committee on Medical Research as well as the American Medical Association's Council on Food and Nutrition expressed concern over the lack of information about possible hazards to humans of chronic exposure to DDT. The latter identified an *"appalling lack of factual data concerning the effect of these substances when ingested with food"*, and went on to assert that *"The chronic toxicity to man of most of the newer insecticides is entirely unexplored."*[39]. In 1946 the FDA set provisional tolerance levels for residues of DDT on fruit at 7 ppm, the same as that for the lead residues from lead arsenate, the substance for which DDT was substituting on most fruit crops. Citing its importance to infants, it set a "zero tolerance" level for DDT in milk[40]. The FDA was not acting symbolically, just for the sake of acting; it had concerns. As early as 1944, its own researchers had reported on rat feeding studies that showed that at 800 ppm DDT in their diet, one half of the animals died after only two weeks. At lower levels of DDT and fed for the full 50 weeks of study, *"nervous symptoms"* and *"a slight effect on growth"* were observed and the study concluded that more research was required.[41]

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[39] AMA-CFN, "Health Hazards of Pesticides", *JAMA*, 137, August 23, 1948, 1603
[40] Federal Security Administration, Food & Drug Administration, *Annual Report of the FDA, 1946*, Government Printing Office, Washington, DC, p 6
[41] Draize et al, 1944, "Summary of Toxicological Studies of the Insecticide DDT", *Chemical and Engineering News*, vol 22, no 17(September 10), p 1503

But in general, toxicological methodologies that extrapolated from animal studies in order to estimate chronic toxicity risks to humans were inconclusive. They did not indict DDT, but neither did they clearly demonstrate DDT's safety. On the other hand, methodologies for determining chronic toxicity that drew upon samples from overexposed populations were interpreted as supporting the claim that DDT was safe:

> *"**One may turn to the experience of those who handle DDT in manufacture and in use.** These are men who make and handle the raw material, at the rate of tons per week. Others have produced concentrates (20 to 30 percent) in considerable quantity, or impregnated very large numbers of shirts from solutions; such men wear protective clothing. There are also entomologists who have handled and distributed DDT for a period of nearly two years (and longer on the Continent) in many forms, as solutions, emulsions, dusts and so forth. Tons of dust (5 to 10 percent) have been distributed under clothes and some thousands of men have worn impregnated shirts. In addition a small number of factory hands, after considerable exposure, have been carefully watched by physicians, whose examination has included biochemical work on blood, the function of the liver, and so forth.*
>
> *"In all this varied, practical experience on human beings, some of them ignorant and careless me, no harmful symptoms of any sort have been recorded in any single case. **My conclusion, given without reserve and in simple words, is that DDT used as an insecticide is quite safe.**"*
>
> (Buxton, P.A., 1945, "The use of the new insecticide DDT in relation to the problems of tropical medicine", Transactions of the Royal Society of Tropical Medicine & Hygiene, 38 (5), 367)

This methodological conflict would reappear - often - in the story of DDT. The work of Dr. Wayland J. Hayes, himself an advocate of the latter methodology while he researched DDT during his time with the Public Health Service, would come to form the backbone of the safety argument offered by DDT supporters. In his view, DDT posed no hazard to human health; DDT was safe.

DDT dissenters were ultimately unsuccessful. Its use in the U.S. was legitimated by (a) the provisional tolerance levels for residues set by the FDA and (b) recommendations explicitly calling for its use that were issued to farmers by USDA researchers and other officials at the experimental stations and extension services. And if this was not enough, further adding to and reinforcing DDT's already great fame and reputation, in 1948 it was announced in Stockholm that Paul Muller of the Geigy Company, discoverer of the insecticidal properties of DDT, would be the next recipient of the Nobel Prize of Physiology and Medicine for his contribution to public health.

DDT was quickly and enthusiastically adopted into the U.S. civilian economy.

5.5 Claims of Efficacy and Safety Dominate: DDT Substitutes for Incumbent Insect Controls because of its Superior Performance

The entry of DDT into the U.S. civilian economy was dramatic, as declining wartime demand was easily replaced by pent-up peacetime demand that had been stoked by all the publicity. Supply and manufacturing capacity was not a problem, as by the end of 1945 "*many reputable insecticide, chemical, and drug corporations are in or going into production* [of DDT] *with reasonable certainty of making substantial profits.*"[42]. Chemical plants and facilities were already in place, and experience with DDT had been built up throughout the war. Spraying equipment and airplanes, surplus from the war, were or quickly became available. In 1945, domestic sales of DDT more than tripled (in volume) those in 1944, at just over 31 million pounds of active ingredient, worth $17 million. During 1946, more than 43 million pounds were sold and by 1950 annual sales were more than double this. Figures for 1951-52 indicate that total U.S. production of DDT had increased by a factor of 10 since 1944. Sales of DDT alone reached just shy of $40 million in 1951[43].

The adoption of DDT for use against agricultural pest insect species was driven by its superior performance along evaluation criteria that mattered to growers: it killed insects, dramatically increasing the yields of numerous crops; it could be applied safely; and it

[42] Fortune (January 1946, p 149)

was cheap, as a single application resulted in a long residual killing effect. On this last point, DDT's persistence (although this term was not common at the time) *Business Week* wrote in 1944 that *"the quality that sets DDT apart from other insecticides is what chemists call its residual effect."*[44]

I examine here the adoption and enthusiastic acceptance by farmers of DDT for spraying in cotton fields and apple orchards. These "markets" for DDT were selected because they were the two biggest markets for insecticides at the time of DDT's entry into the economy. Additionally, I describe the entry of DDT into three other markets: by growers of citrus crops; by dairy farmers; and by municipalities for use against the bark beetles which serve as vectors of Dutch Elm disease. In subsequent Chapters, as I describe and analyze the process of adopting substitutes for DDT, the exit of DDT from each of these same five markets is presented.

5.5.1 Cotton

Cotton is especially vulnerable to insect pests, and cotton has always been at the top of the list of crops to which the most agricultural sales of insecticides have been made.

> *"Cotton is a plant that nature seems to have designed specifically to attract insects. It has green succulent leaves, many large, open flowers, nectaries on every leaf and flower, and a vast amount of fruit. ... The difference between a profit and a loss on any given acre of cotton often depends entirely on whether the insects are controlled."*
>
> (Rainwater, for the USDA, 1952, p 497 & p 500)

In the years prior to DDT, nicotine was used against the cotton aphid, and lead arsenate dust had been used since 1908 against the cotton leafworm and other insects, but *"never proved entirely satisfactory"* against the boll weevil or bollworm. Indeed, until 1916, the emphasis remained with cultural controls for the function of insect control on cotton. At that point, calcium arsenate was discovered to be highly effective against certain cotton

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[43] Production and sales figures are from the CMA's *Chemical Facts & Figures* (1946, 1950) which became the *Chemical Statistics Handbook* as of its fourth edition (1955).

[44] Section VI "War on Bugs" in its Report to Executives, *Business Week*, 1944 11 25, p 66

pests and it became a *"proved insecticide against the boll weevil, bollworm and cotton leafworm"*[45]. The era of chemical controls had come to cotton:

> *"For the next three decades,* [subsequent to 1916] ... *research on the control of cotton insects was largely devoted to developing dusts and dust mixtures and methods of applying them. It was demonstrated during this period that insect pests of cotton could be economically controlled and that cotton production could be made profitable even under conditions of heavy attack."*
>
> (Rainwater, for USDA, 1952, p 198)

Cotton, economically one of the most important crops in the United States, especially in southern states, was one of the first for which the USDA began testing the efficacy of DDT against pests during WWII. DDT was found to be effective against the bollworm, the pink bollworm, plant bugs and thrips, recommended for use, and quickly adopted. Against the first two species listed, both pre-use and post-use evaluation of DDT was overwhelmingly positive:

> *"Insecticidal control of the pink bollworm was never successful on a field scale until the development of DDT."*
>
> (Curl & White, for USDA, 1952, p 510)

> *"DDT is the most effective chemical so far used for the bollworm. DDT does not control the boll weevil, the cotton leafworm, or the cotton aphid, however. Because one or more of them often occur in damaging numbers at the time the bollworms occur, it is desirable to use an insecticide that will kill two or more insects at once. A dust mixture containing 3 percent of the gamma isomer of benzene hexachloride, 5 percent of DDT, and 40 percent of sulfur, commonly called 3-5-40, was developed in 1946 for cotton insects. It is one of the best all-purpose insecticides for use on cotton insects."*
>
> (Ewing, for USDA, 1952, p 513)

As indicated in the quotation, because it did not control the boll weevil, DDT was often mixed with other substances for application to cotton fields. Besides benzene hexachloride (also known as hexachlorocyclohexane or HCH), listed above, these also

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[45] Rainwater (1952), writing for the USDA.

included other organochlorines such as toxaphene and chlordane. Pink bollworm control up to levels of 70% was achieved by applying DDT at weekly intervals during the period when cotton is susceptible to pink bollworm attack. After the introduction of DDT and other organochlorines, net returns for every dollar spent on insecticides were frequently between \$20 and \$28[46]. Average annual cotton yields per acre jumped 75% from the 1930s to the 1950s, with much of the credit going to *"highly effective insecticides ... introduced after World War II that controlled many cotton insects for which there was little or no control previously"*, along with herbicides and changed agricultural practices[47].

5.5.2 Apples

With respect to apples, the yellow light of 1946 did not stop orchardists, who, facing increasingly difficult problems, began applying DDT that year. The light soon turned to green however, with the USDA and extension entomologists recommending its use against the codling moth. This insect, which in its larvae stage is the infamous worm in the apple, was by far the insect pest species of most concern to apple growers:

> *"As recently as 1944, apple growers throughout the United States feared that the codling moth would put them out of business. ...*
>
> *Losses due to the codling moth reached alarming proportions during the 1930's and 1940's. Fortunate indeed was the grower who could hold them down to 10 or 20 percent of his crop. Much larger losses were not unusual. Despite the use of stronger spray mixtures and more frequent and heavier applications, control became more and more difficult. The harder the orchardists fought the codling moth, the harder it was to control and the greater the injury it caused. The codling moth was so all-important that other pests received but scant attention. That was the situation when DDT was introduced to a discouraged industry.*
>
> (USDA entomologist, Howard Baker, for the USDA, 1952, p 562)

The spray mixtures referred to in the above quotation are of lead arsenate. This substance was widely adopted amongst apple growers just prior to the turn of the century and, up to

[46] Rainwater (1952), writing for the USDA.
[47] Warren et al (1998, p 755)

the arrival of DDT, was the primary insecticide used in commercial apple production. For lead arsenate manufacturers, apples provided their main market[48].

But the continued use of lead arsenate was complicating and making more expensive farmers' operations. The codling moth was becoming resistant to lead arsenate applications, farmers were spraying more of it, and this was leading to significant residue problems. It even got to the point, at least in the northeastern states, that apples had to be washed in an acid solution before being sent to market to remove the lead arsenate residues. Obviously, both these things (more insecticide plus extra washing) increased growers' costs. And prior to DDT, *"there wasn't a next best option"*, as lead arsenate was *"pretty much the universal pesticide for orchards"*[49]. Calcium arsenate and Paris Green were less effective and more phytotoxic. As one entomologist put it, the arsenicals *"were far from ideal and fading fast"*[50]. DDT was received by apple orchardists as an incredible solution to their growing problem:

> *"First tested by a few growers on a large scale in 1945, DDT became generally available to the industry in 1946. It promptly proved its worth in checking the codling moth and soon displaced lead arsenate or other materials in most spray programs. Timely, thorough applications of 1 or 2 pounds of a 50% DDT wettable powder per 100 gallons of spray in an average of three to six cover sprays, depending on the region, brought the codling moth under control. Growers who had become accustomed to losses of 15% or more of their crop are now dissatisfied with losses of more than 1 or 2 percent. Many have losses of less than 1 percent."*
> (USDA entomologist, Howard Baker, for the USDA, 1952, p 562)

Apple growers were enthusiastic about DDT because it solved a multi-dimensional problem confronting them: it controlled the codling moths; it was not phytotoxic; it did not lead to residue problems; and it presented no hazards for applicators nor animals. All in all, *"DDT was the answer to a great need for apple growers"*.[51]

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[48] Shepherd (1951, p 18)
[49] Glass interview
[50] Glass interview
[51] Glass interview

5.5.3 Citrus

Prior to the arrival of DDT, citrus growers were not important users of insecticides. Indeed, it was on citrus crops that biological controls had achieved one of their greatest success, when vedalia beetles (also known as lady beetles or ladybirds) were introduced into California groves in the late 1800s[52]. These beneficial insects controlled the "cottony cushion scale" *Icerya purchasi.*

But citrus thrips remained a problem for the plants, and mosquitoes were a nuisance for grove workers. DDT was famous for its effectiveness against mosquitoes, and during WWII testing it was demonstrated to be quite toxic against citrus thrips. So by 1945 it was being enthusiastically applied by citrus growers[53].

> *"Upon my return after this work in the south of California, the fame of DDT had spread. It was found to be a rather effective control for the citrus thrips in the Central Valley of California, and it was enthusiastically applied in 1945."*
>
> (De Bach, 1969, cited in Henkin et al, 1971, p 130).

5.5.4 Dairy Barns

As DDT was being introduced into agriculture, it was not just applied to field crops. It soon came to be used in formulations applied directly to livestock and fowl, as well as those applied to the barns they lived in. The use of DDT in and around dairy barns grew quickly. Anyone who has ever visited a dairy barn can attest to the seeming omnipresence of flies. Arsenicals were too toxic for this use, and while botanicals were safe enough, they were expensive.

Dairy barns represent a market for DDT that was heavily promoted. Consider these extracts from the books written about DDT:

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[52] Hagen & Franz (1973)
[53] Hagen & Franz (1973)

"Contented Cows: ... Insects attack us; but they also attack other animals. Ordinarily this would not interest us in the least, but where the cow is concerned we do take a personal interest. Our interest, of course, is entirely selfish. The mere fact that cows might suffer from fly bites is not, in itself, sufficient reason for us to kill flies that attack the cows. But we get milk from cows, and - at least so we have been told - a cow must be contented if she is to give large quantities of wholesome milk. ... In the few years since DDT first became available, thousands of dairy barns have been treated with no damage to the livestock but with a great improvement in Bossy's life and with more milk for the farmer. Reports indicate that cows pestered with flies give 3 to 8% less milk than their fly-free sisters. ... A 5% DDT-kerosene spray, a 5% emulsion, or a 2.5% dispersion of wettable powder (approximately 2 pounds of 50% wettable powder to 5 gallons of water) are all satisfactory for application to barns ... For direct application to the animals, the oil solution, of course, should not be used, but either emulsion of the dispersion of wettable powder can be applied without harm to the animals ... When applying the spray, particular attention should be paid to the belly, rump, and back. ... An alternative method of applying DDT to animals is by means of a dip .."

(Zimmerman & Levine, 1946, p 109)

"A heavy DDT spray - 5 per cent solution or suspension - sprayed on walls and partitions clears barns and other buildings for the protection of diary and other cattle, as successfully as it clears human habitations. This residual spray, used at the standard 1 gal. per 1,000 sq. ft., is the best technic for using DDT. In the North Dakota report quoted above, a 10 per cent dust was found only partly effective against flies in livestock barns, so that it became necessary to resort to fly spraying at milking time."

(Leary et al, 1946, p 95)

The advertisement by Penn-Salt Company in Time magazine in 1947 that depicted a housewife, a cow, a dog, a chicken, an apple and a potato, all dancing together and singing *"DDT is good for me-e-e!"* specifically addressed dairy barns:

"Knox-Out for Dairies - Up to 20% more milk, more butter, more cheese. test prove greater milk production when dairy cows are protected from the annoyance of many insects with DDT insecticides like Knox-Out Stock and Barn Spray."

(Time, June 30, 1947)

With production gains like those mentioned in the above quotations at stake, dairy farmers quickly became important users and purchasers of large quantities of DDT.

5.5.5 Dutch Elm Disease Vector Control

Another market, opened later than those in agriculture, was the spraying of DDT against Dutch elm disease. This disease is caused by a fungus that is spread by bark beetles which are therefore known as the disease "vector". The fact that this disease attacked predominantly ornamental elm trees located in parks and along streets where adults and children were to be found meant that treatments with arsenicals were never practical[54]. Cultural insect control methods, like the removal of dead or dying trees, were the alternative most often employed. But the arrival of DDT gave government scientists and municipalities worried about their elms hope that the disease might be overcome.

DDT was found to be toxic to these beetles as early as 1947 when the Bureau of Entomology and Plant Quarantine began an experimental spray program[55]. Soon, the BEPQ was recommending DDT against Dutch elm disease, and communities were adopting it. Official Dutch elm disease spraying programs were launched as early as 1949. By 1964, the equivalent of over two million acres had been sprayed with DDT, mostly dispersed with large volumes of water and with doses ranging from 2.5 to over 17 pounds of active ingredient per tree[56].

5.6 Substitution as a Consequence of Tool-Making

The entry of DDT into the five different markets just discussed is an example of what I call in this thesis "substitution as a consequence of tool-making" (or artifact-making). The critical dynamic that triggers and drives this type of substitution occurs largely in the commercial or industrial arena of society. It is a process that is relatively well-understood in the business strategy and economics literature, as compared to the other types of substitution described later in this document. The stories are familiar, especially for cotton and apples where DDT clearly displaced an identifiable competing product (as

[54] Dunlap (1981, p 79)
[55] Dunlap (1981, p 80)
[56] Rudd (1964, p 33)

opposed to a *system* of activities and techniques which was the case with the displacement of biological and cultural controls by DDT). All cases represent instances of what might be termed "normal" marketplace competition by R&D-intensive firms. Firms searched for and discovered a product whose measured performance was higher than that of the incumbent products along the evaluation criteria of relevance to - and attended to by - domain actors at that time. DDT was adopted based on its superior performance/price ratio: it helped farmers and other users to achieve higher insect control at a lower cost than what they were previously using. Incumbent controls, like the arsenicals, were no longer the best insect control choice. In effect, the "Efficiency" of the incumbent insect controls was successfully challenged by those firms promoting and selling DDT.

I wish to draw readers' attention to three key points which characterize this type of substitution process:

(1) First, these substitutions were triggered and driven by the appearance of DDT in the commercial marketplace, an artifact which reached and surpassed the *performance* of incumbent products. Had DDT not appeared, the incumbent insect controls would not have changed. Each had its problems and shortcomings which set the stage for DDT, but it was the arrival of DDT which triggered the substitutions.

(2) Second, the evaluation criteria and decision rules employed by actors in the pesticide domain to define what constituted superior insecticide "performance" at the time of DDT's entry into the economy were longstanding ones. This is important because, as we will present in Chapter 6, later this *definition of performance* came to be contested and this was critical to substitution events and the exit of DDT from certain markets through a process I term "substitution as a consequence of rule-making". But at the time of DDT's arrival, the evaluation criteria used to evaluate DDT were stable: efficacy (operationalized as high

toxicity to a wide spectrum of insects, with long residual action) and safety (operationalized as low acute toxicity to humans).

(3) Third and finally, there was no uncertainty, ambiguity or controversy as to the performance level of the incumbents; when compared to DDT, the arsenicals were undebatedly less toxic to insects and more toxic to humans. This is important because, as I will present in Chapter 7, the *measured performance* of DDT did come to be contested later and this was critical to substitution events and the exit of DDT from certain markets through a process I term "substitution as a consequence of fact-making". Stated in terms of the conceptual language I am advocating, the dominance of incumbent "tools" was overturned subsequent to the appearance of a challenger tool, through the application of existing decision "rules" and without falsifying any "facts" as they stood at the time. New information about the efficacy and safety of DDT was generated, and was certainly important in insecticide users' and regulators' decisions, but it did not falsify users' beliefs about incumbent products. This information was commensurable with existing beliefs. These new facts about DDT were complementary additions to - rather than substitutes for - the existing set of facts.

Specifically, in the tool- or artifact-making arena, actors (agrichemical firms in the case of DDT) searched for, developed or "made" products (i.e. DDT) which they believed had potential for being adopted, then brought these to organized structures of exchange (i.e. to "markets") where they demonstrated their superiority in terms of performance/price ratio. DDT resulted from systematic and structured problem-solving search inside a private commercial firm that was guided by clear idea of what was being sought. Muller detailed this neatly in his Nobel Lecture when he described an "ideal" agricultural insecticide. Muller and Geigy set out to "make" a "tool" with particular characteristics and properties. Once discovered, this new artifact or tool, DDT, was brought to market where it was demonstrated that it "outperformed" the incumbent insect control techniques - some chemical, some cultural, some biological - along the evaluation criteria in place and preoccupying actors at the time.

The term "outperformed" is a good one because it explicitly makes the connection to a product's "performance" or "performance/price ratio". The quasi-monopolistic dominance of incumbent artifacts was challenged and successfully contested with appeals to and demonstrations of the new tool's "Efficiency": cotton crop yields would increase; dairy cattle milk production would increase; apple losses would be reduced; etc. The actors who promoted the new tool understood and satisfied the demand for products with a particular functionality (i.e. tools which when used produce certain outcomes) at the lowest price possible. Note that in such contests, the fate of the promoters of a particular tool is closely linked to that of the tool. In other words, it is difficult to separate the fate of firms from the fate of the products they are selling. Through this process, new artifacts *substitute* for older incumbent ones.

Consider the cases of cotton and apples, where the substitution was "pure" in the sense of a product replacing a product (rather than a system of activities as with biological or cultural insect control). DDT substituted for calcium and lead arsenate because it outperformed those molecules. Both customers (i.e. farmers) and the institutional gatekeepers (i.e. the regulatory bodies; FDA & USDA), although each had their own distinct view of what constituted acceptable and superior performance, were ultimately satisfied with the new substances. DDT had dramatically higher *efficacy* and *safety* as those terms were understood and operationalized at that time, and was *less costly* in addition.

In the literature on technological evolution, a new artifact which represents a major breakthrough in terms of performance, as DDT certainly did for insect control, is termed a "technological discontinuity". Such discontinuities are typically followed by an "era of ferment" wherein many variations on this new theme are tried and experimented with until use patterns crystallize around one. As a particular design becomes more and more widespread, it becomes *institutionalized* into the "dominant design". This was precisely the case with DDT; its discovery and commercial success led to an explosion of R&D activity as agrichemical firms poured ever-increasing amounts of resources into a search for insecticidal organic chemicals, much of it "local search" amongst other chlorinated hydrocarbon molecules as well as the organophosphates just subsequent to WWII. But until its substitution - in different markets for different reasons and through different processes, described in subsequent Chapters - DDT and the other organochlorines was certainly the "dominant design" for insecticidal molecules, remaining at the top of the list of insecticides until the mid 1960s.

5.7 The Rise of DDT and Other Synthetic Organic Chemical Controls

5.7.1 From DDT to Other Organochlorines and Newer Synthetic Organic Substances

Stories similar to the ones recounted above can be told for most other commercially significant agricultural crop in the United States, including major ones like tobacco and corn, as well as a host of more minor crops like beans, potatoes, peanuts, cabbage, cauliflower, brussel sprouts, sweet peppers, pimentos, onions, and garlic to name just a few. DDT came to be used almost everywhere:

> *"The spectrum of insecticidal activity shown by DDT is remarkably broad and it is far easier to discuss the pests which are not controlled satisfactorily than to discuss the whole range of DDT's practical applications".*
>
> (Brooks, 1974, vol I, p 28)

That DDT *"revolutionized"* insect control in agriculture is still acknowledged today by entomologists and agricultural scientists:

> *"In the agricultural field the chemical control of phytophageous insects was revolutionized by the appearance of DDT."*
>
> (Perry et al, 1998, p 32)

Led by DDT, synthetic organic insecticides quickly displaced inorganics and botanicals in the economy. Demand for the inorganics and botanicals did not fall to zero though, and a number of these early substances continue to find uses in insect control today. But the physical and dollar volumes transacted are very small compared to those of synthetic organic molecules like DDT, other organochlorines and the organophosphates. As early as 1948, lead arsenate production had declined 73% from its 1944 peak levels[57]. Similarly, calcium arsenate production had declined 69% from its 1942 peak levels by that same year.[58] It can safely be said that organic chemical controls *substituted* for the inorganics and botanicals in the period just subsequent to WWII.

Throughout the 1940's, the success of DDT *"provided a tremendous worldwide stimulus to insecticide research and a great deal of structural analogues were made in a very short time"*[59]. A number of compounds with insecticidal properties were uncovered. Typically, activity against one species would not guarantee activity against another species, and so while some molecules outkilled DDT against certain insects, none outperformed it against a broad spectrum of insect species.

A glance at the molecular structures of other chemicals in the DDT family of substances detailed in Chapter 3 provides an excellent illustration of the role of "local search" in technological progress. Many of these molecules are identical to DDT except for a few changed atoms or functional groups. Many, many DDT analogues were experimented with. Indeed, the 1950 book by West and Campbell summarizes the insecticidal properties of more than 100 molecules derived from DDT's basic structure.

As was presented in the introduction to various chemical families in Chapter 3, the years immediately following WWII were good ones for the agricultural chemical industry, filled with numerous discoveries of molecules with insecticidal properties warranting commercialization. Many new active ingredients were introduced between 1945 and 1955, mostly organochlorines (including: DDT, DDD, methoxychlor, dicofol, aldrin, dieldrin, endrin, chlordane, heptachlor, and toxaphene), but also the first

[57] Calculations of % reductions were made with figures from Shepherd (1951, p 22).
[58] Calculations of % reductions were made with figures from Shepherd (1951, p 23).
[59] Brooks (1974, p 14)

organophosphates as well (including tetraethylpyrophosphate or TEPP, ethyl parathion, methyl parathion, and malathion). All of these substances became major insecticides enjoying much commercial success. The first carbamates (isolan, pyramat, pyrolan) and pyrethroids (allethrin) were invented during this period, but their moderate to low effectiveness combined with the high cost of their synthesis meant that they were quickly abandoned. The first major carbamate insecticide to enjoy commercial success did not come until 1956 (carbaryl) and, among the synthetic pyrethroids, it was not until 1972 when a molecule from that family (fenvalerate) achieved commercial success against agricultural pests.

DDT heralded a new era in the agricultural chemicals industry, which grew dramatically, *"by leaps and bounds"*[60] over the decades following WWII, according to NACA's official historian, and evidenced by a consideration of its impressive statistics. In just a few years following WWII, pesticide sales climbed quickly to reach $146 million by 1950[61]. The volume of pesticide active ingredients applied in the United States increased by more than 6 times in the period from 1934 to 1979[62]. On a per capita basis, this represented an increase from 1.4 lbs per U.S. citizen to 5 lbs/citizen[63]. By 1997, 975 million pounds of active ingredients worth $11.9 billion were used in the United States, with 129 million lbs of these being insecticides and miticides with a value of more than $ 3.5 billion[64]. Worldwide pesticide sales surpassed $31 billion in 1996[65].

As briefly explained earlier, the success of pesticide products fueled demand for more of them. As more and more pests came under control and crop yields rose, so did farmers' expectations as well as the incentives they had to further protect their higher yielding crop acreage. Once the original *"insect problem"* was dealt with, industry, agricultural scientists and farmers turned their attention to other *"pests"*. Whereas in the first half of this century the agricultural chemical industry was basically just the insecticide industry,

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[60] Hayley (1983, p 21)
[61] Hayley (1983, p 24)
[62] Aspelin (1999, Ch. 4, p 4). Calculations are for "conventional" pesticides.
[63] Aspelin (1999, Ch. 4, p 6). Calculations are for "conventional" pesticides.
[64] Aspelin (1999, Ch 3, p 9 & 14).

soon fungicides and herbicides came to play a much bigger role. Indeed, herbicide sales began to top those of insecticides after 1965, and over time the place and importance of insecticidal compounds in the industry and within the product portfolios of the dominant larger firms declined. The herbicide market is currently just over four times that of insecticides in terms of volume sales but not quite double in terms of dollar sales.[66] Insecticidal molecules are more valuable on a per pound basis.

A number of factors contributed to the incredible growth enjoyed by insecticide producers after the introduction of DDT. Clearly, the dramatic improvements in performance of the synthetic organic compounds over the arsenicals and botanicals helped them to achieve remarkable penetration of the markets existing at the time. In addition, many of the new insecticidal chemicals were complementary. For instance, DDT was often combined with a bit of pyrethrum in household formulations because of the latter's quick "knock-down" action, giving housewives quick visible evidence that, yes, the flies were dead. Ineffective against the boll weevil, bollworm-killing DDT was combined with toxaphene or dieldrin by cotton growers who sought formulations with killing power across the total spectrum of cotton insect pests. In addition, the properties of these new molecules permitted expansion into new markets and uses. This was fueled and facilitated by the development and adoption of both new attitudes and new complementary technologies. Insects, once a common or at least unremarkable feature in homes, suddenly became intolerable and housewives armed themselves with an impressive arsenal of "bug bombs", sprays and dusts. In agriculture, aerial spraying took off. Perfected and commercialized in the early 1920s, this application technique was not used extensively on crops other than cotton until after WWII because of its cost, but *"DDT changed that situation"*[67]. By 1952, more than 5,000 airplanes were equipped for aerial spraying of insecticides, and more than 500,000 hours were being flown annually

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[65] Agrow: World Crop Protection News, 1997 07 11
[66] Aspelin (1999, Ch. 4 & p 6).
[67] Yuill et al, for the USDA (1952, p 252)

be pest-control aircraft[68], much of this made possible by DDT, a substance with properties ideal for this application, at least as seen by employees of the USDA:

> *"Some day it may be said that the air age in insect control arrived with the discovery of the unusual values of DDT during the Second World War."*
>
> (Yuill et al, 1952, p 252)

Besides agricultural crops, the combination of new insect killing chemical technologies with new application technologies meant also that new forestry uses of insecticides - mostly DDT throughout the 1950s - were also identified as being "economic". Vast swatches of trees could be sprayed to protect them from injurious species like the spruce budworm or the tussock moth. In 1947, the Forest Pest Control Act was passed and approved by Congress. It authorized the cooperation of the federal government with states or even private interests against forest insect pest species, recognizing a "need" for control of forest insects and diseases. Chemical controls substituted for cultural insect controls in forestry.

5.7.2 Eradication becomes the Goal, and Biological Controls become Marginalized

The new synthetic organic insecticides seemingly opened up a vast universe of possibilities for more and more insect control. Economic entomologists and the USDA began to speculate optimistically, and very publicly, about what was viewed at the time as an attainable and desirable ideal: eradication of insect species:

> *"We know that insects have survived ... and that they are endowed with marvelous mechanisms by which they should be able to survive for many more years. ... Yet I give an unqualified yes to the question 'Can insects be eradicated?'". **It is possible to wipe out destructive insects and desirable to do so.**"*
>
> (Lyle, 1952, p 197)

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[68] Popham, 1952

DDT changed the goals of those working and researching insect control from mere control and containment to complete eradication. In the presidential address to the 58th annual meeting of the American Association of Economic Entomologists, entitled *"Achievements and Possibilities in Pest Eradication"*, Clay Lyle summarized the situation and laid down the following challenge:

> *"**The recent progress in the development of new insecticides and insect repellents has not been equaled in all history**. ...*
>
> *"The improvement in methods of application of insecticides merits no less praise. ...*
>
> *"Suffice it to say that at no previous time in history have the achievements of entomologists, working in collaboration with chemists and engineers, been of such universal value as to make in so short a time the name of an insecticide*[DDT] *a common word in every household however humble or remote. **The entomologist has become a wizard in the eyes of the uninitiated - and indeed some of the achievements seem little short of magic.***
>
> *"Unfailing evidence of this rise of the entomologist in popular favour is shown in increased expenditures for pest control. These increases in most cases are far beyond those justified by rising prices and apparently indicate a willingness to follow the leadership of entomologists in attacking problems which have long needed attention.*
>
> *"With all of this scientific progress and with the world believing in our ability to accomplish great things, should we not consider whether our post-war plans in entomology - local, national and international - are as comprehensive and as challenging as this favourable situation justifies? **Is not this an auspicious time for entomologists to launch determined campaigns for the complete extermination of some of the pests which have plagued man through the ages? ...***
>
> *"In conclusion, may **I plead for your serious consideration of the proposals for eradication of these age-old pests**. Let us not be satisfied with anything less than a post-war program which will challenge the imagination of the world. ... Unless we can enlist the aid of farmers' organizations, public health agencies, schools, chambers of commerce, the press, civic clubs, city and country officials, legislators and members of Congress, we shall not succeed* [at eradication]. *May I urge that you read the article in* The American Scientist *for January 1946 entitled* "Scientists

Should Knock at the Door of Politics' *by M.L. Cooke.* ***We must develop political know-how to secure funds and cooperation in executing our plans. ... In the words of Daniel Hudson Burnham, let us 'Make no little plans. They have no magic to stir men's blood'*** "

(Lyle, 1947, p 1 & 8)

The last few lines are telling. Those doing science - making facts as I put it - were far from naive about the need to "enlist" or "enroll"[69] supporters and to build coalitions.

Entomologists - especially those at the USDA - picked up the challenge, and by the mid 1950s, had secured funds for large scale spraying programs aimed at eradication. Insects targeted by the USDA in such campaigns included the gypsy moth, the Mediterranean fruit fly, the Khapra beetle, the gypsy moth, the bark beetle vector of Dutch elm disease, and the fire ant. These programs required incredible volumes of insecticides to be applied via indiscriminate spraying over massive areas including populated suburbs and recreational lakes.

All of these new uses and markets for insecticides, combined with the contingent and economic status of pests, meant that as DDT, its organochlorine relatives and other new synthetic insecticides entered and penetrated deeper into the economy, frequently they were not competing with old products and hence did not have to "steal" market share. A substantial market was being "created", not "contested" away from incumbent products. And as more products became available, more and more insects became "pests". Once-tolerated insect damage suddenly become intolerable. This avoidance of head-to-head competition during the entry of DDT into many parts of the economy is significant because it meant that no industrial actors had an obvious interest to contest or resist this technological change. No actors from the commercial arena were available to form a coalition with the dissident actors from the scientific arena, mostly economic entomologists favouring biological controls as well as a few suburban dwellers who objected to the periodic rains of milky white DDT solution coming down from the skies.

DDT and synthetic organic chemical controls soon crowded out alternatives, not only in the marketplace, but in science as well. Those favouring biological controls were increasingly marginalized within their discipline, even *"so long ridiculed by the dominating chemical control proponents as a lunatic fringe of economic entomologists"*[70] by the arrival and success of DDT. The research priorities within science shifted along with the boom in research within the chemical industry. This is illustrated in Table 5.7.2.1.

Table 5.7.2.1 - Patterns in Applied Entomological Research

Patterns in applied entomological research over a period of 44 years, as reflected in *Journal of Economic Entomology*

	Papers (percent) 1927-1970									
	1927	32	37	42	47	52	57	62	67	70
General biology	45	40	27	28	13	13	23	16	20	22
Insecticides	44	46	58	60	76	79	64	62	42	43
Biological control	3	7	6	8	4	3	7	8	9	6
Other measures	8	7	8	3	7	4	6	14	29	29

* Table is from Jones (1973, p 326)

In the *Journal of Economic Entomology*, the percent of papers addressing the general biology and/or biological control of insects fell by one half while that devoted to the testing of insecticides and other aspects of chemical controls rose by almost a third. Economic entomology came to resemble even more applied chemistry as *"pesticide papers clearly dominated the contents of the journal."*[71]. Writing in their "*History of Biological Control*", entomologists have noted the same:

[69] Note that "enlist" is Lyle's own term, from the quotation; it obviously has a meaning similar to that of "enroll" as that term is used by Latour (1987).
[70] Doutt & Smith (1971, p 5)
[71] Jones (1973, p 326)

> *"Through the late 1940s and into the 1960s chemical control of insect pests with persistent organic insecticides was so spectacular and successful that the biological control approach received little support. In fact, **it was considered passe** except for a few research centers. Entomological research, in general, also suffered a setback for it was thought that little had to be known about the ecology or biology of insects to bring about insect reduction with the new chemicals."*
>
> (Hagen & Franz, 1973, p 435)

By the way, the increase in papers on "other measures" in the later years in the Table reflects papers *"concerned with the consequences of pesticide use (resistance, residues, wildlife effects) rather than the control measures themselves"*[72], which I address in my discussion of the fall of DDT, yet to come.

5.7.3 The New Era of Synthetic Organic Chemical Controls Triggers Regulatory Change

Besides science and industry, DDT and its huge success also had an impact on the regulatory regime in the pesticide domain. In response to the growing number of new synthetic chemicals flooding onto the market, many of them quite acutely toxic to man and mammals especially among the organophosphates, the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) replaced the 1910 Insecticide Act[73]. As its name suggest, its scope of coverage of economic poisons was wider than the Act it replaced, expanding to cover rodenticides as well as herbicides. Like the Act it replaced, it was administered by the USDA. For the first time, it required registration of pesticides with that Department. FIFRA 's purpose was to *"regulate the marketing of economic poisons and devices by means of a registration and labeling procedure which requires producers to present evidence of the safety of these products when used as directed and their*

[72] Jones (1973, p 326)
[73] This discussion has benefited greatly from the following works: Bloom & Degler (1969); Blodgett (1974); NAS (1980); Dunlap (1981); NRC (1987); Briggs (1992); Wargo (1996)

effectiveness for the purpose stated on the label."[74]. It prohibited shipment in interstate commerce of adulterated, misbranded or unregistered products.

It should be noted that FIFRA did not assert federal authority over state registrations, but was meant to supplement intrastate registration procedures. But following FIFRA's adoption at the Federal level, the Council of State Governments adopted and published registration rules based on FIFRA as "Suggested State Legislation", and many states enacted similar legislation requiring registration and labeling as a prerequisite to their lawful introduction into intrastate commerce. So although, technically, a myriad of laws apply to pesticides in the United States, for all intents and purposes the legislation of reference is FIFRA.

FIFRA made no provisions for, and contained no rules governing, the actual use of pesticides. It was essentially a labeling law: pesticides were to be safe and effective when used according to the labels appearing on them, which had to be registered with the USDA[75]. The "safety" referred to here was that of pesticide applicators and farmers. To apply for a registration, manufacturers were obligated to furnish *"a complete copy of the labeling accompanying the economic poison and a statement of all claims to be made for it, including the directions for use."* Claims about effectiveness and safety were reviewed and could be challenged. A full description of tests made and their results had to be furnished as well *"if requested by the Secretary of Agriculture."*[76]

FIFRA applied to individual formulations and not just the technical mixtures registered by the manufacturers of active ingredients. This meant that upon its enactment it created a huge amount of work, as all existing pesticide products had to be registered and USDA employees were warned in a memo at the time, *"if you're not processing 50 applications a day, you're looking at them too closely."*[77]. Such an attitude made sense, given the provisions of a controversial section of FIFRA which created a loophole by which

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[74] Pesticide handbook (1974, p 9)
[75] Briggs (1992)
[76] FIFRA (1947), reprinted in Bloom & Degler (1969)

manufacturers could easily obtain a *"registration under protest"* which permitted marketing, pending the outcome of a full investigation, of any substance refused by the USDA. In other words, if an application for registration was originally denied, or if an existing registration was cancelled, the pesticide continued to be sold. Ambiguity over what constituted a full investigation meant, essentially, that any pesticide that became embroiled in controversy left the economy only if it was voluntarily withdrawn by the manufacturer. The USDA shouldered the burden of proof of a substance's lack of safety or efficacy until this loophole was closed and the burden of proof reversed in 1964, in the wake of the publication of Rachel Carson's *Silent Spring*. Prior to that, few full investigations were initiated[78].

NACA supported FIFRA and its requirement for product registration as a mechanism for clamping down on ineffective products which proliferated along with the array of increasingly difficult and technical choices available to users. They wanted a *"federal stamp of approval"*[79] on their products; that arsenic was toxic farmers knew, but suddenly they were confronted with a bewildering array of insect control products with awkward chemical names. The legislation generated little conflict and little public notice. Upon its passage on June 26, 1947, the New York Times ran only a small Associated Press item on page 26 entitled *"New Law to Color Poisons"* reflecting FIFRA's stipulation that economic poisons be coloured to *"lessen the chances of housewives putting bug killer instead of baking powder into their biscuits"*[80]. That such major regulatory reform received such little attention is a reflection of the public's and others' (lack of) concerns at that time; they had confidence in government, in science and in the marvelous stream of new technologies resulting from WWII research that were being brought to market; "technical" issues were left for experts to discuss amongst themselves. Pesticide registration was viewed by all as a mere administrative matter.

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[77] anonymous EPA employee who has seen the memo
[78] Blodgett (1974, p 220)
[79] Bosso (1987, p 54)
[80] New York Times, 1947 06 26

It was not until the 1950s that an official public debate took place over how the new synthetic insecticides affected the safety of anyone other than farmers. This occurred at the hearings before the House Select Committee to Investigate the Use of Chemicals In Food Products, with James J. Delaney of New York as Chairman. Looking into all of the issues surrounding the growing use of synthetic chemicals along the chain of activities involved in supplying and delivering food from farmers to final consumers, with respect to pesticides the committee was " ... *authorized and directed to conduct a full and complete investigation and study of ... the nature, extent and effect of the use of pesticides and insecticides with respect to food and food products, particularly the effect of such use of pesticides and insecticides upon the health and welfare of the consumer by reason of toxic residues remaining on such food and food products as a result of such use.*" [81]

The central problem at issue was, as before, residues. Along with consumers' groups, the food processing industry wanted to settle the many questions surrounding tolerances. With more and more insecticides and other agricultural chemicals being used on more and more crops, manufacturers of canned foods were finding it almost impossible to secure uncontaminated raw materials, without detectable quantities of residue. Firms making baby foods were especially concerned, and had begun to implement costly residue detection and measurement routines in response to the near impossibility of finding residue-free produce[82]. With questions of safety unsettled, the uncertainty over what would be acceptable and even legal was difficult to resolve.

The committee heard from scientists (food and nutrition scientists, medical authorities, biochemists, etc.) industry (chemical companies, food companies, growers, canners, etc.), government (USDA, FDA, PHS) and others concerned about public health. NACA came out against any changes to the current rules, which readers will recall allowed the FDA to set enforceable tolerances that others wished to contest only after extended and costly hearings at which the FDA effectively bore the burden of proof of a substance's hazard.

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[81] Hearings before the House Select Committee to Investigate the Use of Chemicals in Food Products, House of Representatives 81st Congress, second session (1951, p 1)
[82] Dunlap (1981, p 68)

The current set of rules, NACA claimed, was sufficient for protecting the public interest, as evidenced by these excerpts from the testimony of its executive secretary, Lea S. Hitchner:

> *"This association and members of the chemical industry are vitally interested in the health of the public. ...*
>
> *"Existing legislation makes possible adequate protection of the public: We want to emphasize that pesticides are not sold without legislative control. I know of no other industry which has to comply with more laws and regulations in order to sell its products. ...*
>
> *"We are convinced that no new legislation is necessary in order to protect the public health. If, on the other hand, the committee is of the opinion that there is need for facilitating the enforcement of the present laws and regulations and encouraging original research and development of new products, then consideration might be given to the simplification of the present residue tolerance procedure to make it more rapid, less expensive and more realistic."*

In the process of making and defending this strong assertion about the appropriateness of existing rules, NACA was forced to disagree with other important and credible groups, including the American Medical Association. After being read a statement issued by that organization's Council on Foods and Nutrition, which concluded that *"essential information is underdeveloped for many of the economic poisons now in use"*, the following exchange[83] took place:

Hitchner:

I disagree with that statement.

Committee Chief Counsel:

You disagree with the American Medical Association?

Hitchner:

I do and I think the committee has definitely changed its position [...]

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[83] Hearings before the House Select Committee to Investigate the Use of Chemicals in Food Products, House of Representatives 81st Congress, second session (1951, p 367)

Committee Chief Counsel:

Have they issued a supplemental statement changing their viewpoint?

Hitchner:

No; I do not know; I have not seen one.

Committee Chief Counsel:

Why do you not ask them to?

Hitchner:

Well, we are cooperating with them. They have a committee on pesticides. We think it is very sound. They are directing their efforts to educating the doctors in country towns on how to treat cases of poisoning due to these agricultural chemicals. We think they have a definite place and are part of the sound education of the public in the use of these materials.

Committee Chief Counsel:

I repeat, Mr. Hitchner, that as of January 1, 1950, the American Medical Association said that much essential information is underdeveloped for many of the economic poisons in use.

Hitchner:

I would like to ask them on what basic chemical that information is not developed [...]

Committee Chief Counsel:

What is your academic background, Mr. Hitchner?

Hitchner:

[...] I quit both and went into business.

Committee Chief Counsel:

You didn't graduate?

Hitchner:

I did not.

Committee Chief Counsel:

You are not a chemist?

Hitchner:

No.

Committee Chief Counsel:

You are not a scientist?

Hitchner:

No.

Hitchner was discovering the hard way that credentials and reputations mattered. NACA and others at these hearings was making claims and assertions that they hoped would be accepted and adopted to guide policy and action. This exchange is reproduced here because it is one of the earliest and clearest indicators of the need for particular resources that would come to take on incredible value later in the life of DDT: discursive legitimacy and credibility on particular issues. Indeed, one of the easiest ways of winning at "discursive struggle" is to dismiss the claim by discrediting the source and/or their right to voice. This strategy was often employed by actors at this and later hearings. Actors/talkers sought to untangle and address "business", "scientific" and "government" / "political" issues as separate, distinct and requiring of the expertise that only they or their allies could provide. Consider the emotional testimony of Mr. Samuel Fraser, Secretary of the International Apple Association which was representing the interests of apple growers, who had particularly unkind words[84] for the FDA and its "experts":

> *"I have read the statement made by Lea S. Hitchner, ...*
>
> *"If the door of progress is to be slammed shut and bolted by law, what is the value of further research?. ...*
>
> *"The place of an expert is as a witness.* ***The witness is not competent to pass on or administer a business problem.*** *The work of* ***determination of the facts in such technical problems as confront us in this field should never rest in an administrative agency. ...***
>
> *"If we open up the field of plant growth as this bill* [proposed legislation presented to the committee that would give the FDA more authority for establishing and policing residue tolerances] *with the subjection of the producer to findings of so-called "experts" on whose word seizures and*

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[84] Hearings before the House Select Committee to Investigate the Use of Chemicals in Food Products, House of Representatives 81st Congress, second session (1951, p 668)

condemnation proceedings may be applied of the fruits and vegetables held until they rot pending determinations we are entering so vast a field that it staggers the comprehension.

"This is not legislation. ***This is a grab for power*** *which is to be secured under the whip of hysteria. ...*

"Fruits and vegetables cannot be shackled in this manner.

The complexities and interdisciplinary nature of pesticide issues meant that issues of discursive legitimacy and credibility would come up over and over again. They also meant that building a successful argument for or against an insecticide would require a coalition.

At this set of hearings, those who supported the rules as they were included pesticide manufacturers, farmers, agricultural scientists and USDA officials. Scientists and officials from the FDA, including its Commissioner Paul Dunbar and Dr Arnold Lehman, Director of its Division of Pharmacology, felt that more research into chronic toxicity was needed and that more controls over the introduction and use of pesticides were justified:

> *"I feel that no new chemical or no chemical that is subject to any question as to safety should be employed until its possible injurious effect, both on an acute and on a long-time chronic basis, has been shown to be nonexistent. In other words, any chemical that is proposed for use ought to be proved in advance of distribution in a food product to be utterly and completely without the possibility of human injury"*
>
> (Dunbar at Hearings, 1951, p 36)

In addition, the prospect of undertaking many long and expensive hearings to establish tolerances was not a pleasant one for the FDA. At the time of the hearings it was estimated that 125 active ingredients had already been mixed into some 22,000 commercially available formulations[85].

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[85] These numbers are from the Hearings. Wargo (1996, p 72) puts the estimate at 30,000 products by 1951.

The identification of DDT residues in the fat of Americans who were not occupationally exposed to that insecticide at the time of the hearing served as a symbol underlining the FDA's claim that there was growing cause for concern. In 1950, the fat of an average American was made up of 5.3 ppm DDT, a figure which rose to 15.6 ppm by 1955.[86] What would become an even more powerful symbol also emerged at this time; breast milk samples from U.S. women showed 0.13 ppm DDT in 1951.[87]

In addition to the public discussion of human fat tissue, the subject of DDT came up in other matters as well. It was unavoidable really. Given that substance's fame, reputation and widespread use, it was frequently used to make examiners' questions about insecticides less abstract and more concrete, or to illustrate a point. Dr. Wayland J. Hayes Jr., a toxicologist at the Public Health Service, which used DDT against disease vectors including malaria in the U.S. south, presented what he believed was strong evidence of the safety of DDT at any residue levels that might result from normal agricultural activity· He drew his conclusions from studies of overexposed populations, including workers at chemical plants and "volunteers" that he had recruited at prisons. The endpoints of his studies were the classical symptoms of illness and poisoning used in clinical medicine: pathological changes to major organs resulting in bodily dysfunction, disease and/or death. Biochemical and enzymatic effects - whether DDT and other insecticides had the potential to disrupt physiological and biochemical processes - were not examined. Hayes' testimony and methodology would eventually come to form the backbone of the pro-DDT arguments on safety and absence of hazards to human health[88].

Ultimately, new regulations did emerge from the hearings, despite NACA's aggressive defense of the status quo. NACA did not achieve its objective of no changes to the rules, but it did succeed in getting a more streamlined tolerance-setting process. A member of the committee, Arthur L. Miller of Nebraska, used the committee's 1952 recommendations to develop a bill that became known as the Miller Amendment to the

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[86] Wargo (1996, p 168)
[87] Wargo (1996, p 169)
[88] Dunlap (1981, p 70) has informed most of this paragraph.

Food, Drug and Cosmetic Act (section 408) when it was passed in July of 1954. The Miller Amendment provided that any raw agricultural commodity could be condemned as adulterated if it contained any pesticidal chemical whose safety had not been cleared or if residue levels found thereon exceeded the tolerances set by the Secretary of Health, Education and Welfare (i.e. the FDA). Manufacturers of active ingredients were obliged to submit to the FDA, along with their request for a tolerance to be established, data on: the chemical identity of the substance; amounts, frequency and timing of its application to specific crops; expected residue levels if applied as per label instructions; its toxicity to laboratory animals, as measured in standardized tests spelled out in detail; the tolerance level they recommended and were seeking. Residue data was to be developed using the most sensitive analytical method available which, at that time, meant in the range of ppm[89].

FIFRA and the Miller Amendment to the FDCA supplemented each other and were interrelated by law and in practical application. So although FIFRA had no specific provisions relating to the contamination of food, once the Miller Amendment was passed, the USDA, in administering the Act, would not register any insecticide for use on food crops unless (a) the FDA had set a tolerance or (b) it had been demonstrated, by the manufacturer, that no residues would result from use as per the substance's label. This latter case resulted in a "no residue" registration. Conversely, the FDA typically refused to grant tolerances until an application for registration had been filed with the USDA, which would certify to the FDA that the chemical was effective on the crop in question and that the tolerance proposed represented was not inflated above a lower amount attainable through reasonable agricultural practices. With the Miller Amendment, the FDA also obtained the authority to set a "zero tolerance" for a chemical on certain foods if the scientific data did not justify a greater one[90].

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[89] Blodgett (1974)

[90] See "Report of the Pesticide Residues Committee" by NAS-NRC (1965) for a clear presentation of these terms - "no residue" and "zero tolerance" - and the problems they created for farmers and regulators alike.

The burden of proof of new substances' absence of hazard to consumers due to residues - and hence the requirement to organize and undertake particular toxicological studies - had been shifted to manufacturers. But (1) if manufacturers' claims of "no residue" were accepted by the USDA, this meant that the FDA was not even involved in the registration of new substances; (2) the possibility of "protest registrations" still existed under FIFRA; and (3) the question of what to do with substances already in commerce remained.

NACA had more success with another major outcome from the committee's hearings: the "Delaney Clause" in the Williams bill of 1958 modifying the FFDCA (section 409) which regulates additives in processed foods which are added "intentionally" or "incidentally". This clause, promoted by the committee's chairman, James J. Delaney of New York, was accepted only after much debate and manipulation of its language. It basically states that no material capable of causing cancer under *any* conditions may be added to foods in *any* quantity. NACA congratulated itself on having pesticides excluded from the definition of an "additive":

> "*One of the major distinctions established in this work* [NACA's "broad educational efforts on the residues issue"] *was the separation of pesticides from food additives. This became especially important with the 1958 passage of the Delaney Amendment to the Federal Food, Drug and Cosmetic Act. The amendment (which through diligent NACA work didn't apply to pesticide residues in or on agricultural commodities) states that 'no additive shall be deemed to be safe if it is found to induce cancer when ingested by man or animal, or if it is found, after tests which are appropriate for the evaluation of the safety of food additives, to induce cancer in man or animal.*"
>
> (Hayley, official NACA historian, 1983, p 30)

That more stringent rules aimed at limiting carcinogenic risk to consumers applied to processed as opposed to raw foods - the "*Delaney Paradox*"[91] - was a reality that all actors in the pesticide domain lived with for the next few decades. And NACA's initial success did not go uncontested. Attempts were made to link the pesticides to the Delaney Clause were indeed made, and it was eventually ruled that that pesticides which

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[91] NRC (1987)

concentrated or *accumulated* during *the processing of food* would be treated as additives under this law[92].

Though residues were the major one receiving public attention at this time, other "insecticide problems" were beginning to be identified, framed and discussed. The widespread adoption of DDT (and other synthetic insecticides), an incredibly successful tool for solving the "insect problem", was leading to certain outcomes that actors were increasingly inclined to label as "problems":

> (a) DDT's acute toxicity to birds, fish and wildlife (which led to certain instances of substitution described in Chapter 6);
>
> (b) DDT's chronic toxicity to birds, fish and wildlife, as well as the multiplication and extension of these hazards in space and time due DDT's persistence, transport and bioaccumulation (which led to certain instances of substitution discussed in Chapter 6); and
>
> (c) DDT's aggravation - rather than resolution - of insect problems due to the phenomena of secondary pests, resurgence and insect resistance (which led to certain instances of substitution discussed in Chapter 7).

Discussion of these problems was heating up, albeit in obscure and unpublicized scientific journals and government reports.

But this changed.

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[92] NRC (1987)

6 The Fall of DDT (I): Substitution as a Consequence of Rule-Making

6.1 Introduction

In this Chapter, I describe the fall of DDT, from some of the earliest *successful* critiques (recall, there were earlier *unsuccessful* critiques of DDT upon its entry into the economy) up until its final days of use. In some ways, its fall began at the same time as its rise - if not before - because of DDT's particular physical, chemical and toxicological properties. But these were not enough *in and of themselves*. No, the fall of DDT was not preordained nor determined in any strong sense of those terms, as will be demonstrated by describing and analyzing those processes of substitution in which DDT was involved as the incumbent exiting product, replaced by other organochlorines such as methoxychlor or organophosphates such as methyl parathion and EPN. The substitution of DDT came about only after much struggle over what constituted acceptable and desirable outcomes from insecticide use. Simply put, what counted as superior insecticide *performance* came to be *redefined* in a way that was highly unfavourable from the perspective of DDT manufacturers. This occurred only after new entrants to the pesticides domain succeeded in having their interests included in the calculus of insect control evaluation and decision-making.

I argue that these instances of substitution are relatively pure examples of the phenomena which I term *substitution as a consequence of "rule-making"*, a process whose dynamic is dominated by activities in the public or political arena of society. Substitution as a result of this mechanism is less well-understood in the business strategy and economics literature, and the story is less familiar. In instances of this type of substitution, what prompts the disappearance of a product from the economy is not the sudden appearance of an obviously superior alternative. Rather, one product replaces another in performing a particular function in the economy primarily because the evaluation criteria, values and decision rules used to evaluate and to compare products have changed. In the limit, new decision rules can explicitly preclude use of particular substance, as with the case of product bans. In other words, substitution of one artifact for another follows and is triggered by the substitution of one rule for another. The fate and status of actors is closely linked to the rules they propose and promote. In the rule-making arena, actors (i.e. politicians, NGOs, the public, and others in the case of DDT) search for and "make" normative claims (i.e. "ought" statements as to what *should be* the outcomes of the accomplishment of a particular functionality in society), alternative decision logics and arguments with a potential for becoming adopted, then bring these to organized arenas of communication (i.e. discourses) where they attempt to demonstrate their superiority. In this process, the monopoly or quasi-monopoly of incumbent rules, norms and values are challenged and contested, essentially, with appeals to and demonstrations of rules' **"Rightness"** or **"Justice"**.

I demonstrate how, in the case study, the "Justice" of DDT - once widely accepted normative assertions and claims as to the absence of violations of rights in or due to its use - was successfully contested. Through a process of discursive struggle, undertaken in this case largely within the structures and organizations of government and law, new rules *substituted* for older incumbent ones. Stated in terms of the conceptual language we are advocating, the dominance of incumbent "rules" was overturned subsequent to the appearance of competing rules employing different and/or differently weighted evaluation criteria to be applied in insect control decision-making. In the examples discussed here, the array of alternative artifacts (i.e. active ingredients available for use) on actors' choice menus remains constant, as do actors' expectation (i.e. beliefs) about the outcomes of using the various products. But the decision rules invoked by actors to select among various products come to be changed as novel evaluation logics are adopted, triggering substitution. Analogous to the institutionalization of artifacts and the emergence of dominant designs in the physical world, as a competing value judgment or normative logic becomes more and more widespread, it becomes *institutionalized* and when contestation ceases it has become a "rule" and part of the dominant paradigm.

6.2 An Unsuccessful Challenge to the "Rightness" of DDT

The first challenge to the Rightness of the use of DDT occurred in reaction to a vast USDA eradication spraying campaign on Long Island in New York, and it was unsuccessful[1]. No substitution resulted, but I feel it is appropriate nevertheless to begin this Chapter by recounting this early episode here for a couple of reasons. First, it illustrates that substitution is driven by ongoing struggles; the absence of substitution of incumbent products (i.e. ongoing steady demand for products) does *not* necessarily mean that their place in the economy is unchallenged. Contestation may be occurring in the background, just unsuccessfully. Note that this is also true of "normal" processes of substitution driven by outcomes of contests over tools; many products are brought to market which do not succeed in making a dent in the dominance of incumbents, while even more are abandoned earlier in the "search" or R&D phase of tool-making, but its just that these are rarely researched. Second, although new decision rules or regulations affecting DDT were not made in the Long Island lawsuit, the efforts by actors to bring such new and more restrictive rules into existence did catch the attention of DDT opponents and proponents alike, influencing subsequent behaviour and outcomes in the domain:

> *"The decision in what has come to be known as the "DDT Trial" favoured the government agencies, but the issue was much larger than could be settled in a single court action. In any case,* ***the public airing of the facts resulted in much wider awareness of the hazards, both known and potential****, of large-scale chemical control programs.* ***The government agencies involved were made acutely aware of the hitherto largely silent opposition****, and have now retrenched to consider modifications of their programs."*
>
> (Rudd, 1959b, p 496)

The suit spurred other citizens and organized conservation groups to become more vigilant and active in their anti-spraying activities, taking their own municipal and state governments to task or all the way to court when spraying decisions were made. The publicity also helped the Department of the Interior to lobby successfully for the passage of the Pesticide Research Act which was the first formal allocation of federal funds to a 1958 budget envelope specifically devoted to research on the effects of pesticides on fish, birds and mammals[2].

On the other side, among those who supported spraying, the USDA came to anticipate public resistance and this contributed to their eventual abandoning of their optimistic goal of insect species eradication and their scaling back of massive spraying programs. Also becoming aware of increasingly organized resistance to agricultural chemicals, in 1958 NACA felt it necessary to publish its public relations booklet *Open Door To Plenty*, a lengthy effort (more than 60 pages), which was *"written for the consumer, to explain to the general public **the facts** about pesticides and their use"* and which was reprinted seven times in only two years to fill the large volume of requests for information from a public beginning to become concerned about agricultural chemicals[3]. It told *"the story of man's struggle to control some of the hostile elements in the world around us, ... pests which destroy our foods and our property, and attack our health"*[4], but ignored mention of any problems linking pesticides and wildlife, even concluding a section devoted to that topic by claiming that *"when properly used, pesticides become tools for improving wildlife"*[5]. But despite NACA's efforts to downplay the growing opposition, denying even a basis for it - *"There is never any real conflict of interests when all groups are seeking the same objectives - an adequate and safe food supply, protection of health and property from pest damage, and safety in the use of pesticide chemicals"*[6] - the evidence presented here suggests that the conflict was very real and that it was over which values would be used in insect control decision-making and become institutionalized into "rules" to be followed.

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[1] Accounts of this case can be found in: Cort (1958); Rudd (1959a); Rudd (1959b); Rudd (1964); Dunlap (1981); Bosso (1987); Lear (1997). Rachel Carson also mentions it (1962, p 159).
[2] Blodgett (1974, p 210)
[3] Hayley (1983, p 30)
[4] NACA (1958, p i)
[5] NACA (1958, p 51)
[6] NACA (1958, p 52)

In 1956, with a stated goal of eradication, the USDA undertook a vast spraying campaign against the gypsy moth that included the treatment of, besides public lands, large areas of private farmland and suburbs on Long Island and mainland New York state. Aerial spraying of DDT formulated with fuel oil took place, leaving an oily scum on private and public property alike that people cared about and attended to: cars, swimming pools, houses and yards, as well as pastures and lakes[7]. Not only did fish and birds die as a result, but there were also cases of contaminated and hence unsellable milk and organic vegetables. Numerous complaints were made, prompting Governor Harriman to complain to the Secretary of Agriculture[8].

Some citizens went further than complaints. In an attempt to stop the second year of spraying, on May 8, 1957, Robert Cushman Murphy, a well-known ornithologist (who also maintained a friendly professional correspondence with Rachel Carson), and other prominent residents of Long Island filed suit in federal district court against the Secretary of Agriculture, Ezra Taft Benson, the area supervisor of the Pest Control Branch of Agricultural Research Service within the USDA, and the Agricultural Commissioner of the State of New York, seeking an injunction that would restrain these defendants from continuing with the spraying program, claiming that it might impair citizens' health and endanger their lives. In addition, they believed they had a constitutional right as property owners to keep their land as they wished, free from DDT, likening its spraying to government trespass[9]. The injunction was denied and spraying went ahead, again coating property, killing birds, and causing people to reflect upon its appropriateness and upon the values behind it. One journalist, writing in *The Nation*, described *"the pesticide that came to dinner"* as follows:

> *"The fact that the moth was 'light and scattered' on Long Island's two outer counties, Nassau and Suffolk, did not deflect the government's mighty rage. It sprayed them too, instead of the few localities where the moths were lightly entrenched. It sprayed wash-lines, children's*

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[7] See Cort's (1958) "The Pesticide That Came to Dinner" and Waller's (1958) for vivid descriptions of the effects of the eradication campaigns' aerial spraying.
[8] Dunlap (1981, p 87)
[9] Cort (1958, p 316)

playgrounds, and baby carriages from planes often flying as low as 200 feet. This is a relatively congested suburban area dotted with poultry and vegetable farms and well-tended estates. The overwhelming mass of sprayed acreage had no gypsy moths whatever. Vengeance was visited alike upon the just and the unjust."

(Cort, 1958, p 316)

The case was not heard until February of 1958, when it failed, but only after accumulating 1400 pages of testimony from 50 witnesses[10]. The judge found that a program promising such significant benefits to the community could not be stopped on the grounds of nuisance and that the case presented against DDT based on its impact on human health and the environment was insufficient[11]. This ruling came to take on more significance nearly a decade later when the Environmental Defense Fund, aware of the legal dynamics of this case fought on the grounds that DDT constituted a public nuisance, made an explicitly stated point of *not* litigating on this particular legal terrain, and asserted instead that DDT spraying violated other even more fundamental rights (discussed later in this Chapter)[12].

At the hearing, the cases presented by both sides were basically those presented a few years earlier before the Delaney Committee[13]. On human health, the Public Health Service's Dr. Wayland Hayes' findings from studies of overexposed human populations (workers in DDT manufacturing plants, and "volunteer" research subjects recruited from prison populations) were not seriously challenged. The testimony of Dr. Malcolm Hargreaves, a hematologist whose research investigated the links between DDT and blood diseases, was found to be overly speculative. This was also the case with the testimony of Murphy who, besides describing the immediate impact of DDT spraying, addressed the potential for long term systemic damage to local ecosystems and the economic activity that depended on them. DDT and spraying program supporters conceded that *misuse* of DDT could pose a danger to wildlife, but asserted that when properly applied, bird and animal casualties were minimal and that DDT was safe for

[10] Rudd (1964, p 29)
[11] Dunlap (1981, p 89); also Rudd (1964, p 29)
[12] Yannacone interview

wildlife. The case went all the way to the Supreme Court where it was ultimately rejected, although Justice William O. Douglas wrote a dissenting opinion[14].

6.3 A Contest of Values Triggered Initially by Dead Robins on Suburban Lawns

Other citizens began to question the widespread spraying of DDT in the gypsy moth eradication campaign, explicitly framing their protests in the language of values and even rights. Speaking at the 53rd Annual Convention of the National Audubon Society, November 11, 1957 in New York City, Mrs. Wilhelmine Waller described the effects of *preventive* - and not *eradicative*, she stressed - spraying on her family's farm property and her objections in the following terms:

> *"**Death came to many forms of wildlife on our farm as a direct result of the spraying.** ... We found during the period of from 48 hours to a month after the spraying, the following dead birds: two goldfinches, one Baltimore oriole, and five starlings, and, in addition, three obviously sick pheasants. ... Now to summarize the damage on our own property: our milk and pastures were contaminated - our spinach crop ruined and our peonies spoiled - our horses were dangerously frightened by low flying planes - our fish and pond life and many valuable predatory and parasitic insects killed, and our wild birds definitely affected. But our chagrin and sorrow goes much deeper than this visible damage. First, **we question the right of the U.S. Department of Agriculture to carry out a program the far-reaching results of which are still an unknown factor.** ... Second, we strongly object to the manner in which the program was carried out. ... I have always been proud of being an American - proud of the freedom of thought and action so largely responsible for this country's greatness. But since the blanket spraying of personal property last spring, and the manner in which the U.S. Department of Agriculture carried out the spray program, **I have been just a little less proud of this country**, ..."*
>
> (Waller, 1958, p 70)

In the meantime, other massive spray efforts were being undertaken against mosquitoes, fire ants, Japanese beetles, spruce budworms and the bark beetles which spread Dutch

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[13] This paragraph has been condensed from Dunlap (1981, p 88)

elm disease. This spraying activity also resulted often in high bird and wildlife mortality; fish suffered as well from these eradication efforts and from agricultural uses of DDT. The term "fish kill" refers to instances characterized by the sudden death of large numbers of fish in a body of water, and is a standard one in the pesticide domain:

> *"Fish kills resulting from DDT use have been documented on numerous occasions. For example, dead and dying fish have been observed when heavy rainfalls followed application of DDT to Mississippi cotton fields."*
> (EPA, 1975, p 41)

I do not have the space here to detail and discuss all instances of acute bird, fish and wildlife mortality linked to the use of DDT and other pesticides, or even those that generated some sort of public reaction; the literature is volumous[15]. I will instead focus here on one particular *problem* for the focal *product* DDT in one particular *market*. I will focus on bird mortality which resulted immediately following and directly as a result of spraying to control Dutch elm disease to illustrate how different values came to dominate in insect control decision-making in this market and eventually led to the substitution of DDT by methoxychlor for this particular purpose. But readers should keep in mind the wider controversy and debate over the impact of DDT on *all* life forms, including humans, which formed the context within which struggles over particular uses, like that for Dutch elm disease control, took place. Also, the impact of Rachel Carson's *Silent Spring* was felt way beyond the Dutch elm disease market for insecticides, but I present this author and her book in this section to facilitate the chronological recounting of the story.

The spraying of DDT against Dutch elm disease, spread by its insect vector of bark beetles, took place throughout much of the Eastern and Midwest United States[16]. The fact that this disease attacked predominantly ornamental elm trees located in parks and

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[14] Lear (1997, p 319)
[15] For a comprehensive review of the impact of DDT and other pesticides, see Pimentel's (1971) report prepared for the President's Office of Science and Technology entitled *Ecological Effects of Pesticides on Nontarget Species*.
[16] This discussion of Dutch elm disease spraying has benefited greatly from: Rudd (1964); Dunlap (1981). Rachel Carson also discusses it (1962, p 114).

along streets where adults and children were to be found meant that treatments with arsenicals were never practical[17]. But the arrival of DDT gave government scientists and municipalities worried about their elms hope that the disease might be overcome. As early as 1947 the Bureau of Entomology and Plant Quarantine of the USDA began experimental spray programs in Princeton, New Jersey[18]. Dead birds and complaints of residents resulted, but these were dismissed by officials as unimportant and spraying programs proliferated, becoming especially aggressive in the mid 1950s. By 1964, over two million acres had been sprayed with DDT, mostly dispersed with large volumes of water and with doses ranging from 2.5 to over 17 pounds of active ingredient per tree[19].

It was at that point, in the mid to late 1950s, that voices of protest, expressed locally for the most part, grew noticeably louder, motivated by the immediate avian mortality caused by the spraying. Upon observing, first hand, birds already dead or in the process of dying with violent tremors (this neurological effect was called the "DDT jitters"), not all citizens accepted the calculus of officials that had weighed the lives of the trees against the lives of the birds and found the public interest to be with the former.

Accounts of the effects of spraying on birds and wildlife, and the debate over them, began to appear in public discourse, at town hall meetings and in the popular press: *"Ground-feeding birds, particularly robins, have seriously declined in several states where elm trees have been treated in DDT for Dutch elm disease control. The birds die of poisoned earthworms eaten many months after the trees have been sprayed."* wrote Dr. Robert Rudd in *The Nation* early in 1959, describing proponents of the eradication programs as *"irresponsible poisoners"*[20]. Articles such as those listed in Table 6.3.1 appeared in the popular press in the decade preceding the publication of *Silent Spring*, especially in magazines aimed at people who *cared about* and hence *attended to* birds, wildlife and the outdoors (which is why I have included the articles which appeared in

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[17] Dunlap (1981, p 79)
[18] Dunlap (1981, p 80)
[19] Rudd (1964, p 33)
[20] Rudd (1959b, p 497)

the magazine of the National Audubon Society, an organization which became quite engaged with the movement to ban DDT).

Table 6.3.1 - Examples of Popular Press Articles Featuring "Injurious Effects" of Pesticides, Insecticides &/or DDT

Periodical	Title	Date
Audubon	Wildlife in a chemical world	May-52
Audubon	Death in Florida marshes	Sep-52
Audubon	Insecticides, boom or bane?	May-56
Audubon	Company abandons agricultural insecticides	Sep-57
Audubon	Effects of chemical sprays on wildlife	Mar-58
Audubon	Poison on the land: property owners' viewpoint on aerial spraying of DDT	Mar-58
Audubon	Insecticides are a threat to humans and wildlife	Mar-58
Audubon	Some suggestions for needed research	Mar-58
Audubon	Cure worse than the disease: fire ant treatments	Jul-58
Audubon	US is losing its bald eagles: sterility suspected. DDT cited	Nov-58
Audubon	Greatest killing program of all?	Nov-58
Audubon	Insecticides and birds	Jan-59
Audubon	Protest against spraying	Jul-59
Audubon	Another year of robin losses on a university campus	Mar-60
Audubon	Needed: a coordination act for pesticides	May-60
Audubon	Price of DDT	Jul-60
Audubon	Silent killer of wildlife: excerpt from Chemicals in your Food	Sep-61
American Forests	Are we slowly committing suicide?	May-58
American Forests	Court upholds DDT spraying	Aug-58
American Forests	Truth about chemical controls	Nov-58
American Forests	Man vs. ant; fire ant menace	Nov-58
American Forests	Pesticides, blessing or curse?	Nov-58
Field and Stream	Pesticides a menace?	Aug-57
Field and Stream	Poison from the air: the fire ant program	Feb-59
Field and Stream	Pesticides: doom in small doses	Jun-59
Newsweek	Did DDT do it?	Feb-58
Newsweek	Insects revenge	Jul-61
Outdoor Life	Insecticides and dead fish	Aug-57
Outdoor Life	Will spraying boomerang?	Jun-58
Outdoor Life	Big Spray trouble	Mar-59
Readers Digest	Backfire in the war against insects	Jun-59
Sat Evening Post	Pesticides are good friends, but can be dangerous enemies if used by zealots	Sep-61
Science digest	Are our songbirds doomed?	Jun-59
Science digest	Bird mortality boosted by DDT	Mar-60

By the end of the 1950s, the ratio of popular press articles addressing the injurious effects of insecticides to those dealing with insecticides in general increased substantially, as shown in Table 6.3.2. Notice also how articles on "injurious effects" of DDT disappeared from the public arena after the initial discussion of this *"double-edged sword"* during its entry into the economy in the late 1940s, as presented in Chapter 5.

Table 6.3.2 - Pesticide, Insecticide &/or DDT Discourse on "Injurious Effects"

"Injurious Effects" Articles as % of Total in the Popular Press, by subject:

	Pesticides	Insecticides	DDT
Mar-82/Feb-83	38	-	75
Mar-81/Feb-82	49	-	-
Mar-80/Feb-81	27	-	100
Mar-79/Feb-80	40	58	-
Mar-78/Feb-79	31	50	50
Mar-77/Feb-78	28	42	-
Mar-76/Feb-77	21	50	0
Mar-75/Feb-76	15	25	17
Mar-74/Feb-75	30	18	0
Mar-73/Feb-74	18	17	20
Mar-72/Feb-73	5	20	41
Mar-71/Feb-72	13	36	32
Mar-70/Feb-71	16	43	19
Mar-69/Feb-70	59	27	40
Mar-68/Feb-69	16	27	71
Mar-67/Feb-68	31	50	55
Mar-66/Feb-67	23	22	80
Mar-65/Feb-66	36	20	50
Mar-63/Feb-65	60	49	100
Mar-61/Feb-63	79	57	86
Mar-59/Feb-61	0	79	80
Mar-57/Feb-59	0	63	85
Mar-55/Feb-57	0	11	0
Apr-53/Feb-55	-	0	0
Apr-51/Feb-53	-	7	0
May-49/Apr-51	-	0	30
May-47/Apr-49	-	0	5
May-45/Apr-47	-	0	0
July-43/Apri-45	-	0	0
July-41/June-43	-	0	-
July-39/June-41	-	0	-
July-37/June-39	-	0	-
July-35/June-37	-	0	-

* Data for this and the previous Table is from the DDT Discourse database, described in Chapter 2. The ' - ' means that no popular press articles were referenced according to that subject that year.

In addition, letters to the editors of local newspapers openly questioned the wisdom - and justice - of these campaigns and similar ones against mosquitoes. For example, a Mrs. Olga Huckins wrote to the Boston Globe. She believed that the spraying was "*inhuman, undemocratic and probably unconstitutional*", an affront to values that resonated with her and many others, including Rachel Carson to whom she also wrote[21]. Though seemingly trivial, these small acts of protest during this period of growing public ferment did have consequences. Indeed, "*In a letter written January 1958, Olga Owen Huckins told me of her own bitter experience of a small world made lifeless, and so brought my attention sharply back to a problem with which I had long been concerned. I then realized I must write this book.*" acknowledged Miss Carson a few years later in the her acknowledgements which appeared in the first pages of *Silent Spring.*[22]

6.4 Rachel Carson's *Silent Spring*

6.4.1 Rachel Carson

Rachel Carson was born on May 27, 1907, in Springdale, Pennsylvania[23]. Ever since her childhood she had pursued her passion for writing. She published her first literary work in 1918 in *St Nicholas*, an illustrated children's magazine[24]. In 1932, she received her Masters of Arts degree from the department of zoology at Johns Hopkins University, which she had entered on a scholarship[25].

In 1936, Miss Carson accepted a job with the Bureau of Fisheries in the United States Department of the Interior where she wrote "seven-minute fish tales" - scripts for a public education radio series produced by the Bureau called "Romance Under the Waters"[26]. She replaced an expert on fish biology who had had problems making it interesting for

[21] Lear (1997, p 314)
[22] Carson (1962, p xiii)
[23] This section on Rachel Carson is drawn mostly from Lear (1997), supplemented by Brooks (1972).
[24] Lear (1997, p 7)
[25] Lear (1997, p 74)
[26] Lear (1997, p 78)

the public. Her work was appreciated and before long she was responsible for preparing other government documents destined for laypeople. Leveraging what she was learning from her work on the radio scripts, and with access to Bureau libraries as a government scientist, she also began to write densely researched articles for local newspapers. In September of 1937, she had an article published in the *Atlantic Monthly.*[27]

In 1939, as part of the Government Reorganization Act, a new conservation agency - the US Fish and Wildlife Service - was created in the Department of the Interior[28]. It combined the Bureau of Fisheries from the Department of Commerce with the U.S. Biological Survey from the USDA[29]. As a writer and editor and finally editor-in-chief of the Fish and Wildlife's publications, Miss Carson had access to information about the many technological discoveries flowing from the war effort[30]. Of particular significance, she had access to internal government reports concerned with predator and pest control, as well as access to reports about experiments being carried out at Patuxent by her mentor and former boss at the Bureau of Fisheries, Elmer Higgins, at that time working with wildlife biologist Clarence Cottam, who also became a friend of Miss Carson. These two researchers published one of the first articles detailing the effects of DDT on fish, birds and wildlife with their "DDT and Its Effect on Fish and Wildlife", which appeared in *The Journal of Economic Entomology* in February of 1946. Their research was undertaken with the assistance of the National Audubon Society among other organizations, and concluded with the recommendation *"Don't use DDT unless you must."*[31].

On July 15, 1945, Miss Carson wrote to Harold Lynch at Reader's Digest with a suggestion for a story about DDT:

> *"Practically at my backdoor here in Maryland, an experiment of more than ordinary interest and importance is going on. We have all heard about what DDT will soon do for us by wiping out insect pests. The*

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[27] Lear (1997, p 87)
[28] Lear (1997, p 95)
[29] USDA (1963)
[30] Lear (1997, p 118)
[31] Cottam & Higgins (1946, p 51)

experiments at Patuxent have been planned to show what other effects DDT may have when it is applied to wide areas: what it will do to insects that are beneficial or even essential; how it may affect waterfowl, or birds that depend on insect food; whether it may upset the whole delicate balance of nature if unwisely used."[32]

Her idea was rejected, but she went on with other writing projects, ultimately achieving fame and fortune. She published in 1950 a chapter of her upcoming book *The Sea Around Us* entitled "Birth of an Island" in the *Atlantic Naturalist* and later in the *Yale Review* and won that year's Westinghouse Science Writing Award[33]. Her writing was poetic yet scientifically accurate. Few authors could communicate the intricate details of biological life and the natural world with as much affect and effect as her. Her works were infused with a profound respect for nature. Consider her winning entry to a competition sponsored by *Outdoor Life* seeking the best "Conservation Pledge" for young Americans, in 1946:

"I pledge myself to preserve and protect
America's fertile soils, her mighty forests
and rivers, her wildlife and minerals,
for on these her greatness was established
and her strength depends."[34]

Also in 1950, Miss Carson discovered she had a tumour in her breast, much larger than the cyst she had removed in 1946[35].

Rachel Carson published *The Sea Around Us* in 1951, after *The New Yorker* had bought 9 of its chapters and had her condense them into 3 parts, publishing them as a "Profile of the Sea". This was the first time ever that a nonhuman had been so "profiled" by this respected magazine, and it received much critical acclaim[36]. Her book made her a literary celebrity. It was condensed in *Reader's Digest* and eventually came to be

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[32] Letter is cited in Lear (1997, p 118)
[33] Lear (1997, p 189)
[34] Pledge is cited in Lear (1997, p 137)
[35] Lear (1997, p 184)
[36] Brooks (1972, p 126)

published in 33 languages, staying on the U.S. best seller lists for an incredible 86 weeks, with 32 of them spent in first place. Miss Carson received the National Book Award for Non-fiction in 1951. Upon receiving the award, she addressed the crowd by drawing attention to what would come to be an important theme for her, especially in *Silent Spring*, the growing elitism in science and its detachment from everyday human life:

> *"Many people have commented with surprise on the fact that a work of science should have a large popular sale.* ***But this notion that 'science' is something that belongs in a separate compartment, apart from everyday life, is one that I should like to challenge.*** *We live in a scientific age; yet* ***we assume that knowledge of science is the prerogative of only a small number of human beings, isolated and priestlike*** *in their laboratories.* ***This is not true. It cannot be true.*** *The materials of science are the materials of life. Science is part of the reality of living; it is the what, the how and the why of everything in our existence. It is impossible to understand man without understanding his environment and the forces that have molded him physically and mentally. ....*
>
> *" ... the aim of science is to discover and illuminate truth. And that, I take it, is the aim of literature, whether biography or history or fiction. It seems to me then that there can be no separate literature of science. ..*
>
> *"The winds, the sea, and the moving tides are what they are. If there is wonder and beauty and majesty in them, science will discover these qualities. If they are not there, science cannot create them.* ***If there is poetry in my book about the sea, it is not because I deliberately put it there, but because no one could write truthfully about the sea and leave out the poetry."***[37]

Speaking in 1952 to an audience gathered to celebrate her winning of the Burroughs Medal for excellence in nature writing, she made herself even more clear:

> *"Mankind has gone very far into an artificial world of his own creation. He has sought to insulate himself, in his cities of steel and concrete, from the realities of earth and water and the growing seed.* ***Intoxicated with a***

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[37] Carson's acceptance speech of 1952 01 29 is reprinted in Brooks (1972, p 127) and is also cited in Lear (1997, p 219).

sense of his own power, he seems to be going farther and farther into more experiments for the destruction of himself and his world."[38]

Having taken a leave of absence from the Fish and Wildlife Service before her first book was published, Miss Carson officially resigned effective June 3, 1952, to devote her full time to writing[39]. She went on to publish another book, *The Edge of the Sea*, in 1955, and again the book itself appeared only after parts of it had been serialized in the New Yorker.

Involved with her local branch of the Audubon Society, Miss Carson became aware in 1957 of the USDA's plans for massive fire ant eradication programs, which were strongly criticized in birdwatching circles. She also followed closely the efforts of a group of citizens on Long Island, led by her friend the ornithologist Robert Cushman Murphy, to legally force the cessation of the spraying of their properties with a mixture of DDT and fuel oil to fight Dutch elm disease and mosquitoes. Never fully at ease with pesticides, ever since being privy to government reports in the FWS during WWII, Miss Carson undertook a research and writing project that would change the world.

6.4.2 Silent Spring

Miss Carson began to write Silent Spring in 1958, with a working title that was initially "Control of Nature", but which was rejected for being too inclusive. Later titles included "Man Against the Earth", "Dissent in Favour of Man", and finally *Silent Spring*[40]. Her reputation opened up lines of communication very easily, and she had collaborators in both science and government, including: C. J. Briejer (Director of the Dutch Plant Pest Control Service); William L Brown Jr. (Curator of Insects at Harvard's Museum of Comparative Zoology, later at NY State College of Agriculture at Cornell); Clarence Cottam (one of America's leading wildlife specialists, who had been her superior at the

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[38] Carson's speech of 1952 04 07 is reprinted in *Atlantic Naturalist* (1952) 7, 5, pp 232-234, and is also cited in Lear (1997, p 221).
[39] Lear (1997, p 233)

Fish and Wildlife Service, later the Director of the Welder Wildlife Foundation in Sinton, Texas); Robert Rudd (zoologist at university of California who had published papers on the impact of pesticides on wildlife and who was working on his own book - *Pesticides and the Living Landscape*); John J Biesele (professor of Zoology at the University of Texas); many ex-colleagues at the US Fish and Wildlife Service; a friendly informant at the USDA; and Supreme Court Justice William O Douglas, among others[41]. She spent a great deal of time at the Library of Medicine at the National Institutes of Health, motivated by her conviction that:

> "... ***what I will be able to achieve is a synthesis of widely scattered facts,*** *that have not heretofore been considered in relation to each other. It is now possible to build up, step by step, a really damning case against the use of these chemicals as they are now inflicted upon us.*"[42]

She was also aware that she was about to engage in a battle, and framed her work in those terms; though she was urged to speak out by her friends, she was reluctant to display her arsenal of facts prematurely.

> "*But as you know* [she is writing here to Clarence Cottam], *the whole thing is so explosive and the pressures on either side so powerful and enormous, that I feel it far wiser to keep my own council insofar as I can until I am ready to launch my attack as a whole.*"[43]

When later she learned that near her home town of Silver Spring, Maryland, the local government was considering a spraying program, she broke her silence, attended a town meeting and spoke out against it. The community association voted decisively against spraying[44].

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[40] Lear (1997)
[41] Brooks (1972); Lear (1997)
[42] Carson's correspondence is cited in Lear (1997, p 340).
[43] Carson's correspondence is cited in Lear (1997, p 342).
[44] Brooks (1972, p 259)

In 1960, Rachel Carson learned that she had cancer, underwent a mastectomy, and began radiation treatment[45]. Her life became more precious; her work became more urgent.

In that same year she served on the Natural Resources Committee of the Democratic Advisory Council, working for the election of John F. Kennedy. This committee recommended in its report submitted to the candidate that a new "Bureau of Environmental Health" be created in the Federal government[46]. Upon his election, she received a personal thank-you note from the President. Later, in spring of 1962, she attended Interior Secretary Stewart Udall's White House Conference on Conservation, convened at President Kennedy's request, where she was invited as a distinguished guest[47]. By this time proof copies of *Silent Spring* were available and many delegates to this conference had received one. Those who did not were advised to be on the lookout for the coming June 16 issue of the New Yorker.

Paul Knight, a senior member of Udall's staff, was assigned to follow the book's reception and to report back to his boss political information and suggestions for public policy that might surface[48]. Udall was one of the earliest politicians to make a career as an "environmentalist" politician. CBS Reports, a news analysis program, had heard of the imminent publication of *Silent Spring* and had contacted her publisher to secure the rights to a television interview[49]. The Book of the Month Club confirmed that *Silent Spring* would be its choice for October[50]. Soon after, the first installment of *Silent Spring* appeared in the New Yorker. The pesticide domain would never again be the same.

> *"The publication of* Silent Spring *in 1962 marked the end of closed debate in this field. Rachel Carson uncovered the hiding places of facts that should have been disclosed to the public long before; she broke the information barrier. Much of the subsequent history of pesticide policy is a response (pro and con) to Rachel Carson's judgment."*
>
> (Graham, 1970, p xii)

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[45] Lear (1997, p 364, 378)
[46] Lear (1997, p 376)
[47] Lear (1997, p 406)
[48] Lear (1997, p 406)
[49] Lear (1997, p 407)
[50] Lear (1997, p 408)

Rachel Carson brought the questions, debates, claims and counter-claims about pesticides from the pages of obscure scientific journals and little-read government reports out into public, an act of *discursive entrepreneurship* that ushered in a new era of insect control technology as surely as prior more traditional entrepreneurial acts of bringing new products to markets. *"DDT's marketing problems began in earnest with the publication of the late Rachel Carson's Silent Spring"* wrote *Chemical Week* in 1969[51].

Perhaps the best way to begin to communicate the impact of Miss Carson's writing is simply to reproduce it and to allow readers the opportunity to experience it themselves. The first portion of the New Yorker serialization, a shortened version of the first chapter of Silent Spring, "A Fable for Tomorrow" is shown in Table 6.4.2.1.

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[51] see Graham (1970, p 232)

Table 6.4.2.1 - A Fable for Tomorrow

There was once a town in the heart of America where all life seemed to be in harmony with its surroundings. The town lay in the midst of a checkerboard of prosperous farms, with fields of grain and hillsides of orchards, where white clouds of bloom drifted above the green land. In autumn, oak and maple and birch set up a blaze of color that flamed and flickered across a backdrop of pines. Then foxes barked in the hills and deer crossed the fields, half hidden in the mists of the mornings. Along the roads, laurel, viburnum, and alder, great ferns and wild flowers delighted the traveler's eye through much of the year. Even in winter, the roadsides were places of beauty, where countless birds came to feed on the berries and on the seed heads of the dried weeds rising above the snow. The countryside was, in fact, famous for the abundance and variety of its bird life, and when the flood of migrants was pouring through in spring and fall, people came from great distances to observe them. Other people came to fish streams, which flowed clear and cold out of the hills and contained shady pools where trout lay. So it had been from the days, many years ago, when the first settlers raised their houses, sank their wells, and built their barns.

Then, one spring, a strange blight crept over the area, and everything began to change. Some evil spell had settled on the community; mysterious maladies swept the flocks of chickens, and the cattle and sheep sickened and died. Everywhere was the shadow of death. The farmers told of much illness among their families. In the town, the doctors were becoming more and more puzzled by new kinds of sickness that had appeared among their patients. There had been several sudden and unexplained deaths, not only among the adults but also among the children, who would be stricken while they were at play, and would die within a few hours. And there was a strange stillness. The birds, for example--where had they gone? Many people, baffled and disturbed, spoke of them. The feeding stations in the back yards were deserted. The few birds to be seen anywhere were moribund; they trembled violently and could not fly. It was a spring without voices. In the mornings, which had once throbbed with the dawn chorus of robins, catbirds, doves, jays, and wrens, and scores of other bird voices, there was now no sound; only silence lay over the fields and woods and marshes. On the farms, the hens brooded but no chicks hatched. The farmers complained that they were unable to raise any pigs; the litters were small, and the young survived only a few days. The apple trees were coming into bloom, but no bees droned among the blossoms, so there was no pollination and there would be no fruit. The roadsides were lined with brown and withered vegetation, and were silent, too, deserted by all living things. Even the streams were lifeless. Anglers no longer visited them, for all the fish had died. In the gutters under the eaves, and between the shingles of the roofs, a few patches of white granular powder could be seen; some weeks earlier this powder had been dropped, like snow, upon the roofs and the lawns, the fields and the streams. No witchcraft, no enemy action had snuffed out life in this stricken world. The people had done it themselves.

* Excerpted from "A Reporter at Large - Silent Spring I" by Rachel Carson, June 16, 1962, The New Yorker, 35-99

** A Fable for Tomorrow is the title of the first Chapter of *Silent Spring*, from which Rachel Carson drew material for this particular excerpt from the serialization of that book.

The next two installments appeared in subsequent editions, while Carson worked frantically to prepare the book for fall publication. Before it was published it had been bought by the Book-of-the-Month Club and advance sales were 40,000 copies by September 27, its day of publication by Houghton-Mifflin[52].

Reaction to the *New Yorker* serialization and the actual publication was nothing if not spectacular. Reviewers, commenting on the uproar and activity that had been generated by her work, refereed Miss Carson's creation of a *"not-so-silent spring"* and a *"noisy summer"*[53]. One reviewer, Dr. William J. Darby, a Professor and Chairman of the Department of Biochemistry and Director, Division of Nutrition at Vanderbilt University School of Medicine who was also a member and past Chairman of the Food Protection Committee, National Academy of Sciences-National Research Council and a member of the NAS-NRC Food and Nutrition Board, writing in *Chemical & Engineering News*, entitled his book review with a simple command: *"Silence, Miss Carson"*.[54]

Coincidentally, in July, the thalidomide scare reinforced a main theme of her work. Never permitted for sale in the United States, the drug thalidomide, it was revealed that summer, was the cause of horrible birth defects when taken by women during their first few months of pregnancy, as was the case with more than a thousand unfortunate European and Canadian families. Commenting to a reporter, Rachel Carson made the connection between that drug and pesticides explicit; chemical products were being used without full knowledge of their consequences[55].

Her book was widely reviewed; it appeared as if nobody ignored Carson's book and that nobody was left indifferent after reading it. Strongly worded reviews appeared both for and against the text, as well as its messenger. Some attacks were sexist and personal, while many focused on Miss Carson's lack of scientific credentials. She had, after all, not

[52] Lear (1997, p 411)
[53] See *The New York Times Book Review* (1962 09 23, p 26) for example.
[54] Darby (1962)

earned a Ph.D. (although she had received a few honorary doctorates for her previous writing). Others reacted, ironically, with much emotion at Carson's "emotionalism". Many criticized her "biased" and "selective" use of facts. This was not a scientific document, they scorned, and the author was no scientist. This critique missed the point according to other reviewers, more sympathetic, who understood *Silent Spring*, as its author did, to be a document that was based on fact yet specifically designed to awaken and to stir the public sentiment. Supreme Court Justice William O. Douglas, the dissenting opinion in the Long Island spraying case, wrote a review of *Silent Spring* for the Book-of-the-Month Club in which he stated *"This book is the most important chronicle of this century for the human race. The book is a call for immediate action and for effective control of all merchants of poison."*[56]

Silent Spring is both a scientific and political synthesis. Carson's biographer and others refer to it as *"a fundamental social critique of a gospel of technological progress"*[57]. Covering an incredible range of scientific material - entomology, wildlife biology, ecology, and various disciplines within medicine - it pulled together facts that, once assembled, organized and juxtaposed in her manner, called into question the operation and organization of the pesticide domain. *Silent Spring* indicted industry, the government (especially the USDA) and even scientists. Using the various and numerous problems (presented in Chapter 3) of pesticide use as threads, she began to tie together a vast set of diverse actors and to stitch the fabric of arguments that would incite and unite a coalition. Certainly Miss Carson was conscious that she and other DDT opponents were up against a coalition that included not only NACA members, but the USDA in government, the vast majority of economic entomologists, and many toxicologists, medical doctors and public health researchers in science. Drawing attention to the network of actors allied against her and her own network, she publicly posing the following pointed questions:

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[55] Dunlap (1981, p 105); Lear (1997, p 412)
[56] Douglas (1962)
[57] Lear (1997, p 429)

"As you listen to the present controversy about pesticides, I suggest you ask yourself - Who speaks? - And why?."[58]

"When the scientific organization speaks, whose voice do we hear, that of science or of the sustaining industry?"[59]

Note her emphasis on "speaking" and "voices"; this, along with the review which called for *"Silence, Miss Carson"* has undoubtedly influenced my own preferences as to the best terminology and set of concepts for communicating my findings. My emphasis on discourse and discursive struggle has not been imposed blindly upon the data.

6.5 The Discursive "Era of Ferment" Following the "Discontinuity" of *Silent Spring*

6.5.1 *Reactions to Silent Spring in the Public Arena*

Rachel Carson moved the discourse about DDT and other pesticides from the obscure pages of scientific journals and government documents to the front pages of national newspapers and even directly into the living rooms of average Americans via television. The book generated a lot of activity in politics and government: candidates for public office began writing to Miss Carson asking what she suggested as an appropriate stand on the pesticide issue; portions of the *New Yorker* serialization were read into the Congressional Record; in August of 1962, President Kennedy, familiar with both the book and its author, answered a reporter's question at a press conference by referring to Miss Carson by name, assuring the public that his officials were already examining the matter of pesticides[60].

And so they were. Dr. Jerome B. Weisner, Special Science Advisor to the President, had called a meeting on the subject of pesticides to which all concerned bureau chiefs went and at which he appointed a task force (PSAC) to report back in a few months.

[58] Speech to Garden Club of America, 1963 01 08, is cited in Lear (1997, p 440)
[59] Speech to Women's National Press Club, 1962 12 05, is cited in Lear (1997, p 426)

CBS produced a documentary film *The Silent Spring of Rachel Carson*, which aired April 3, 1963, although the interviews with Miss Carson which appear in the film had been conducted the prior year[61]. The documentary included comments from Dr. Luther Tery (US Surgeon General); Orville L Freeman (Secretary of Agriculture); George Larrick (Commissioner of the FDA); John Buckley (Department of the Interior); Robert White-Stevens (American Cyanamid); and Rachel Carson. The contrast of Carson, quiet and assured, with American Cyanamid's Dr. Robert White-Stevens predicting that *"If man were to faithfully follow the teachings of Miss Carson, we would return to the dark Ages, and the insects and diseases would once again inherit the earth."*[62] was notable. What shone through in the hour long broadcast was all the ignorance: basic questions could not be answered or were evaded by officials and experts. This must have unnerved the more than 10,000,000 viewers.

After the broadcast, Senator Hubert Humphrey from Minnesota revealed that he had asked Senator Abraham Ribicoff from Connecticut to preside over a broad review of environmental problems, including pesticides. Rachel Carson eventually appeared before the Ribicoff sub-committee to offer her recommendations on pesticide use and used her forty minutes, besides detailing the evidence of pesticide pollution and hazards she had accumulated, to call for *"the right of the citizen to be secure in his own home against the intrusions of poisons applied by other persons." "I speak not as a lawyer but as a biologist and as a human being, but I strongly feel that this is or should be one of the basic human rights."*[63].

In May 15, 1963, the PSAC report entitled *Use of Pesticides: A Report of the President's Science Advisory Committee*[64] was released. Selected findings are reproduced in Table 6.5.1.1.

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[60] Lear (1997, 419)
[61] As part of my data collection, I viewed this film a few times. It is difficult to communicate the strong emotional impact of hearing Rachel Carson in her own voice reading from *Silent Spring*.
[62] CBS film
[63] Rachel Carson's testimony is cited in Lear (1997, p 454)
[64] PSAC (1963)

Table 6.5.1.1. - PSAC Report, Selected Findings & Recommendations

Selected Findings:

In recent years, we have recognized the wide distribution and persistence of DDT *(p 5).*

... ***biological methods of insect control have received relatively little attention in the United States by comparison with the great emphasis on chemical control. ...the panel believes this approach should be expanded*** *(p 14)*

... The Panel has found that decisions on safety are not as well based as those on efficacy *despite recent improvements in the procedures required by the Federal Food, Drug and Cosmetic Act for the establishment of safe tolerances for pesticide residues on food (p 17).*

... Current registration procedures are primarily intended to protect people and domestic animals from damage by pesticides. ***The protection of fish and wildlife resources will require affirmation of this intent by Congress.*** *... the Panel believes that the Secretary of the Interior should actively participate in review of all registrations that may affect fish and wildlife (p 18).*

... Although eradication of a pest population is a laudable goal, it is seldom realistic. Control programs by contrast, apply pesticides in less volume, to a smaller land area, with fewer undesirable side effects at any one time, yet produce the same economic results. ***The gypsy moth, fire ant, Japanese beetle, and white-fringed beetle programs, which have been continued for years, are examples of failures of the "eradication" approach.*** *(p 18)*

Selected recommendations:

In order to augment the safety *of present practices, it is recommended that ... the accretion of residues in the environment be controlled by* ***orderly reduction in the use of persistent pesticides.*** *As a first step, the various agencies of the Federal Government might restrict wide-scale use of persistent insecticides except for necessary control of disease vectors. The Federal agencies should exert the leadership to induce the States to take similar actions.* ***Elimination of the use of persistent toxic pesticides should be the goal.***

__In order to develop safer, more specific controls of pests,__ it is recommended that Government-sponsored programs continue __to shift their emphasis from research on broad spectrum chemicals to provide more support on:__

> ***(a) selectively toxic chemicals***
> ***(b) nonpersistent chemicals***
> ***(c) selective methods of application***
> ***(d) nonchemical control methods such as the use of attractants and the prevention of reproduction.***

The Panel recommends that toxicity studies include determination of -

> *(a) **Effects on reproduction through at least two generations** in at least two species of warm-blooded animals. Observations should include effects on fertility, size and weight of litter, fetal mortality, teratogenicity, growth and development of sucklings and weanlings.*
> *(b) **Chronic effects** on organs of both immature and adult animals, with particular emphasis on tumorigenicity and other effects common to the class of compounds of which the test substance is a member.*

The Panel recommends expanded research and evaluation by the Department of the Interior of __the toxic effects of pesticides on wild vertebrates and invertebrates__.

In order to strengthen public laws on pesticides, it is recommended that amendments to public laws be requested. These should ... __clarify the intent of the Federal Insecticide, Fungicide and Rodenticide Act to protect fish and wildlife by including them as useful vertebrates and invertebrates__.

__To enhance public awareness of pesticide benefits and hazards,__ it is recommended that the appropriate Federal departments and agencies initiate programs of __public education__ describing the use and the toxic nature of pesticides. Public literature and the experiences of the Panel members indicate that, __until the publication of Silent Spring by Rachel Carson, people were generally unaware of the toxicity of pesticides__. The government should present this information to the public in a way that will make it aware of the dangers while recognizing the value of pesticides.

Though not as critical nor hard-hitting as Miss Carson and her supporters would have liked, it nevertheless signaled the dissatisfaction of the Administration with the present pesticide situation and their tendency to side with them rather than the supporters of agricultural chemicals. Some media reported that "*Rachel Carson Stands Vindicated*"[65].

Moving back to 1962 to look at industry's reaction, after Kennedy's new conference, NACA moved quickly to issue its own booklet entitled "*Fact and Fancy*" which pitted Carson's claims against their own (cited to scientific articles), in a tabular point by point comparison[66]. The National Pest Control Association sent a collection of negative book reviews to its members and included a song parody entitled "Rachel, Rachel" which mimicked the lyrics and tune of the old song "Rubin, Rubin" which included the lines that could not be more clear about the contest of values[67]:

Rachel, Rachel, we've been hearing,
All the dread words that you said,
Were they true and Spring was silent,
Then I'm sure we'll soon be dead.

In those lands where stark starvation,
Stalk a child from birth to grave,
Gratitude for food production,
Calms the clamor, knights the brave.

Hunger, hunger, are you listening,
To the words from Rachel's pen?
Words which taken at face value,
Place lives of birds above those of men.

Shortly after *Silent Spring's* publication, Monsanto published "The Desolate Year" in its company magazine, a text which mimicked Carson's style, phrasing, and her "Fable for Tomorrow" which was the first chapter of *Silent Spring*. It described a "*desolate*" world of plagues and starvation in which the "*bugs were everywhere*" if there were not pesticides. A second section sought to set the record straight and was entitled "*Not Fiction, ... Fact*", and ended by quoting the Manufacturing Chemists' Association:

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[65] Lear (1997, p 451)
[66] Lear (1997, p 420)
[67] Reprinted in Lear (1997, p 435)

"Industry, government and non-profit institutions have laboured to create these chemical ***tools****, and to research, develop, test, and establish safety standards for them. Nevertheless, like other tools of our civilization, they are susceptible to misuse and abuse which can result in destruction to crops, harm to humans and pollution of our environment. But instances of such misuse and abuse must not be allowed to obscure* ***the fact*** *that* ***these tools are vital to the health and even survival of humanity.****"*[68]

This was the typical reaction of industry, the USDA and economic entomologists to criticism of DDT and other pesticides: absorb the blow of the critique by "minimizing" it in interpretation. They would concede that yes, sometimes, fish and birds died, but proper training could remedy this. When this didn't silence critics, another strategy they used was to rebuff the blow of the critique by "maximizing" it in interpretation. The ambiguity of the critique of pesticides as to *level of analysis* facilitated this discursive strategy. It was far from clear what DDT opponents of DDT wanted to see changed and/or substituted:

- misapplied DDT?
- excessively applied DDT?
- DDT?
- the persistent organochlorine insecticides?
- all organochlorine insecticides?
- all insecticides?
- all pesticides?
- technology?
- Capitalism?

These last few "levels" seem exaggerated but such accusations were commonplace in the debate over DDT[69]. For example, consider the response of Jamie Whitten, Congressman for the DDT-dependent cotton-growing state of Mississippi and a perennial holder of key

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[68] Cited in "The Desolate Year" in *Monsanto Magazine*, October 1962, p 9

[69] See Lear (1997, p 409, 417) for examples of accusations that "Communists" and "sinister forces" were behind the pesticides controversy. Many of the negative reviews of *Silent Spring* make reference to the horrors of a world without technology. The review in *Time* (1962 09 28, p 45) categorized matter of factly *"pesticides: the price of progress"*.

positions on the House of Representatives Appropriations Subcommittee for Agriculture including over 15 years as Chairman, to *Silent Spring*. He wrote an entire book entitled *That We May Live!* that was published in 1966, that concluded:

> *"As I have tried to make plain,* ***in our fight against Communism our agriculture is perhaps our greatest asset. Its scope embraces both national security and national health.*** *... We must not permit anyone or any group to saddle our sources of food and fiber with the burden of the unknown.* ***We must not restrict our use of our best weapons*** *against insect-borne diseases. ... We must be ready with new weapons and new methods; but in the meantime we must not give up those we have. ...* ***We must use all our known weapons****, as we spend millions of dollars annually in our efforts to find new ones, if we are to enable man to keep that important one step ahead in his continuing contest with insects and disease, with pest and pestilence. To this end we need public understanding, that we may continue to add to the years of our lives,* ***indeed, THAT WE MAY LIVE!*** [his emphasis].
>
> (Whitten, 1966, p 214, 216)

I argue that these discursive strategies are attempts to "enroll" allies in the "struggle" in which the talkers were engaged. The level of the debate defines who would naturally be for and against change and substitution. If DDT opponents had made it clear that they only wanted to see DDT substituted, it is likely they could have gathered the support of the manufacturers of alternative products. By defining the debate at such a broad level, and also by harnessing the discourse of war, DDT supporters escalated the stakes. Note that this applied to DDT opponents as well; *both* sides in the DDT debate attempted to harness fear and emotion.

Within science, an unprecedented amount of research was undertaken focusing on DDT. Beginning with the arrival of DDT, and continuing through the 1950s, wildlife biologists in academia along with those employed by government in the Department of the Interior, had begun to inquire about, study, measure, and document the impact of pesticides on birds, fish and wildlife. Ultimately they would also challenge the wisdom and protest against these impacts, but this did not begin until the end of the 1950s. Dissemination of results, discussion and debate was therefore largely limited to a number of closed professional circles, "inside the black box" of science. With only a few notable exceptions - instances where scientists got involved in public debates and legal challenges over DDT (noted a bit later when I return to the discussion of the fate of DDT in the Dutch elm disease vector control market) - it was not until Rachel Carson published Silent Spring that the problems that DDT and other agricultural chemicals posed for the environment received widespread attention. So although research had been underway prior to *Silent Spring*, it was as if the floodgates had opened, especially in ecotoxicology; the "environmental fate" and the safety of DDT residues to birds, fish and wildlife were investigated like never before. Rather than address all of it here, it will be introduced as the story of the fall of DDT unfolds.

6.6 Rachel Carson: Silenced in Spring, 1964

Weakened by cancer, Rachel Carson died at home of a coronary heart attack on April 14, 1964[70]. Among her pallbearers at Washington's National Cathedral were: Stewart L Udall, Secretary of the Interior; Senator Abraham Ribicoff, who eulogized *"Today we mourn a great lady. All mankind is in her debt."*; Robert Cushman Murphy, the ornithologist who had taken his local government to court to stop it from spraying DDT; Charles Callison of the National Audubon Society; and Edwin Way Teale, a nature writer who had penned an article on the possible ill effects of DDT on wildlife as early as 1945. Even Prince Phillip of England sent a wreath.

> *"Rachel Carson's gifts as both a poet and scientist turned Silent Spring into an eloquent book. Because of her, we undertook landmark hearings in the U.S. Senate that aroused Congress and the nation to the dangers she described. Her purpose, she told me before she died, was to call attention to the ever-increasing contamination on the balance of nature, global in scope and detrimental to mankind."*
>
> (Senator Abraham Ribicoff, 1992
> writing in the foreword to Briggs' *Basic Guide to Pesticides*)

[70] Details of Carson's death and funeral can be found in Lear (1997) and Graham (1970).

6.7 Bird Values Dominate: Methoxychlor Substitutes for DDT for Dutch Elm Disease Vector Control

I will return now to my story of the market for DDT represented by federal, state and municipal programs for Dutch elm disease vector control, what had been simmering dissent just below and at the surface of public life in the late 1950s came to a complete public boil in June of 1962 with the publication of the three-part serialization of Rachel Carson's *Silent Spring* in the New Yorker. Much of her second installment was devoted to a description and critique of the various Federal and State eradication programs, including those aimed at the vector of Dutch elm disease[71]. Besides calling for more consideration of bird and wildlife values in insect control decision-making, Miss Carson also challenged the use of DDT in massive spraying programs on other grounds linked to values and justice, appealing to what she felt were fundamental rights:

> *"We have subjected enormous numbers of people to contact with these poisons, without their consent and often without their knowledge.* ***If the Bill of Rights contains no guarantee that a citizen shall be secure against lethal poisons distributed either by private individuals or by public officials, it is surely only because our forefathers, despite their considerable wisdom and foresight, could conceive of no such problem."***
>
> (Carson, 1962, p 12)

Later, before the Ribicoff Committee in 1963, she would testify:

> *"I hope this committee will give serious consideration to a much neglected problem - that of* ***the right of the citizen to be secure in his own home against the intrusion of poisons*** *applied by other persons."*
>
> (United States Senate Committee on Government Operations, 1966, p 30).

Given impetus by Miss Carson's book, it was not long before concerns of the public began to appear in political discourse as well. President Kennedy's Science Advisory Committee's report explicitly refereed to the effects of spraying for Dutch elm disease on wildlife, as well as those of other Federal and State eradication campaigns. It signaled its support of the inclusion of bird and wildlife values in insect control decision-making by stating:

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[71] Carson (1962)

> *"The protection of fish and wildlife resources will require affirmation by this Congress. Following such action by Congress, the Panel believes the Secretary of the Interior should actively participate in review of all registrations that may affect fish and wildlife."*
>
> (PSAC, 1963, p 18).

It also stated, in no uncertain terms, that *"although eradication of a pest population is a laudable goal, it is seldom realistic"*, described USDA eradication campaigns as *"failures"*, and recommended that Federal pest control programs *"be conducted not only with attention to maximum effect on the target organisms, but with further evaluation of the associated hazards."*[72]. In perhaps the report's clearest signal of the values the Committee wanted to see promoted in insect control decision-making, and most damning as far as DDT was concerned, it stated bluntly:

> *"**Elimination** of the use of persistent toxic pesticides should be the goal."*
>
> (PSAC, 1963, p 20)

Besides public and political activism, the mounting toll of dead birds stimulated scientific research as well. Indeed, these two activities became entwined like they never had before in American life[73]. It was the Dutch elm disease spraying program on his own university campus at Michigan State University, beginning in 1954, that prompted the ornithologist Dr. George Wallace to undertake ongoing multi-year research involving laboratory tests and field monitoring of bird populations[74]. Dr. Charles Wurster Jr. also traces his involvement with the DDT controversy to the spraying of his town for Dutch elm disease, occurring a bit later, around the time of the publication of Silent Spring[75]. He tried to block the spraying locally and failed, but, as the scientific driving force at the heart of the Environmental Defense Fund, would go on later to play a much bigger role in "rule-making" in the domain. Similarly, another scientist whose research and testimony would come to central to the justification of a strong regulatory response to DDT, Dr. Joseph J.

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[72] PSAC (1963, p 18, 19)
[73] Dunlap (1981); Bosso (1987)
[74] Wallace (1959)
[75] Wurster interview

Hickey, also began his involvement with DDT because of Dutch elm disease spraying[76]. In 1958, he just could not comprehend the sight of a mulberry bush loaded with fruit but with no birds on it, and decided to investigate. He began to research the acute effects of DDT spraying on birds by monitoring populations on the University of Wisconsin campus at Madison. This eventually led him to undertake research into more chronic effects of DDT on bird populations and, specifically, the links between DDT and eggshell thinning which would be critical to justifying the ultimate ban on DDT (discussed in the next section of this Chapter). Writing in his comprehensive report, *The Ecological Effects of Pesticides on Non-Target Species*, commissioned by the Office of Science and Technology in the Executive Office of the President of the United States, Pimentel gives an excellent summary of scientific research into DDT's acute toxicity to birds specifically linked to spraying for Dutch elm disease, and it references these scientists specifically:

> *"DDT applied to elms for control of Dutch elm disease resulted in a heavy mortality of robins and of many other species as well on Michigan State University campus (Bernard, 1963; Bernard & Wallace, 1967; and Wallace, Etter and Osborne, 1964). Three habitats in Wisconsin received DDT for control of Dutch elm disease, and 3 areas were unsprayed (Hunt, 1960). In the 3 DDT-treated habitats songbird numbers averaged 31, 68, and 90 percent below those of unsprayed areas. Robin populations in the sprayed areas were 69, 70, and 98 percent below those of the unsprayed areas. Treatment of 2 acres in Wisconsin with DDT to control Dutch elm disease (about 2 pounds of DDT per tree) resulted in a robin mortality ranging from 86 to 88 percent (Hickey and Hunt, 1960). **The number of nesting robins on the Madison, Wisconsin campus increased from 3 pairs to 29 pairs after a change from DDT to methoxychlor** (Hunt, 1965). Elms were treated with DDT at 1.9 lb/A in Hanover, New Hampshire, resulting in 151 birds found dead, compared with untreated Norwich, Vermont where only 10 birds were found dead (Wurster, Wurster & Strickland, 1965)."*
>
> (Pimentel, 1971, p 19)

The second to last sentence of the above extract draws attention to our focal phenomena of substitution, describing the replacement of DDT by methoxychlor. Ultimately, through local activism, protestation and contestation, municipal and state governments

[76] Hickey interview

did substitute active ingredients less toxic to birds than DDT in their spraying programs for Dutch elm disease. **Our focal phenomena of substitution was a common response to the problem of acute toxicity to birds and other wildlife.** Demand for the active ingredient DDT to be used in spraying programs for Dutch elm disease fell as users switched to alternatives. By 1964, this was the case for a growing number of communities, as described here in a summary that clearly underlines the conflict in values at the core of the controversy:

> *"Control of Dutch elm disease with DDT has always provoked controversy between bird lovers and control officials. Recently the controversy was strongest in Michigan, Wisconsin and Illinois (Hickey, 1961). The problem is paradoxical. Elm trees are appealing and valuable; so also are birds. In saving the elm by current control measures, we preserve a refuge for the bird but we kill the bird. The only logical position is to safeguard both trees and birds.* ***Fortunately there exists a chemical near-relative of DDT - methoxychlor - that is about as effective as DDT in killing beetles but poses no real hazard to birds (Wootten, 1962). Unfortunately, methoxychlor costs three times as much as DDT. Until the last year or two this cost differential (one dollar per tree with DDT to three dollars per tree with methoxychlor) was enough to exclude methoxychlor from control programming. However several communities have elected the seemingly more expensive course on the basis that greater value accrues in the long run.*** *Doubtless other communities will make the same decision and perhaps ultimately DDT will not be recommended for Dutch elm disease control. Other chemicals are under study as control agents, but none yet satisfies the requirements of both bird and tree protection. Few will accept the premise implicit in using DDT on elms: that most birds must be sacrificed to protect trees."*
>
> (Rudd, 1964, p 34)

Throughout the 1960s, more and more jurisdictions reversed their position on the use of DDT for Dutch elm disease control, arriving at different value judgments than they had earlier. Even the USDA took note of the shift:

> *"Hazard to wildlife should be considered in planning a program for insect control. Methoxychlor has in some cities replaced DDT to combat Dutch elm disease in the spring when DDT might be a hazard to song birds."*
>
> (Pesticide Situation, 1963-64, p 14)

Note that these jurisdictions who switched away from DDT did so by employing the **same set of beliefs about the consequences** of using various alternatives. That spraying with DDT for Dutch elm disease would result in bird mortality had been known and accepted since 1947. Those making insect control decisions were also faced, in most cases, with **the same choice menu of alternatives** as in years prior to the growing public outcry. The alternative methoxychlor, available for almost as long as DDT (since 1944), was one of the most popular substitutes:

> *"Methoxychlor is one of the safest insecticides known, as indicated by the low oral rat and dermal rabbit toxicities (each 6,000 mg/kg or more) and the chronic dose at which effects appear is said to be 5000 ppm. ... The treatment of elm trees to control the beetle vectors of Dutch elm disease requires unusually large DDT treatments which are believed to have resulted in bird deaths (especially robins) through contamination of their food (earthworms) with insecticide. For this reason, there has been a tendency in recent years to use methoxychlor for such purposes."*
>
> (Brooks, 1974, vol II, p 126)

So it was not the appearance of a superior substitute product which motivated or triggered the substitution. Rather, it was changes to the value judgments, preferences and evaluation logics employed to weigh insect control alternatives and their consequences that led to the supplanting of DDT by methoxychlor.

It took more contestation to sway some municipalities than others. Consider the case of Michigan, where the Environmental Defense Fund (EDF), which we present and discuss in more length in the next section of this Chapter, adopted an aggressive litigation strategy that was successful at forcing substitution of DDT.

> *"Legal action against nine Michigan municipalities, brought by EDF in October 1967, was instrumental in discontinuation of DDT for attempted control of Dutch elm disease in these Western Michigan communities. In early 1968 an additional 47 Michigan municipalities were added to the EDF action, thereby involving all that intended to apply DDT. Before the year was out, 50 of the 56 municipalities had capitulated."*
>
> (Bloom & Degler, 1969, p 59)

The EDF did not technically win its 1967 legal action seeking an injunction against the nine towns planning to spray DDT against Dutch elm disease in 1968, but it did achieve its objective of stopping the spraying. None of the nine towns contested the suit, all affirming that they would not use DDT[77]. Soon afterwards, the Cooperative Extension Service (affiliated with the Agricultural Experiment Station) of Michigan State University withdrew its statewide recommendation for DDT against Dutch elm disease, recommending instead improved sanitation around already diseased trees and the use of the substitute methoxychlor in spraying[78].

At the end of the decade, in places where these new value judgments had not been adopted voluntarily as new "norms" through persuasion and the involvement of local activists and concerned citizens in municipal decision-making, nor adopted reluctantly through mild coercion by the legal actions and threat of legal repercussions initiated by groups like the EDF, they were ultimately forced. The preferences of actors who placed a higher value on birds and wildlife than those habitually making insect control decisions became institutionalized into formal rules - "regulations" - in a number of jurisdictions, compelling even the most recalcitrant insecticide users to adopt, or at least act "as if" they had adopted, a substitute set of values:

> *"The pesticide boards of Maine and Massachusetts have banned DDT as a weapon to control Dutch elm disease."*
>
> (Higdon, 1969, p 6)

6.8 Substitution as a Consequence of Rule-making

The exit of DDT from the market for insecticides represented by all the federal, state and municipal purchases for Dutch elm disease control is an example of what I call in this thesis "substitution as a consequence of rule-making". The critical dynamic that triggers and drives this type of substitution occurs largely in the public and political arena of

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[77] Dunlap (1981, p 149)
[78] Higdon (1969)

society. It is a process that is not well-understood in the business strategy and economics literature; the primary trigger for this instance of substitution driven by problems of acute toxicity to birds was "rule-making" by concerned citizens, government officials and other actors in the public arena. Basically, the decision rules employed by those responsible for insect control decision-making shifted to reflect the public's expression of its values; dead birds became less desirable outcomes for users of insecticides as they became less tolerable to citizens. Different degrees of contestation were necessary to cause switching in different municipalities, but in each case these were essentially contests over values and preferences re outcomes of insect control activities.

Stated another way, in the calculus of insecticide use, involving elms, birds, spraying costs, etc., one value judgment was substituted for by another value judgment through a process of contestation in the public arena. Yes, DDT was abandoned in this market because it had inferior performance to methoxychlor, but this was because **performance was redefined.** As *values* change, what counts as the most *Efficient* tool changes. The "Rightness" (and to some degree, the "Justice") of insect control outcomes that left dead birds scattered across suburban lawns was successfully challenged by actors promoting different values.

I wish to draw readers' attention to three key points which characterize this type of substitution process:

(1) First, these substitutions were *not* triggered and driven by the appearance of methoxychlor in the commercial marketplace. The tools available to insecticide users - those appearing on the "choice menus" - were unchanged before and after the substitution process; both DDT and methoxychlor had been available since WWII.

(2) Second, there was no uncertainty, ambiguity or controversy as to the performance of the incumbent product DDT as compared to methoxychlor along *any* evaluation criteria. The "facts" were constant. That each had similar *efficacy*

in achieving insect control but that methoxychlor was *safer* to birds and would leave fewer of them dead or trembling on people's lawns had been known since the 1940s.

(3) Third and finally, what changed were the evaluation criteria and decision rules employed by actors in the pesticide domain to define what constituted superior insecticide "performance". The "facts" about dead birds did not really matter - they had little *significance* - *until* the actions of concerned citizens in the public arena made them relevant. Through their protests, complaints and contesting, actors succeeded in elevating the status and importance of what originally were unimportant evaluation criteria in insecticide users' decision-making - acute toxicity to birds and other wildlife as well as the impact of insecticide users' activities on the rights of non-users.

Specifically, in the rule-making arena, actors (concerned citizens, NGOs) developed and made normative claims - "ought" statements reflecting their preferences for insect control outcomes that did not include dead birds - that they believed (or at least hoped) had potential for being adopted, then brought these to organized structures of conversation (their town hall meetings, their city council meetings, the courts in certain instances) where the fate of normative claims are decided and where they attempted to demonstrate the superiority of their proposed decision values and rules as compared to the incumbent. Just as the entry of DDT resulted from systematic and structured problem-solving activities in the commercial arena, the exit of DDT from these markets was also the result of systematic efforts by organized individuals to solve what they perceived as a problem of values and decision rules. The "acceptability" or "appropriateness" or, more generally, "Rightness" or "Justice" of the outcomes of insect control decisions was successfully challenged by actors affected adversely by the spraying along with their sympathizers and supporters. Using the institutional resources at their disposal, they succeeded in changing the values invoked by municipal, state and federal authorities in insect control decisions, and in the limiting cases, had these ensconced into "rules" applicable to entire jurisdictions. The substitution of one value (i.e. decision rule) for another triggered the substitution of one product for another.

6.9 A Contest of Values Triggered by Problems of Persistence, Transport and Bioaccumulation

Whereas in the previous section I focused on the substitution of DDT in relatively minor markets represented by Dutch elm disease spraying programs, here I focus on the substitution of DDT in the biggest market for insecticides in the United States, which is that for use against pests of cotton. In this section I recount and analyze the series of events leading to and comprising the exit of DDT from use as an insecticide by cotton growers.

It should be noted that the problems of persistence, transport and bioaccumulation are not specifically linked to the use of DDT on cotton, but are rather problems associated with all uses of DDT. It is just that cotton growers were the last to abandon DDT and substitute it with alternatives, and this they did only after being forced by the 1972 decision of William D. Ruckelshaus, Administrator of the Environmental Protection Agency, to ban it. The clear and dramatic nature of the decline of DDT use on cotton - falling to zero as soon as the ban took effect - makes it relatively easy to draw readers' attention to the key points characterizing this substitution process that we wish to emphasize. Just as with the case of Dutch elm disease, the alternative substances selected to replace DDT had been around for some time. It was clearly not their arrival on the scene that triggered the displacement of DDT. Indeed, the coalition supporting DDT made up of the agricultural chemical industry, cotton growers and other insecticide users, the USDA and most economic entomologists, argued vociferously that "*DDT is necessary*" because in their view the alternatives were ineffective or too expensive. According to the criteria of importance to them, DDT had superior performance compared to these alternatives when it left the economy. Second, both before (i.e. when DDT was the insect control tool chosen) and after the substitution process (when DDT was not being used), users' beliefs about the consequences of various alternatives were basically unchanged. But what did change, I point out here, was the significance of these consequences. What had originally been unimportant evaluation criteria in insecticide users' decision-making - persistence, transport, and biomagnification (also referred to as "bioaccumulation") as well as the impact of insecticide users' activities on the rights of non-users - gained substantially in importance specifically because these non-users protested, complained, contested and fought to make this so. The "Rightness", "acceptability", "appropriateness" or, more generally, the "Justice" of the outcomes of insect control decisions was successfully challenged by actors affected adversely by the use of DDT along with their sympathizers and supporters. Using the institutional resources at their disposal, they succeeded in having their values formalized and ensconced into the "rules" to be applied in entire jurisdictions; DDT became banned.

It should also be noted that persistence and bioaccumulation are not problems, per se, but that these physical properties do multiply and extend, in space and time, the intrinsic toxicological hazards attributed to DDT by its opponents, with respect to human health (especially oncogenicity - the carcinogenic risk it posed for humans) and the environment (especially eggshell thinning among birds at the top of food chains). These also formed an important part of the case against it. In addition, these particular physical properties ensured that, unlike many other pollutant "externalities" as they are called in economics, DDT was *attended to* and *accounted for*. It turned up, literally, everywhere. DDT's awkward appearance in, and disappearance only with difficulty from, parts of the physical world which are attended to and which have emotional salience to people - pristine Antarctica, neighbourhood robins, bald eagles, human fat and breast milk - fueled and sustained the public controversy. Indeed, after compiling this biography of DDT, I would suggest that it was perhaps this aspect of *violation of sacred place* or *transgression* by this omnipresent molecule that stirred people and led ultimately to its ban. But here I am digressing into interpretive speculation. It will suffice to complete this Chapter by demonstrating that our focal phenomena of substitution was a consequence of rule-making in the pesticide domain.

The rule-making in Washington - the EPA's consolidated DDT hearings of the early 1970s which resulted ultimately in the ban of DDT - followed a series of other rule-making contests and struggles in various jurisdictional arenas. I have already mentioned some of these in the discussion of the debates surrounding the use of DDT for control of Dutch elm disease, and the activities of the Environmental Defense Fund (EDF). Because of its groundbreaking and central role in the legislative history of DDT, this non-government organization and its strategies merit attention and analysis.

6.9.1 The Environmental Defense Fund Enters the Domain

The people comprising the EDF in its early years were brought together and spurred to action just like other citizens concerned about DDT in the 1960s, by local spraying programs that killed birds, fish and wildlife[79]. In April of 1966, Carol Yannacone learned that the Suffolk County Mosquito Control Commission would be using DDT against mosquito larvae in Yaphank Lake, where she grew up. In prior years, this had resulted in fish kills that had angered her. She asked her husband, lawyer Victor Yannacone, to help her to stop this action. Actually, she threatened him with "*not getting dinner until he did something*", he recalled in an interview[80].

Yannacone filed a suit seeking an injunction to preclude the use of DDT, and got a temporary one for a year, but ultimately lost the case[81]. But after having been forced to substitute alternative mosquito controls, the Commission did not switch back to DDT the following year, fearing more legal problems, so Yannacone's legal action was a success in terms of outcomes. Others joined them in the suit, notably the Brookhaven Town National Resources Committee and Dr. Charles Wurster who later became the principal scientist advising the EDF. Together, Wurster and Yannacone made what the latter called a "*great decision*" when they "*conceived of the idea of submitting a technical*

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[79] This discussion has benefited greatly from Wurster (1975); Dunlap (1978b); Dunlap (1981); and the taped interviews with Yannacone and Wurster.
[80] Yannacone interview
[81] Dunlap (1981, p 145)

appendix" of photocopied scientific articles to their affidavit[82]. This affidavit also included what would come to be the often-quoted line:

> *"Using DDT to control mosquitoes is like using atomic weapons to control criminals in New York City"*
>
> (Yannacone interview).

Avoiding legal terrain on which victories against DDT had been elusive - claiming personal damages or seeking abatement of a nuisance - the EDF asserted that citizens had a right to a clean environment.

> *"The objective was to compel major institutions of enormous inertia and slow reaction times to litigate in our ball field with our rules and our umpire. ... That was the whole thesis behind legal litigation at that time."*
>
> (Yannacone interview).

The only way to do this the EDF believed was to find an *"unclaimed area of the law"* and so they decided to use *"equity litigation for declaratory judgments and equity relief, with no money damages, and alleging broad constitutional grounds not yet litigated, in this case the ninth amendment"*[83].

Technically, the EDF came into being as an organization just after this first action, and was made up of only ten people, including Yannacone & Wurster. Unique and novel among conservation groups, it existed to *"define human rights through research, education and litigation"* and its purpose was *"to provide a direct means for bringing science to bear on environmental issues."*[84] The EDF was entrepreneurial in its approach to institutions and making arguments; by utilizing the judicial sub-system of the public rule-making arena rather than the legislative sub-system, they could maintain their charitable tax-exempt status because their activities were technically not "political"[85].

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82 Yannacone interview
83 Yannacone interview
84 Dunlap (1981, p 147)
85 Bosso (1987, p 135)

Subsequent to the Suffolk County case, the EDF began *"practicing a form of legal guerilla warfare"* motivated by Yannacone's firm belief that:

> *"If there is a social need that must be filled, and something must be done for the People, with a capital P, there must be a legal way to do it. It was a lawyer's job to find this way or to invent it."*
>
> (Yannacone interview).

Speaking at a convention of the National Audubon Society in September of 1967, Yannacone summarized his philosophy for filling these social needs in a short and now-famous phrase: *"Sue the bastards!"*[86].

Only 5 days after its incorporation, the EDF filed 2 suits in Michigan, encouraged by the head of the Michigan Department of Natural Resources[87]. The first was the one against nine towns planning to spray DDT for control of Dutch elm disease, and has already been discussed in the previous section. The second challenged the Federal-State insect control program wherein the USDA and the Michigan Department of Agriculture planned to spray dieldrin, another persistent organic organochlorine like DDT, against Japanese beetles. In this case the judge ruled, in October of 1967, that the EDF had no standing to bring a suit, but the EDF's legal maneuvering, which included an appeal to the Michigan Supreme Court, delayed spraying for one year anyway. Undeterred, in October of 1968 the EDF filed another action in the neighbouring state of Wisconsin, alleging that spraying of dieldrin in Michigan would damage the Lake Michigan ecosystem in which Wisconsin also had a vital interest. The suit proceeded and the EDF presented its scientific evidence against, in this case, dieldrin. That judge too ruled against them and allowed the spraying to continue. The EDF again returned to DDT and its use against Dutch elm disease, but this time in Wisconsin. And it was here that they eventually achieved significant legal and public relations success.

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[86] Yannacone interview

[87] This paragraph has been assembled from material in Dunlap (1981, p 149, 150)

6.9.2 DDT on Trial in Madison, Wisconsin

The EDF was brought to Wisconsin at the urging of Lorrie Otto, a non-scientist, non-politician "housewife" offended by the bird mortality she had seen result from use of DDT[88]. She predicted more dead birds when she heard in August of 1968 that the Wisconsin Department of Agriculture had recommended it yet again for use against Dutch elm disease and that towns around her were planning to use it. Subsequent to the publication of *Silent Spring*, she and other local conservationists (the Citizens' Natural Resources Association of Wisconsin, Inc.; CNRA) had actively campaigned against persistent pesticides by holding seminars and speaking out against the use of DDT for Dutch elm disease in municipal forums. Otto had also been collecting data on DDT use and bird mortality. They had had some success, with a few towns stopping their use of DDT just like those discussed earlier.

The EDF agreed to represent the CNRA in a complaint filed with the Wisconsin Department of Natural Resources, responsible for such spray programs, naming the city of Milwaukee and the company destined to win the contract for spraying, Buckley Tree Service, as defendants. The city and the company backed down, agreeing not to use DDT. Despite this apparent victory, the EDF was upset. It had not yet found a forum to air their scientific evidence against DDT and get a clear judgment against it. It success was bittersweet; the EDF wasn't interested, per se, in coercing insecticide users into substituting DDT on a one by one basis[89].

The hearing examiner for this last complaint of theirs, Maurice Van Susteren, informed them that if this was their goal, then they had chosen the wrong legal route and pointed them in another direction. In Wisconsin, citizens had the right to ask for "declaratory rulings" from government departments, through public hearings, on the applicability of a set of facts to any rule that that department enforced. The EDF could essentially sue

[88] This paragraph has been assembled from material in the Otto interview, and Dunlap (1981, p 152, 153)
[89] Yannacone interview

DDT[90]. The CNRA quickly went ahead and, together with the Wisconsin Izaak Walton League, asked the Department of Natural Resources, under Wisconsin Statute 144.01, which defined pollution to include *"contamination or rendering unclean or impure the waters of the state, or making the same injurious to public health, harmful for commercial or recreational use, or deleterious to fish, bird, animal, or plant life."*[91], did DDT constitute a pollutant?

It did.

But this was made official only on May 20, 1970, when the hearing examiner issued his declaratory ruling on behalf of the State of Wisconsin:

> *"**DDT, including one or more of its metabolites in any concentration or in combination with other chemicals at any level, within tolerances, or in any amounts, is harmful to humans and found to be of public health significance.** No concentrations, levels, tolerances, or amounts can be established. Chemical properties and characteristics of DDT enable it to be stored or accumulated in the human body and in each trophic level of various food chains, particularly the aquatic, which provides food for human consumption. Its ingestion and dosage therefore cannot be controlled and consequently its storage is uncontrolled. Minute amounts of the chemical, while not producing observable clinical effects, do have biochemical, pharmacological, and neurophysiological effects of public health significance.*
>
> *"No acute or chronic levels of DDT which are harmful to animal or aquatic life can be established. For the reasons above set forth, a chronic level may become an acute level. Feeding tests, laboratory experiments, and environmental studies establish that DDT or one or more of its analogs is harmful to raptors and waterfowl by interfering with their reproductive process and in other birds by having a direct neurophysiological effect.*
>
> *"Feeding tests or experiments and environmental studies establish that DDT at chronic low levels is harmful to fish by reducing their resistance to stress.*

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[90] Van Susteren interview

[91] Statute is cited in Henkin et al (1971, p 9)

*"**DDT and its analogs are therefore environmental pollutants** within the definitions of Sections 144.01 (11) and 144.30 (9), Wisconsin Statutes, **by contaminating and rendering unclean and impure the air, land and waters of the state and making the same injurious to public health and deleterious to fish, bird, and animal life.**"*[92]

Van Susteren had assigned himself to the hearing, which began on December 2, 1968 and was supposed to wrap up before Christmas but only finished on May 21, 1969. Some 32 witnesses appeared and 2,500 pages of testimony and cross-examination were produced, along with thousands more pages of exhibits, much of it scientific papers. The witness list included a number of notable scientists, many of whom were called to testify for the petitioners (i.e. the EDF) like Paul de Bach (entomologist; biological insect control specialist who demonstrated that DDT could make insect control problems worse), Joseph Hickey (ecologist; author of important scientific works linking DDT to eggshell thinning and declining populations of peregrine falcons); Robert Risebrough (molecular biologist; provided evidence of effect of DDT and its metabolites on birds); Robert Rudd (zoologist; and author of the acclaimed book *Pesticides and the Living Landscape* which chronicled the impact of DDT on populations of different animal species and the subsequent impact this had on ecosystem functioning), Robert van den Bosch (entomologist; strong promoter of biological insect controls and vocal critic of chemical insect controls, *"squirt-gun entomologists"*, and industry's dominance in science; gave evidence of effectiveness of alternatives to DDT); George F. Wurster Jr. (ecologist; EDF founder who outlined and synthesized the case against DDT). Defending DDT were scientists who were mostly economic entomologists, along with Dr. Wayland Hayes Jr. (the doctor repeatedly called upon to present epidemiological evidence that DDT was not chronically toxic)[93].

Other witnesses were representatives from industry, including the president of Montrose Chemical Company, Samuel Rotrosen, whose company was the last to abandon DDT and remained the sole producer by 1972, as well as government employees from the United

[92] Van Susteren's ruling is reprinted in its entirety in Henkin et al (1971, p 191).
[93] Both Henkin et al (1971) and Dunlap (1978) provide an excellent account of the Wisconsin DDT trial.

States Department of Agriculture and the Department of the Interior. A Wisconsin senator who had made a reputation as an environmentalist, Gaylord Nelson, opened the hearings with an impassioned plea to stop "*dangerous environmental contamination*", stressing the importance of the Wisconsin hearings as a first step towards a national ban[94].

Yannacone presented witnesses to argue the EDF's case that: (1) ecosystems existed; (2) the properties of DDT meant that it contaminated ecosystems if released into them at any point; (3) residues of DDT had adverse effects on wildlife (this was the heart of the challenge, essential to their case and to the national case against DDT); (4) residues of DDT posed a potential hazard to humans as there was insufficient evidence to demonstrate that they were safe; and (5) safer means of insect control were available[95].

Defenders of DDT - parties could participate "*as interests may appear*" - maintained that (1) DDT was safe; (2) DDT was effective; and (3) DDT was necessary, even essential, to insect control in agriculture and public health[96].

Louis A. McLean, a retired lawyer who had counseled Velsicol Chemical Company and who happened to live only a few hours from Madison but who had little trial experience, initially defended NACA and its Industry Task Force for DDT. But when it became apparent that he was being badly outclassed by Yannacone and the witnesses opposing DDT, McLean came to be accompanied by Willard S. Stafford, a trial lawyer who took over the industry defense, and Frederick S. Waiss, a lawyer employed by Stauffer Chemical Company[97]. NACA and its members had been caught off guard, forced into battle in an unfamiliar arena chosen by an opponent who had been preparing for this contest for a long time. Harry Hays, head of the Pesticide Registration Division of the USDA, also appeared and took the stand on behalf of the USDA where he defended the existing regulatory framework and attempted to demonstrate its adequacy at safeguarding

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[94] Dunlap (1981, p 160)
[95] Dunlap (1978)
[96] Dunlap (1978)

the public's health and interests. But under the aggressive cross-examination of Yannacone he might have done more than anyone to undermine the public's confidence in the set of rules currently in operation in the domain. For example, he admitted that it was chemical companies that supplied their own data in support of the molecules they were hoping to register, and that the USDA had formally cancelled only two pesticide registrations in the previous five years and only for reasons of acute toxicity that had resulted in *"a large number of fatalities"* in one case and *"a significant number of deaths"* in the other[98]. He also confirmed that throughout the 1960s, despite all the public uproar and additions to scientific knowledge about DDT, his organization had not initiated any review of DDT registrations or update of the data supporting them.

Robert McConnell, serving as the "neutral" public intervenor, also cross-examined and called witnesses. He called Swedish scientist Goran Lofroth who, testifying about DDT in human breast milk, made the point that some nursing infants were being exposed to daily amounts of DDT more than twice the WHO's recommended maximum[99]. When being cross-examined by Stafford who was trying to get him to admit that he knew of no instances of children being harmfully affected by DDT from their diet or from the environment, he stated flatly that *"To my knowledge there has been no investigation on the thing even. That's even worse."*[100]. His testimony gave the large number of local and national press covering the trial lots of attention-getting material for their headlines: *"DDT in Mother's Milk"*.[101] Even without this emotion-stirring testimony, the hearings were receiving wide and extensive coverage.

In a nutshell, the hearing pitted industry and mainstream economic entomologists who favoured chemical controls for insects against more marginalized economic entomologists who favoured biological controls. These two sides disagreed over whether DDT was *effective* and *necessary* for insect control. Scientists and doctors of medicine

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[97] Dunlap (1978)
[98] Dunlap (1981, p 182)
[99] Henkin et al (1971, p 104)
[100] Henkin et al (p 107)
[101] Milwaukee Sentinel, 1969 05 06, cited in Dunlap (1981, p 187)

from both sides squared off over the *safety* of DDT, while the scientific evidence of damage to fish, birds and wildlife presented by the EDF went relatively uncontested. Indeed, NACA's lack of preparation showed horribly in this area. They put Frank Cherms, a poultry scientist naturally sympathetic to agricultural interests, on the stand to controvert the testimony on eggshell thinning of the Department of Interior's Lucille Stickel and that of Hickey, whose evidence provided support to Wurster's dramatic claim that "*It is possible to cause the complete collapse of a population and the extinction of species without ever killing a single individual.*"[102] Cherms did not succeed, in the opinion of the hearing examiner who referred to Stickel's testimony on eggshell thinning as "*uncontroverted*"[103]. Cherms was forced to admit that there were significant biological differences between the farm poultry on which he had conducted his DDT experiments and the raptors (meat-eating birds at the top of food chains) at risk of problems of eggshell thinning from DDT about which Hickey and Stickel had testified. His testimony ended up being more useful to the EDF, or at least they found it useful to drew attention to it in their closing brief[104]. Industry's lack of allies competent in issues of ecology and wildlife biology meant that the pro-DDT coalition was incomplete.

In the end, the hearing examiner went a long way towards ruling on the *Justice* of DDT, although he could not, and did not, do so explicitly in his findings as it was not technically at issue. But Van Susteren's categorization of this substance as a pollutant "*contaminating and rendering unclean and impure the air, land and waters of the state and making the same injurious to public health and deleterious to fish, bird, and animal life*" meant that suddenly a whole new set of regulations and rules could be brought to bear on DDT.

The stage was set for the next fight in this ongoing struggle.

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[102] Cited in Henkin et al (1971, p 57)
[103] Van Susteren interview
[104] Dunlap (1981, p 185)

6.9.3 The Fall of DDT

Van Susteren's report was not released until May of 1970, one year after the Madison trial had ended[105]. By that time a number of other events involving DDT occurred in the political arena that, when considered together with the public relations and legal success of EDF's challenge, pointed to an imminent end game over DDT. The publicity surrounding the Madison hearings prompted others to enter into and become active in "rule-making" around pesticides, and DDT in particular. Indeed, the EDF invited the public into the struggle, or at least their money, in March of 1969 with an emotional fundraising advertisement in the New York Times of a nursing infant that asked *"Is Mother's Milk Fit For Human Consumption?"*[106]. In mid 1969, the popular press reported that *"At no time since the publication in 1962 of the late Rachel Carson's best-selling book 'Silent Spring' had DDT, the miracle chemical of World War II, faced such a concentrated attack."*[107]. An annual publication of the USDA, *The Pesticide Review* (formerly *The Pesticide Situation* until 1966), summarized the year as follows:

> *"The use of persistent pesticides underwent more intensive discussion in 1969 than ever before. Although pesticides have contributed tremendously to preventing human disease and to increasing the production of food and fiber, mounting evidence indicates the need for concern about unintended effects on the environment, including injury to the health of man and livestock. Associated with the benefits from the use of pesticides are the risks of injury; and these risks are greater from the use of persistent chemicals. Restrictions have now been placed on the latter with special emphasis on DDT."*[108]

In January of 1969, Arizona implemented a one year ban on the use of DDT and DDD for agriculture to prevent contamination of dairy products. In Wisconsin itself, senators introduced a bill in February, even before the April end of the Madison hearings, that would ban the use of DDT in that state. In April, the country of Sweden announced a two year ban on DDT, and the state of Michigan implemented the first full, permanent ban on DDT in the United States, giving opponents of such a DDT ban 60 days to present their

[105] Henkin et al (1971, p 186)
[106] *New York Times*, 1969 03 29
[107] Higdon (1969)

case[109]. These bans were discussed in a New York Times article of April 30, 1969 which also reported on the Madison hearing that was *"serving as a national public forum"*. It stated that that events had *"taken a new direction that threatens the life of this deadly chemical. ... Science and industry are presenting arguments that may ultimately decide whether the issue will be settled once and for all with DDT bans instituted across the country."*[110]

The *New York Times Magazine* also anthropomorphized DDT, with an 8 page *"Obituary for DDT (in Michigan)"* in July that began:

> *Died, DDT, age 95, a persistent pesticide and onetime humanitarian. Considered to be one of World War II's greatest heroes, DDT saw its reputation fade after it was charged with murder by author Rachel Carson. Death came on June 27 in Michigan after a lingering illness. Survived by dieldrin, aldrin, endrin, chlordane, heptachlor, lindane and toxaphene. Please omit flowers.*
>
> (Higdon, 1969, p 6)

The ban by Michigan followed quickly on the heels of a seizure early in 1969 by the FDA of more than 20,000 lbs of Michigan Coho salmon being shipped interstate that was found to contain enough DDT to be unfit for human consumption[111]. No tolerance level had ever been set for fish, but this Coho exceeded the tolerance level of 7 ppm set for the fat of beef and pork. This particular event meant that suddenly other values - and those who sought to promote and protect them - were brought into the rule-making arena to fight against DDT and other persistent pesticides because *"a few dead robins or eagle eggs without shells are one thing, but $100 million worth of tourist trade is another, and that's what seemed to be at stake ..."* when the Michigan Department of Agriculture cancelled all uses of DDT except for mice, bats and human body lice which required only small quantities of the active ingredient[112]. Citing the Michigan Coho salmon incident, along with another in which contaminated Spanish Mackerel were caught off the coast of

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[108] USDA *Pesticide Review* (1969, p 1)
[109] Higdon (1969)
[110] *New York Times*, 1969 04 30
[111] Higdon (1969)

California, one well-placed interviewee made the points that *"nobody will tell you that's why DDT was eventually banned, but they were important"*[113] These events certainly contributed to the important and substantial initiative of the Department of Health, Education and Welfare to prepare what would come to be known as the Mrak Commission report.

In April of 1969, the Secretary of HEW, Mr. Robert Finch, appointed a special 14 person commission headed by Emil M. Mrak to investigate the risks and benefits of pesticide use[114]. Their 677 page report to the Secretary completed on December 5, 1969, *The Report of the Secretary's Commission on Pesticides and Their Relationship to Environmental Health*, was exhaustive to say the least. It was developed from the individual reports of five 3-5 person subcommittees (Uses and Benefits of Pesticides; Contamination; Effects of Pesticides on Nontarget Organisms Other than Man; Effects of Pesticides on Man; Criteria and Recommendations), with the subcommittee on Effects of Pesticides on Man having four 9-13 member Advisory Panels (Carcinogenicity; Interactions; Mutagenicity; Teratogenicity). Written in the dense technical language of academic papers in the natural sciences, it cited more than 2100 scientific articles. It found that *"there is adequate evidence concerning potential hazards to our environment and to man's health to require corrective action. Our Nation cannot afford to wait until every last piece of evidence has been submitted on the many issues related to pesticide usage. We must consider our present course of action in terms of future generations of Americans and the environment they will live in."*[115]. Among its recommendations, shown below in Table 6.9.3.1, were obligatory vague and abstract feel-good statements (example: recommendation 5), concrete changes to the rules themselves (example: recommendation 3, to ban DDT), as well as concrete changes to the organization of the rule-making domain (examples: recommendations 1 & 6, to restructure and redistribute authority in the domain).

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112 Higdon (1969)
113 anonymous interviewee, 1998
114 This paragraph has been developed from material in the Mrak report (USDHEW, 1969).
115 USDHEW (1969, p 5)

Table 6.9.3.1 - Mrak Report Recommendations:

Report of the Secretary's Commission on Pesticides and Their Relationship to Environmental Health

1) Initiate closer cooperation among the Departments of Health, Education and Welfare, Agriculture and Interior on pesticide problems through establishment of a new interagency agreement.

2) Improve cooperation among the various elements of the Department of Health, Education, and Welfare which are concerned with the effects of pest control and pesticides.

3) **Eliminate within two years all uses of DDT and DDD in the United States** excepting those uses essential to the preservation of human health or welfare and approved unanimously by the Secretaries of Departments of Health, Education and Welfare, Agriculture and Interior.

4) Restrict the usage of certain persistent pesticides in the United States to specific essential uses which create no known hazard to human health or to the quality of the environment and which are unanimously approved by the Secretaries of Departments of Health, Education and Welfare, Agriculture and Interior.

5) Minimize human exposure to those pesticides considered to present a potential health hazard to man.

6) Create a pesticide advisory committee in the Department of Health, Education and Welfare to evaluate information on the hazards of pesticides to human health and environmental quality and to advise the Secretary on related matters.

7) Develop suitable standards for pesticide content in food, water and air and other aspects of environmental quality, that: (1) protect the public from undue hazards, and (2) recognize the need for optimal human nutrition and food supply.

8) Seek modification of the Delaney clause to permit the Secretary of the Department of Health, Education and Welfare to determine when evidence of carcinogenesis justifies restrictive action concerning food containing analytically detectable traces of chemicals.

9) Establish a of Department of Health, Education and Welfare clearinghouse for pesticide information and develop pesticide protection teams.

10) Increase Federal support of research on all methods of pest control, the effects of pesticides on human health and on ecosystems, and on improved techniques for prediction of human effects.

11) Provide incentives to industry to encourage the development of more specific pest control chemicals.

12) Review and consider the adequacy of legislation and regulation designed to:
- improve the effectiveness of labeling and instructions to users
- extend the present concept of experimental permits as a mechanism to register pesticides initially on a restricted basis to enable close observation, documentation, and reassessment of direct and indirect effects under conditions of practical usage

- improve packaging and transportation practices in order to minimize dangers of spillage and the contamination of vehicles and of other merchandise
- provide for monitoring and control of effluents from plants manufacturing, formulating and using pesticides
- provide uniform indemnification to parties injured by mistakes in pesticide regulatory actions by Federal and State authorities

13) develop, in combination with the Council of State Governments, model regulations for the collection and disposal of unused pesticides, used containers, and other pesticide contaminated materials.

14) Increase participation in international cooperative efforts to promote safe and effective usage of pesticides.

While the report was in preparation, events continued to indicate a coming endgame over the use of DDT in the United States. In June of 1969, the National Audubon Society announced its support for a national ban on DDT, and Congress began to investigate accusations made in September of 1968 by the General Accounting Office (GAO) in its report *"Deficiencies in Administration of Federal Insecticide, Fungicide, and Rodenticide Act"*. This report severely damaged the credibility of the USDA and its Pesticides Registration Division. Among a long list of criticisms was the USDA's stubborn ignoring of other stakeholders' concerns; although the USDA, HEW, and the Department of the Interior had signed a cooperation agreement in the wake of *Silent Spring*, of 1,633 objections to particular registrations filed by HEW, not one was ever referred to the Secretary of Agriculture for discussion with the Secretary of HEW[116].

Also in June, the National Cancer Institute completed tests it had began in response to *Silent Spring* which indicated that mice exposed to DDT had a higher incidences of liver tumours, leading 17 Congressmen to petition President Nixon to ban DDT on the grounds that it caused cancer[117]. The Mrak report reiterated these findings when it was later published but also cautioned that the mice studies did not justify the conclusion that DDT caused cancer in humans[118].

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[116] Dunlap (1981, p 202)
[117] Dunlap (1981, p 203)
[118] USDHEW (1969)

The EDF jumped on what it argued was evidence that DDT was carcinogenic. It filed a petition with HEW on behalf of five pregnant or nursing women asking for a zero tolerance level of DDT on food, making the link between the Delaney clause and the National Cancer Institute's recent finding. It also petitioned the USDA and HEW directly to suspend DDT registrations and begin cancellation procedures. This was negatively received by the courts who ruled that private interests had no standing with respect to FIFRA, agreeing with the USDA[119]. This failure had been anticipated by Yannacone who by this time had left the EDF over this petition and other issues. He sensed that *"the psychological impact of suing the USDA alleging that it was incompetent to protect us, was psychologically abhorrent both to the press, the media in general and the vast majority of the intellectual public, because if you admit the possibility that they are incompetent to do what we believe is their mission even though it is not their statutory mission, then my God we could have been poisoned all these years"* and had vowed never to directly challenge the authority of government agencies under existing regulation[120].

Unsatisfied with the responses of HEW and the USDA, the EDF filed more petitions with the U.S. Court of Appeals in the District of Columbia asking the court to direct the Secretaries to take quicker action. In May of 1970, this court reversed the earlier ruling that private citizens had no standing to contest FIFRA administration[121], in what would turn out to be an act of interpretation with incredibly significant consequences. Suddenly, anyone affected by economic poisons (in this instance it was the EDF), not just manufacturers and formulators, could have standing; this interpretation meant that the court ordered the USDA to suspend DDT use within 30 days or to justify its failure to do so.

The Secretary of Agriculture reaffirmed the USDA's decision not to suspend nor cancel DDT registrations. The USDA did take some actions though, promising to elevate the

[119] MacIntyre (1982, chapter V)
[120] Yannacone interview
[121] MacIntyre (1982, chapter V)

status of environmental evaluation criteria in the registration and use of insecticides, as reported in one of their publications:

> *"The Secretary of Agriculture directed on November 13, 1969, that protection of the environment from contamination by persistent pesticides receive greater emphasis in the registration of new pesticide products, and that those already registered be reviewed. His directive established new environmental criteria for registration. It was the basis for subsequent action in canceling certain DDT registrations ..."*
>
> (USDA *Pesticide Review*, 1969, p 4)

And the USDA did announce that it would be canceling certain DDT registrations.

> *"On November 25, 1969, the Federal Register carried a USDA notice concerning DDT registrations, the essential parts of which follow:*
>
>> *Action is being taken to cancel certain uses which contribute significantly to contamination of the environment. These are as follows:*
>>
>> *1. All uses on shade trees, including elm trees for control of elm bark beetle which transmits Dutch elm disease.*
>> *2. All uses on tobacco.*
>> *3. All uses in or around the home, except limited uses for control of disease vectors as determined by public health officials.*
>> *4. All uses in aquatic environments, marshes, wetlands, and adjacent areas, except those which are essential for the control of disease vectors as determined by public health officials*
>
> *In addition the notice states that:*
>
>> *Registrants have been advised of cancellation of registration for DDT products bearing directions for use as indicated above.*
>>
>> *The Department is considering cancellation of any other uses of DDT unless it can be shown that certain uses are essential in the protection of human health and welfare and only those uses for which there are no effective and safe substitutes for the intended use will be continued."*
>>
>> (USDA *Pesticide Review*, 1969, p 4, 5)

Another wave of cancellations came in August of 1970:

> *"In August of 1970, in another major action, USDA cancelled Federal registrations of DDT products used as follows:*

(1) on 50 food crops, beef cattle, goats, sheep, swine, seasoned lumber, finished wood products and buildings;

(2) around commercial, institutional, and industrial establishments including all nonfood areas in food processing plants and restaurants, and;

(3) on flowers and ornamental turf areas."

(EPA, 1975, p 254)

But conspicuous by its absence was the registration for DDT use on cotton, at this point by far the biggest domestic market for that active ingredient. The USDA justified this by claiming that DDT was *essential* and did not represent an "imminent" hazard to human health, fish nor wildlife[122]. This high standard was the one that had to be met in order to justify suspension, and not merely cancellation, of registrations under FIFRA.

Meanwhile, Congress was passing the National Environmental Policy Act (NEPA) which established what Yannacone had been saying for a long time he had been seeking to invent: citizens' rights to a clean environment[123]. Congress also established the Council on Environmental Quality, and the Environmental Protection Agency would come into being on October 2, 1970. Combining programs and offices from various departments, especially Agriculture, Interior, and Health, Education & Welfare, one of its new responsibilities would be pesticide registration which was being transferred to it from the USDA effective December 2, 1970[124]. This implied a major loss of control over rule-making by an important ally for the pro-DDT lobby, the USDA. This was compensated somewhat when, through the hard work of Congressman Jamie Whitten of Mississippi, a large cotton-growing state, the subcommittee he chaired on agricultural appropriations was awarded authority over the EPA's budget. The EPA also obtained responsibility for establishing tolerances for pesticides used on food and feed crops, but the FDA retained responsibility for administering these tolerances and policing compliance.

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[122] Dunlap (1981, p 207)
[123] Blodgett (1974)
[124] MacIntyre (1982, chapter V)

The EDF persisted, again going to court, but now against the EPA (actually, the suit - EDF v Ruckelshaus - named the Administrator of the EPA), newly responsible for pesticide registrations[125]. In January of 1971, the court required that Ruckelshaus cancel all uses of DDT. Ruckelshaus complied.

> *"Cancellation proceedings were begun for all remaining registered uses of the insecticide DDT in compliance with an order issued by the U.S. Court of Appeals for the District of Columbia. This action affected approximately 2,000 products marketed by about 250 companies, mostly for use on cotton, peanuts and certain vegetables. As intended, the notices of cancellation initiated a scientific and public review of the remaining registered uses in which both the benefits and the risks of continued DDT use could be fully explored. In response to manufacturers' appeals, a scientific advisory committee has reviewed the cancellation order and an extensive public hearing was begun on August 17. A final decision on the retention or cancellation of DDT uses will be made by the EPA Administrator early in 1972."*
>
> (USDA *Pesticide Review*, 1971, p 2)

Just like the USDA however, he did not suspend the registrations. DDT continued to be produced, sold and used for insect control, as noted in *Science* magazine in December of 1971:

> *"In cotton fields across the South this year, the bollworms and weevils were out in full force. And so were cotton growers and crop dusters, who battled these destructive pests with an arsenal of insecticides that included - as it has for two decades now - liberal amounts of DDT. Far from having slipped into oblivion, DDT remains in substantial use by American farmers."*
>
> (Gillette, 1971)

The scientific advisory committee refereed to above was requested by Montrose Chemical Company, by this time the sole remaining manufacturer of DDT. It was chaired by James G. Hilton. Its report, short by the standards set by previous government documents dealing with DDT (only 58 pages), was submitted to Ruckelshaus on

[125] MacIntyre (1982, chapter V)

September 9, 1971[126]. Splitting hairs when it came to the issue of whether DDT represented an imminent hazard (and hence suspension of registrations would be just and legal under FIFRA), it pointed out the importance of how that term was defined, concluding that DDT did not represent an imminent hazard to human health but that current environmental levels of DDT did constitute *"an imminent hazard to human welfare in terms of maintaining healthy desirable flora and fauna in man's environment."*[127]. The report also reiterated a point first made all the way back in 1963 with President Kennedy's Scientific Advisory Committee, and again in the Mrak report of 1969, calling for the *"elimination"* of DDT from the economy in its first and most prominent recommendation:

> *"Reduce the use of DDT in the U.S. at the accelerated rate of the past few years with the goal of virtual elimination of any significant additions to the environment."*[128]

The Consolidated DDT Hearings began in Washington, D.C. in August, 1971 and continued until March, 1972.

> *"In August 1971, upon the request of 31 DDT formulators, a hearing began on the cancellation of all remaining Federally registered uses of products containing DDT. When the hearing ended in March 1972, the transcript of 9,312 pages contained testimony from 125 expert witnesses and over 300 documents. The principal parties to the hearings were various formulators of DDT products, USDA, the EDF and EPA."*
>
> (EPA, 1975, p 255)

The hearing examiner was Edmund Sweeney. On one side, protesting the cancellation, were Charles O'Connor & Robert Ackerly. These Washington lawyers represented the 31 firms, mostly formulators, who held registrations for products containing DDT and who were referred to collectively as the Group Petitioners. In addition, Elliot C. Metcalfe & Raymond Fullerton represented the USDA which was also protesting the cancellation order. NACA and other minor parties also defended DDT. Opposed to this side and

[126] *Report of the DDT Advisory Committee*, 1971 09 09
[127] *Report of the DDT Advisory Committee*, 1971 09 09, p 43

supporting cancellation were Blaine Fielding, lawyer for the EPA, and William A. Butler who had replaced Yannacone at the EDF. Other parties included the Sierra Club, the National Audubon Society and the West Michigan Environmental Action Council.

Given all the witnesses and testimony, I cannot, obviously, describe in detail these historic hearings. Like those in Madison, they pitted industry, economic entomologists favouring chemical control of insects, and the USDA against the EDF, economic entomologists favouring biological and integrated controls, and the newly-created EPA. Also as in Madison, two different methodological camps emerged from the medical experts (toxicologists, pharmacologists, epidemiologists, etc.) brought forward to testify on the impact of DDT on human health: those favouring the estimation of risks to human health through the study of over-exposed populations (invoked by the pro-DDT side) and those favouring the estimation of these risks by extrapolation from animal studies (invoked by the anti-DDT side). Once again, the testimony of wildlife biologists, ecologists and eco-toxicologists went relatively, though certainly not wholly, uncontested.

Perhaps the most efficient way to outline what happened at the hearings is to draw upon the ultimate *Opinion and Order of the Administrator* that resulted from them. There, Ruckelshaus wrote:

> *"The Pesticides Office and Environmental Defense Fund (EDF), in presenting their cases against continued registration for DDT, lean most heavily on evidence which, they contend, establishes:*
>
> *(1) That DDT and its metabolites are toxicants which persist in soil and the aquasphere;*
> *(2) that once unleashed, DDT is an uncontrollable chemical which can be transported by leaching, erosion, runoff and volatilization;*
> *(3) that DDT is not water soluble and collects in fat tissue;*
> *(4) that organisms tend to collect and concentrate DDT;*
> *(5) that these qualities result in accumulations of DDT in wildlife and humans;*

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[128] *Report of the DDT Advisory Committee*, 1971 09 09, p 41

[sic] *that once stored or consumed, DDT can be toxic to both animals and humans, and in the case of fish and wildlife, inhibit regeneration of species; and*
(7) that the benefits accruing from DDT usage are marginal, given the availability of alternative insecticides and pest management programs, and also the fact that crops produced with DDT are in ample supply.

The testimony and exhibits include numerous reports of expert scientists who have described observed effects of DDT in the environment and the laboratory."

(Ruckelshaus, 1972, p 13370)

In response to this, he continued:

"Group Petitioners and the U.S. Department of Agriculture (USDA) seek to discredit the Agency's case by citing the record of safety that DDT has compiled throughout the years, and point to the negative findings of epidemiological and feeding studies carried out over the years on industrial workers and volunteers exposed to concentrated levels of DDT far in excess of that to which the average individual is exposed. Proponents of continued registration have also introduced expert testimony to the effect that DDT's chronic toxicity to man or animals has not been established by adequate proof. The registrants have attacked the assumption that laboratory data as to effects of exaggerated doses of DDT can provide a meaningful basis for extrapolating effects on man or the environment. Group Petitioners contend that whatever harm to the environment that might be attributed to DDT, it results from misuse and overdosing that occurred in years past. Lastly, Group Petitioners have attempted to prove that DDT is effective and that its use is more desirable than the organophosphates which are more acutely toxic and costly than DDT."

(Ruckelshaus, 1972, p 13370)

Industry and the USDA began with their witnesses and were on the defensive. Their side had filed a protest against a judgment already rendered, so they faced the burden of proving that DDT was *safe* and *necessary*. In contesting the *necessity* of DDT, economic entomologists favouring biological and integrated controls would ultimately challenge claims that it was *effective* as well, while the pro-DDT side took this for granted.

The hearings were historic for the central role they gave science and scientists in developing policy. They were also emotional. The hearing examiner, Sweeney, often pressed scientists for a yes or no response to questions despite their protests that such a response was misleading. As the hearings progressed, rumours that that Sweeney was biased in favour of industry circulated, even appearing in *Science*[129]. In the end, the Examiner Sweeney sided with the Group Petitioners in his report to Ruckelshaus, ordering the lifting of the cancellations and recommending that all *"essential"* uses of DDT be retained. It appeared that DDT would stay.

But the EPA and the EDF filed exceptions to the Examiner's report, and in the end Ruckelshaus did not feel bound by Sweeney's findings, going directly to the hearing transcripts and records in the preparation of his findings. In addition, he also had: Hilton's scientific advisory committee report; Van Susteren's findings from the Madison, Wisconsin hearings; the Mrak report; and even the PSAC report of 1963, all of which drew conclusions damaging to DDT and/or recommended its elimination. Basing his decision on findings of *"persistence, transport, biomagnification, toxicological effects and an absence of benefits of DDT in relation to the availability of effective and less environmentally harmful substitutes"*[130], on June 14, 1972, Ruckelshaus banned DDT.

His specific findings were reproduced in Chapter 3, where they were contrasted with Muller's characterization of DDT as an "ideal" insecticide (see Table 3.7.2.1). His general findings[131] were as follows:

> *A) No directions of use of DDT, even if followed, can over the long run completely eliminate DDT's injury to man or other vertebrate animals.*
>
> *B) No warning or caution for use of DDT, even if followed, can over the long run prevent injury to living man and other vertebrate animals and useful invertebrate animals.*
>
> *C) The present total volume of use of DDT in this country for all purposes is an unacceptable risk to man and his environment.*

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[129] *Science*, 1971 12 10, vol 174, p 1108
[130] EPA (1975, p 255)
[131] Source: Environmental Protection Agency (1972), *Consolidated DDT Hearings - Opinion and Order of the Administrator*, issued June 14, 1972; printed in the Federal Register, vol. 37, no. 131, July 7, 1972, pp.13369 - 13376

D) The use of DDT in controlled situations in limited amounts may present less risk than usage in greater amounts, but still contaminates the environment.

E) The public health program and quarantine uses of DDT by officials, when deemed necessary, can be judged on an application-by-application basis by professionals.

F) A particular official use, in an isolated instance, may be important.

Thereafter, DDT use would be confined to quarantine and public health uses. Petitions from Federal and State agencies seeking exemptions for use of DDT in *"emergency"* cases of insect problems would also be heard. But the battle continued:

"Immediately following the DDT prohibition by EPA, the pesticides industry and EDF filed appeals contesting the June order with several U.S. courts. Industry filed suit to nullify the EPA ruling while EDF sought to extend the prohibition to those few uses not covered by the order. The appeals were consolidated in the U.S. Court of Appeals for the District of Columbia."

(EPA, 1975, p 255)

On December 13, 1973, this court ruled that *"substantial evidence"* existed in the record to support the Administrator's ban. The ban would stand. But in the meantime, the Appropriations Committee of the U.S. House of Representatives requested, and Congress directed, the EPA to review its ban decision:

"The Agency was also directed to initiate a complete and thorough review, based on scientific evidence of the decision banning the use of DDT. This review of DDT must take into consideration all of the costs and benefits and the importance of protecting the Nation's supply of food and fiber."

(Congressional Record, November 6, 1973, H 9619)

In 1973, the EPA granted a request from the states of Washington and Idaho for a temporary registration of DDT for use against the pea leaf weevil[132]. In 1974, the Forest

[132] The details in this paragraph are from EPA (1975, p 256)

Service was granted a similar request to fight the Douglas fir tussock moth, although previous requests from this agency had been denied. In 1975, the EPA denied the request of the state of Louisiana for emergency use of 2.25 million pounds of DDT on 450,000 acres of cotton to control the tobacco budworm. Louisiana appealed this decision, but lost. In that same year the EPA also completed its review of the 1972 ban decision, confirming all of Ruckelshaus' findings. The ban would continue to stand.

Meanwhile, concerning all pesticides and not just DDT, the Federal Environmental Pesticide Control Act (FEPCA) became law on Oct 21, 1972[133], revising FIFRA to specifically include environmental values in the risk-benefit calculus of pesticide registration, as summarized in the USDA's Pesticide Review of 1972:

> *"Before registration may be granted for a pesticide product, the manufacturer is required to provide scientific evidence that the product, when used as directed, will (1) effectively control the pest(s) listed on the label, (2) not injure humans, crops, livestock, wildlife, or damage the total environment, and (3) not result in illegal residues in food or feed."*
>
> (USDA *Pesticide Review*, 1972, p 1)

The amendment also stated that the EPA should revisit all pesticide registrations and re-register them only if justifiable under the new evaluation criteria. This provided even more impetus to the EPA's efforts, began in 1971, to eliminate persistent pesticides from the economy. It was moving forward on this official goal - traceable to the aftermath of Silent Spring, recall - with an enthusiasm never seen and likely not even conceivable at the USDA when it controlled pesticide registrations. Between its birth in 1970 and 1977, the EPA adjudicated over the fate of eight pesticides, six of them organochlorine insecticides (DDT, aldrin, dieldrin, mirex, heptachlor and chlordane; mercurials and the herbicide 2,4,5-T were the other two)[134].

A 1971 reorganization along functional lines of the EPA's Pesticides Regulation Division was felt immediately in the pesticide domain. Under the new alignment of tasks, one

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[133] Bosso (1987, p 176)

[134] See Briggs (1992); also the USDA's *Pesticide Review* for the years 1970 - 1978.

group of scientists developed standards and criteria for the registration of new chemicals and new uses for existing ones, and continually reviewed the status of current registrations[135]. Another group of scientists, experienced in registration procedures, applied the standards and criteria in case-by-case registration actions. In effect, just as agricultural chemical companies have R&D routines for making new products and bringing them to market, the EPA was putting in place organizational routines for removing products from markets by making new rules.

In 1971, the registrations of all products containing aldrin and dieldrin were placed under review by issuing notices of cancellation, affecting some 1,300 products sold by 377 companies[136]. A scientific advisory committee was formed, submitting their report in March of 1972 which recommended that registrations for most purposes indeed be cancelled. Cancellation of all uses except as termiticides came finally in 1975 after public hearings. Similarly, in 1971 the registration of Mirex was also cancelled on the basis of questions raised about residue problems and its effects on wildlife. Again, at the manufacturer's request, this cancellation action was reviewed by an advisory committee. Mirex was cancelled formally in 1977. In addition, in 1971 chlordane and heptachlor were placed under EPA in-house review to determine if registered uses endangered the environment, signaling to the domain the real possibility that formal notices of intent to cancel registrations might follow. These came in 1975, and then in 1977, after intense negotiations, the EPA finally settled with Veliscol Chemical Corporation, several states, and the USDA who agreed to phase out uses of chlordane and heptachlor on corn and other crops over a 1 to 5 year period ending July 1, 1983. Registrations for the remaining uses of these substances, as termiticides, were voluntarily withdrawn in 1988.

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[135] MacIntyre (1982, Chapter V)

[136] This paragraph has been constructed from material in the USDA's *Pesticide Review* for the years 1970 - 1978. Information for years after 1978 was gathered from EPA online sources and in interviews.

6.10 Environmental Values Dominate: Methyl Parathion and EPN Substitute for DDT on Cotton

Returning to the story of DDT, its use plummeted from 23,546,000 lbs in 1972 to just 1,053,000 lbs in 1973[137]. From 13,500,000 lbs used on cotton in 1972, use fell to close to zero in 1973 as cotton growers replaced it with alternatives. Notice that usage did not drop completely to zero because many farmers had been stockpiling DDT in anticipation of the ban, but these stocks were soon depleted. Methyl parathion received the biggest boost in sales.

> *"Methyl parathion is used widely to control insects on cotton and demand for it, as a substitute for DDT, is said to be increasing."*
>
> (Pesticide Review, 1972, p 46)

> *"The largest single shift from the use of DDT combinations obviously was to the use of toxaphene / methyl parathion combinations, as total acre applications of this combination increased from 2.4 million to 10.4 million."*
>
> (EPA, 1975, p 185)

Prior to the DDT ban, a typical formulation used by growers against the cotton boll weevil, bollworm and tobacco budworm was the *"triple kill"* combination of DDT (2 lbs/gal), toxaphene (4 lbs/gal) and methyl parathion (0.5 lbs/gal) which was applied at a rate of 0.5 gal/acre repeatedly, perhaps 15 times in a growing season. Subsequent to the ban, a mixture containing much more methyl parathion, made up of toxaphene (6 lbs/gal) and methyl parathion (3 lbs/gal), was applied at similar rates and more frequently[138]. The volume of methyl parathion used on cotton in the early 1970s had tripled from that used in 1966, and production rates of this substance in 1974 were at their highest levels ever. Methyl parathion was the leading insecticide used in the United States in 1974. In addition, another organophosphate insecticide, EPN, saw its usage on cotton jump from zero prior to the DDT ban to 6.1 million pounds of active ingredient being used by 1976.

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[137] USDA's *Pesticide Review* (1973)
[138] EPA (1975)

Chlordimeform, an insecticide (and ovicide) from the formamadine family, similarly saw its use climb from zero prior to the DDT ban to 4.4 million pounds of active ingredient being used in 1976. In 1979, methyl parathion was the most heavily used insecticide on cotton crops and EPN was second[139].

IPM, with its integrated use of cultural, biological and chemical control methods, also received a boost from the DDT ban. This approach to insect control received its first mention in the USDA's Pesticide Review in 1973:

> *"Integrated Pest Management - The U.S. Department of Agriculture (USDA) is committed to the development and use of pest-control methods that will protect the health and well-being of the consumer of agricultural commodities and the applicators of pest controls, and exert a minimum impact on the environment. In keeping with these concerns, the Department and the State agricultural experiment stations have continued activities designed to develop more integrated methods of pest control. Research has involved chemical, biological, cultural and genetic techniques."*
>
> (Pesticide Review, 1973, p viii)

On cotton, the phasing in of this new philosophy was not as immediate as the switch to organophosphates, but did occur at such a pace so as to warrant notice only a few years after the DDT ban:

> *"One response to the lack of DDT on the part of many farmers has been to put additional emphasis on the scouting of fields. ... Associated with this relatively intensive program of scouting is "discretionary" use of insecticides (which tend to be EPN/methyl parathion). That is, the farmer adjusts his insecticide schedule to match the information he receives from his scouting report and tends to apply insecticides only when the scouting indicates the need to. In addition, the farmer who adopted this strategy also tended to plant earlier, practice diapause control, defoliate, and destroy cotton stalks after harvesting. ... Overall then, he was an adopter of the new and innovative pest management strategies advocated by the extension service for cotton production."*
>
> (Consad, 1976, p 11.5)

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[139] Information on leading insecticides is from USDA's *Pesticide Review* and also *Pesticide Handbook* for the appropriate years.

As can be seen from this description of the (long) series of events leading to the exit of DDT from what was always one of its strongest markets, control of insect pests attacking cotton, **our focal phenomena of substitution was the mandated response to problems of persistence, transport, and biomagnification.** Demand for the use of this active ingredient on cotton, and all other agricultural crops for that matter, fell to zero with the implementation of the EPA's national ban on DDT.

This is clearly an example of rule-driven substitution.

In substituting DDT by methyl parathion and EPN, insecticide users were faced with the **same choice menu of alternatives available as in the years prior to the ban.** Methyl parathion was introduced in 1952 and EPN in 1949. Cotton growers were already heavy users of methyl parathion, and the ban on DDT simply caused a further increase in their consumption of this active ingredient. The phenomena of EPN consumption by cotton growers, on the other hand, came into being because of the DDT ban. Prior use of this active ingredient by farmers was so low as to warrant a "zero" in official USDA records.

Nor can users' switching away from DDT be attributed to a substitution of beliefs by insecticide users: proponents of DDT employed **the same set of beliefs about the consequences of using various insect control alternatives before and after the ban.** Cotton growers were convinced - and fought to the bitter end because of their convictions - that DDT's *effectiveness* as an economic poison was superior than any alternative and that DDT was the most economic choice for their insect control challenges. Indeed, a significant portion of the Consolidated DDT Hearings was devoted to this particular issue because of the strong economic focus of FIFRA. It stipulated that the risks and benefits of pesticides had to be considered in all decision-making. DDT proponents also believed, and continued to believe, that the *safety* of DDT was superior to that of methyl parathion as well. Notice here how different sides of the debate adopted different definitions for conceiving of, and different criteria for measuring, insecticide safety. Those in favour of DDT put more emphasis on acute toxicity to humans, pointing to the increased hazards and risks to insecticide applicators of the switch to organophosphates. From the applicators' perspective, the organophosphates were in fact much more dangerous. Those against DDT put more emphasis on chronic toxicity to humans, pointing to DDT's carcinogenic potential. They also interpreted safety to include a concern for the environment as well, drawing attention to the effects of DDT on fish, mammals and especially birds.

So it was not the appearance of a superior substitute which motivated or triggered the substitution. Rather it was changes to the value judgments, preferences and evaluation logics employed to with insect control alternatives and their consequences that led to the supplanting of the organochlorine DDT by these organophosphate substances. **The primary trigger for this ultimate instance of substitution, driven by problems of persistence, transport and biomagnification, was clearly, we argue here, rule-making by concerned citizens, their organizations, politicians and government officials in the public arena.**

One can also make an argument that this ultimate instance of DDT substitution was driven by "fact-making" in that this process was crucial to the "rule-making" process. Politicians, government agencies and NGOs needed evidence of eggshell thinning and carcinogenicity - not to mention the availability and effectiveness of substitutes like methyl parathion - in order to demonstrate the justice of a DDT ban. But these toxicological and ecotoxicological facts would not, in and of themselves, have caused substitution in the same way that facts about the problems of resistance, secondary pests and resurgence did, as described in the previous Chapter. This is because these facts documented the consequences and risks of insecticides to third parties: they dealt with "externalities". Without rules forcing insecticide users to take these environmental and health values into account in their insect control decision making, it is unlikely that they would have done so on their own. By changing the rules, other actors were successful at having their concerns and values included in the calculus of insect control decisions, achieving some degree of coercive control (by bringing into existence legal penalties and sanctions for DDT use).

Stated another way, one active ingredient was substituted for by another active ingredient because **one rule was substituted for by another rule** through a process of contestation in the public arena.

The DDT case meant a lot for the EPA. It was the first big test - *"the first big target"* [140]- of this new agency, and to this day agricultural interests accuse it of drawing the "wrong" conclusions and making the ban decision on "political" and "emotional" grounds. The argument is that Ruckelshaus, determined to make an impression in these early and critical years of the EPA, banned DDT "despite" the scientific evidence. EPA insiders both confirm and dispute this politicized view in an odd way. They feel that DDT was legitimately banned "because" and not "despite" the scientific evidence, but that the scientific evidence alone would not have been sufficient. The political and emotional dimensions were crucial as well for the process of rule-making:

> *"You can't just be right. That does not help you in political environment."*[141]

Indeed, subsequent to the DDT case, it has been difficult for the EPA to muster the emotion necessary to overcome political inertia, at least by focusing purely on the environment. Human health concerns, especially cancer, have been behind much of its pesticide activity since (including the cases against endrin, dieldrin, mirex, chlordane, and heptachlor). This was made clear to me by an EPA person involved since those early years of public hearings over organochlorines:

> *"The DDT decision was THE initial major regulatory action be the feds. It was primarily an environmental case and not a human health case. ... We never did get a good human health case against DDT. This made DDT the EPA's best environmental case, because since that time it has been health. ... I'd have to think hard to find something else where we*

[140] EPA employee, interview
[141] EPA employee, interview

(EPA) had done something just for wildlife. Perhaps something in the water treatment division."[142]

DDT, and the rule-making linked to it, contributed to the later success of both the EPA and the EDF. Both knew that there was much more at stake than just the fate of this particular molecule and the changed rules they were promoting:

*"**DDT was the first big trophy chemical.** It was important for all departments: water, air, etc. that they make a big splash."*[143]

Winning the fight over DDT strengthened both these organizations and positioned them well for future battles. This is an important point that I wish to stress. Credibility, as a discursive resource, is both a *stake* and a *weapon* in discursive struggles over Truth and Justice. Being on the winning side of an argument makes one a tougher opponent in future disputes.

NACA and the USDA knew this. They fought for DDT not because of DDT, per se. By the time it was banned, DDT had lost much of its economic significance for the agricultural chemical industry. It had been abandoned by all but one manufacturer, Montrose. But it certainly had gained in symbolic importance. Both EPA and industry interviewees for this research made the point that NACA fought the battle over DDT on principle. EPA was the new *"enemy"* in the arena, and had to be weakened from the start.[144]

But NACA was tied to a government ally, the USDA, itself weakened by its arrogance in the face of public protest over its eradication programs and by its *Deficiencies in the Administration of FIFRA* as went the title of the General Accounting Office's report to Congress in 1968[145]. To get a sense of the conflict and contestation that was occurring and being experienced by actors at the time, and that "facts" were in fact weapons, it is

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142 EPA employee, interview
143 EPA employee, interview
144 EPA employee, interview
145 GAO (1968)

instructive to consider the descriptions offered by those involved of the various EPA hearings into organochlorines in the early 1970s. *"The EDF collaborated closely with the EPA lawyers, fed them information, etc. and they absolutely kicked the USDA's ass."* They continue, *"We had a whole goddamned building filled with scientists and economists"*, making the point that the EPA's opponents had a difficult task before them because the EPA had a *"strong arsenal"* and drawing attention to certain technical documents prepared for these hearings which *"would have cost $1 million to produce by a consultant."*[146]

As far as cotton growers are concerned, why were they the last to give up DDT? Why did they fight until the end? Of course, as a non-food crop, they did not have the same potential for residue and public relations problems that other growers did: most other agricultural sectors had switched away from DDT by the time of the ban. There is some evidence though that, in addition, they just had too much confidence in their ally in the rule-making arena. Speaking, fittingly, in the Jamie Whitten Conference Centre in Mississippi, to some cotton growers shortly after the DDT decision who were perplexed that what they felt was a very strong cost-benefit rationale for keeping DDT did not carry the day in Washington, an industry insider told them *"You guys had it too easy with Mr. Whitten. You didn't learn to play the game, and you do not have the tools to play in this new game"*.[147] This powerful Congressman, long time chairman of the agricultural appropriations committee and author of *That We May Live*, a book-long response to Silent Spring detailing the benefits of pesticide use, had protected them and delivered on whatever was necessary up until the DDT ban. But restructuring of the arena - the transfer of pesticide registration from the USDA to the EPA - made him less effective.

[146] EPA employee, interview
[147] interview

6.11 Conclusion: Substitution as a Consequence of Rule-making

The exit of DDT from the market for insecticides represented by cotton growers is an example of what I call in this thesis "substitution as a consequence of rule-making". The critical dynamic that triggers and drives this type of substitution occurs largely in the public and political arena of society. It is a process that is not well-understood in the business strategy and economics literature; the primary trigger for this instance of substitution driven by problems of persistence, transport and bioaccumulation was "rule-making" by concerned citizens, government officials and other actors in the public arena. The regulations governing the insect control decision-making were changed to reflect the public's expression of its new values. From society's point of view, what constituted acceptable product performance was changed. **Performance was redefined.** As *values* change, what counts as the most *Efficient* tool changes. The "Justice" of insect control outcomes that created risks to the environment (especially to birds like the peregrine falcon at the top of food chains) and to human health (via chronic, not acute, exposure) was successfully challenged by actors promoting different values.

I wish to draw readers' attention to three key points which characterize this type of substitution process:

> (1) First, these substitutions were *not* triggered and driven by the appearance of methyl parathion or EPN in the commercial marketplace. The tools available to insecticide users - those appearing on the "choice menus" - were unchanged before and after the substitution process; both had been available since the early 1950s.
>
> (2) Second, there was no uncertainty, ambiguity or controversy as to the relative performance of the incumbent product DDT compared to the substitutes along the *incumbent* evaluation criteria of efficacy and safety (defined in terms of acute toxicity). That methyl parathion had less insect killing power per unit cost - and was much, much more acutely toxic - than DDT had been known a long time.

(3) Third and finally, there was however ambiguity and controversy along *new* contested dimensions of evaluation: safety to fish, birds and wildlife and to humans via chronic exposure. What changed to trigger substitution were the evaluation criteria and decision rules employed by actors in the pesticide domain to define what constituted superior insecticide "performance" that changed. The "facts" about DDT's environmental fate did not really matter - they had little *significance* - *until* the actions of concerned citizens in the public arena made them relevant. Through their protests, complaints and contesting, actors (especially the EDF!) succeeded in elevating the status and importance of what originally were unimportant evaluation criteria in domain regulators' decision-making - chronic toxicity to birds, other wildlife and even humans, as well as the impact - in terms of risks, of insecticide users' activities on the rights of non-users.

Specifically, in the rule-making arena, actors (concerned citizens, the EDF) developed and made normative claims - "ought" statements reflecting their preferences for insect control outcomes that did not include the bearing of risks by wildlife and humans - that they believed (or at least hoped) had potential for being adopted, then brought these to organized structures of conversation (the courts, public hearings) where the fate of normative claims are decided and where they attempted to demonstrate the superiority of their proposed decision values and rules as compared to the incumbent ones. Just as the entry of DDT resulted from systematic and structured problem-solving activities in the commercial arena, the exit of DDT from these markets was also the result of systematic efforts by organized individuals to solve what they perceived as a problem of values and decision rules. The "acceptability" or "appropriateness" or, more generally, "Rightness" or "Justice" of the outcomes of insect control decisions was successfully challenged by actors affected adversely by the spraying along with their sympathizers and supporters. Using the institutional resources at their disposal, they succeeded in changing the values invoked by municipal, state and federal authorities in insect control decisions, and in the limiting cases, had these ensconced into "rules" applicable to entire jurisdictions. The substitution of one value (i.e. decision rule) for another triggered the substitution of one product for another.

7 The Fall of DDT (II): Substitution as a Consequence of Fact-Making

7.1 Introduction

In this Chapter, I describe the fall of DDT but focus on problems which are different from those discussed in the previous Chapter. I describe some of the earliest critiques of that molecule that successfully led to its exiting certain insect control markets. Once again, in some ways, its fall began at the same time as its rise - if not before - because of DDT's particular physical, chemical and toxicological properties. But these were not enough *in and of themselves*: they had to be *learned about* and related to particular phenomena that insect users labeled as problems. This will be demonstrated by describing and analyzing processes of substitution in which DDT was involved as the incumbent exiting product, replaced by other organochlorines such as methoxychlor or organophosphates such as methyl parathion. The substitution of DDT came about only after struggle and contests over what constituted the truth about its performance level. Simply put, what counted as superior insecticide *performance* remained constant while DDT's "score" along those criteria were *remeasured* or *reevaluated.* This reevaluation was highly unfavourable from the perspective of DDT manufacturers.

I argue that the instances of substitution described in this section are relatively pure examples of the phenomena which I term *substitution as a consequence of "fact-making"*, a process whose dynamic is dominated by activities in the scientific arena of society. Substitution as a result of this mechanism is less well-understood in the business strategy and economics literature, and the story is less familiar. In instances of this type of substitution, what prompts the disappearance of a product from the economy is not the sudden appearance of an obviously superior alternative. Rather, one product replaces another in performing a particular function in the economy primarily because the perceived level of performance of the incumbent product is reevaluated. "Facts" about how well the product performs are contested and "melt"; new facts are made. Users' one-time belief in the incumbent's superiority comes to be changed, replaced by beliefs that rank the incumbent product much lower in terms of performance satisfaction. In other words, substitution of one artifact for another follows and is triggered by the substitution of one "fact" for another. The fate and status of actors in this arena are closely linked to the facts they propose and promote. In the fact-making arena, actors (i.e. scientists in the case of DDT) search for and "make" descriptive claims (i.e. "is" statements as to what *are* the outcomes of the accomplishment of a particular functionality in society), then bring these to organized arenas of communication (i.e. discourses) where they attempt to demonstrate their superiority. In this process, the monopoly or quasi-monopoly of incumbent facts are challenged and contested, essentially, with appeals to and demonstrations of facts' **Truth**.

I demonstrate how, in the case study, the "Truth" of DDT - once widely accepted assertions and descriptive claims as to the wonderful efficacy of DDT for certain uses - was successfully contested. Through a process of discursive struggle, undertaken in this case largely within the structures and organizations of science, new facts rules *substituted* for older incumbent ones. In the examples discussed here, the array of alternative artifacts (i.e. active ingredients available for use) on actors' choice menus remains constant, as do actors' evaluation criteria and decision rules for insect control decision-making. But the beliefs invoked by actors to select among various products come to be changed as novel claims are adopted, triggering substitution. Analogous to the institutionalization of artifacts and the emergence of dominant designs in the physical world, as a competing descriptive claim becomes more and more widespread, it becomes *institutionalized* and when contestation ceases it has become a "fact" and part of the dominant paradigm.

7.2 Substitution Because of the Problem of Insect Resistance

Without being forced or coerced through legislative action, users of DDT in many markets switched, reluctantly, to long-available alternative active ingredients - other organochlorines sometimes, like the cyclodienes, but especially molecules from the organophosphate family - because of the problem of insect resistance.

There are two broad classes of insect resistance: physiological resistance and behaviouristic resistance. The latter describes *"the development of an ability to avoid a dose which would prove lethal"*, while the former is the *"development of an ability in a strain of insects to tolerate doses of toxicants which would prove lethal to the majority of individuals in a normal population."*[1].

Although behaviouristic resistance to DDT is common in the literature, especially with mosquitoes (apparently, before they are able to come into contact with a lethal dose, the insects are motivated to fly away from surfaces impregnated with the toxicant because of the irritation it causes them), most insect resistance is physiological. It is developed through evolution within the context of the "artificial" rather than "natural" selection pressures exerted by toxicant-rich environments. *"Thus, the development of insect resistance to insecticides is due to the presence in normal populations of variants carrying pre-adaptations, factors or genes for resistance and the screening out of these variants by selection with an insecticide is a process of Darwinian selection."*[2]. Natural populations of insects will contain a certain fraction of individuals that are genetically different in such a way so as to make them less susceptible to particular insecticidal substances. If the insect population is exposed to the substance, these individuals have a higher differential survival rate than their "normal" counterparts and hence go on to successfully reproduce at a higher rate and make up an even larger portion of the subsequent generation's population. Continued or repeated exposure to the toxicant only serves to purify the strain, producing a population of insects that is more and more resistant as individuals of intermediate resistance produced in earlier stages of the selection process are subsequently eliminated.

Within applied entomology, resistance has emerged as a very serious problem associated with many insecticide active ingredients. It has been the key motivating factor behind much *substitution* of DDT and other insecticides with alternative substances.

[1] Definition is from WHO, cited in Brooks (1974, vol II, p 3)

"Undoubtedly the phenomena of insect resistance has been the greatest problem encountered in relation to the use of the organochlorine insecticides."[3] states Brooks, probably reflecting the bias of someone who works closely with and promotes insecticides, as it is likely that wildlife biologists and bird watchers would have identified other problems as *"the greatest encountered"*. But nonetheless, that author underlines the significance of this phenomena and the subsequent substitution phenomena it triggers once it is recognized.

As early as 1946, the resistance of houseflies to DDT was noted in Sweden and Denmark, and then in 1947, both Italian houseflies and mosquitoes became resistant to DDT[4]. A bit later, in 1951, DDT-resistance of the body louse in Korea frustrated the military. After only 5 years of agricultural usage of DDT in the United States, resistance appeared in the codling moth, an important pest of apple orchards, in 1951. By 1974, DDT-resistance had occurred in some 29 species of agricultural insect pests of cabbage, potatoes, cotton, tobacco and other crops; the total for all insect species with DDT-resistance was 86 species.

As noted, resistance is not a problem confined to DDT. By 1968, resistance to the cyclodiene family of organochlorine insecticides had occurred in 137 species in total, with 53 of those being insect species of agricultural importance. By 1974, 32 insect species were resistant to various organophosphates, and 27 species demonstrated resistance to insecticidal substances other than the organochlorines and the organophosphates, like the arsenicals for example.

Once resistance is recognized, users' first reaction is often to increase the dosage or frequency of application of active ingredients, and hence the onset of resistance in field settings can initially increase demand for a substance[5]. Under very particular

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[2] Brooks (1974, vol II, p 3)
[3] Brooks (1974, vol II p 30)
[4] The literature on insect resistance is huge. This discussion has benefited greatly from material in Brooks (1974, vol II); his Chapter 2 is devoted entirely to resistance.
[5] Glass interview

circumstances, this can be a viable response to resistance problems, but, in most cases, it does not typically work as by increasing the intensity of selection pressures operating on the target population, insecticide users just make the resistance problem worse. Eventually demand for the active ingredient falls as users switch to alternatives. In other word, **the focal phenomena of substitution was the most common response to the problem of resistance.**

> *"The usual countermeasure for resistance is to switch to a new insecticide. DDT resistance in the housefly was countered by* ***substituting*** *lindane or dieldrin, and the inevitable cyclodiene resistance demanded a switch to malathion or diazinon, which remained effective until organophosphate resistance developed."*
>
> (Brown, 1971, p 527)

> *"The practical outcome of resistance to chlorinated hydrocarbon compounds has been* ***the introduction of a number of new organophosphate and carbamate compounds.****"*
>
> (USDHEW, 1969, p 59)

Indeed, a substantial part of the substitution of DDT with other active ingredients which occurred prior to its ban in 1972 - on virtually all crops except cotton - was driven to a greater or lesser degree by the problem of resistance[6]. Data from numerous sources - interviewees of entomologists and regulators, written histories of insect control, and archival documents - have reinforced this point: it was the development of resistance by insects that frequently led to the substitution of other substances for DDT.

> *"Rachel Carson, one of the critics, in her book, Silent Spring, laid much of her criticism at the door of the chlorinated hydrocarbon insecticides, of which DDT is an example. ... In the meantime,* ***a worldwide shift away from DDT is being made, chiefly because of the growing resistance that some species have developed to it.****"*
>
> (Hall, for the USDA, 1964, p 113)

Dr. David Pimentel, intimately involved with the DDT debate as a member of a number of major federal government commissions (like the Mrak Commission, which published

[6] Almost all interviewees from entomology, industry and the EPA concurred on this point.

its report in 1969[7]) and as the author of *Ecological Effects of Pesticides on Non-Target Species*, a report commissioned by the Office of Science and Technology in the Executive Office of the President, confirmed that *"the development of resistance by pests, in cotton as well as other crops, definitely helped speed the exit of DDT"*[8]. Similarly, in his review of the history of organochlorine insecticides, Brooks states:

> *"The* ***decrease*** [in quantities of DDT used in the United States] *has undoubtedly resulted from the widespread discussion of environmental problems that followed the appearance in 1962 of* ***the book Silent Spring by Rachel Carson****, and in a more practical sense by* ***the advent of DDT-resistance which created a need for replacement toxicants*** *that has been partly met by the development of new organophosphorous and carbamate insecticides."*
>
> (Brooks, 1974, vol 1, p 40)

Consider the substantial market for insecticides represented by *"one of the best known of all fruit pests* [which] *is the codling moth (carpocapsa pomonella) which, in larval form, is mainly responsible form wormy apples."*[9]. Though not as big as those of cotton, corn, nor soybeans, the apple market is nevertheless a significant crop for insecticide manufacturers and formulators, because *"on a per-acre basis, apples receive the highest amounts of pesticides, seasonally, of any major U.S. crop."*[10]. Also, at the time of DDT's entry into the economy, apples and cotton were the biggest markets for insecticides.

DDT was initially adopted with much enthusiasm by apple growers:

> *"In the case of the codling moth (carpocapsa pomonella), it [DDT] has turned out to be the best insecticide yet found. The success against the codling moth, which causes more loss to apple and pear growers in the Pacific Northwest than any other insect, running up sometimes to more than 50% of the crop, is one of the outstanding achievements of DDT. ... A typical report suggests that 1 or 2 lb. of DDT (5 to 10 lb. of 20 per cent water-dispersible powder) per 100 gal. of water, applied according to the usual schedule for spraying, is the most satisfactory."*

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[7] USDHEW (1969)
[8] Pimentel interview
[9] Brooks (1974, vol I, p 31)
[10] Office of Technology Assessment (1979, p 37)

(Leary et al, 1946, p 155)

But DDT usage in apple orchards came to a halt. Other active ingredients were substituted, and there is little doubt that the substitution of DDT in apple orchards was driven by problems of insect resistance long before any DDT ban or even public controversy:

> *"About 5 years after it first came into use for agricultural purposes, resistance to DDT appeared in the codling moth (carpocapsa pomonella) in the United States ..."*
>
> (Brooks, 1974, vol II, p 30)

> *"During the 1930's there was widespread resistance in the codling moth for lead arsenate, an insecticide then in general use against this insect. Growers in several areas were unable to prevent devastating losses. This same insect was able to evolve resistant strains to DDT after less than 10 years of exposure, and the red-banded leafrollers developed resistance to TDE in about the same length of time.* ***As a result, DDT and TDE were little used beyond 1960, long before the use of DDT was banned in the United States."***
>
> (Office of Technology Assessment, 1979, p 41)

> *"DDT resistance in the codling moth has been met by the* ***substitution*** *of organophosphate insecticides or carbaryl."*
>
> (Brown, 1971, p 527)

> ***"Apple growers did not stop using DDT because of Rachel Carson, they stopped because of other problems, like resistance.*** *... The major impact of Silent Spring was on the lay public and back yard gardeners, not farmers & experiment stations."*
>
> (agricultural experiment station entomologist interviewee, Ed Glass, 1998)

By what mechanism or process did this actually occur? **The primary trigger, I argue here, was fact-making by extension entomologists and farmers.** The fact that was "re-made" had to do with the *efficacy* or *biochemical effectiveness* of DDT as an economic poison towards the target insect species, in this case the codling moth.

Resistance is measured using precisely the same operationalized measure as is used to screen substances for their insecticidal value: the LD50 or LC50 towards a target insect species. The median lethal dose (LD50) or concentration (LC50) defines the amount of toxicant required to kill 50% of the individuals in a randomly chosen sample. *"Resistance to an insecticide is measured by comparing the response of an insect strain under test (frequently in terms of LD50 or LC50 ...) with the response of a normal strain which has not been subjected to pressure with the insecticide."*[11]

This operationalization of resistance underlines the point I wish to make about the underlying mechanism at work here and which I identify as driving this particular substitution event: the changes that led to substitution because of resistance were primarily changes to the "facts". Individual switching behaviour away from DDT to alternative substances, that when aggregated gives us the phenomena of substitution, was driven by changes to users' beliefs about the outcomes which would be obtained through the continued use of DDT. In other words, in situations where resistance was identified as a new problem, the beliefs of insecticide users as to the toxicity of DDT were changed. DDT's LD50 towards insect species could no longer be considered a *timeless, universal* measure. New, local measurements of DDT's LD50 towards targeted insect species replaced the official LD50 recorded in texts and academic papers.

Note that farmers, foresters, and public health officials who switched away from DDT - to the cyclodiene organochlorines or to an organophosphates - did so by employing the **exact same set of evaluation criteria and decision logics** they used when they were choosing and using DDT. They were also faced, in most cases, with **the same choice menu of alternatives** as in years prior to the resistance problem. It was not the appearance of substitute products like the cyclodienes, which had been around since about the same time as DDT, nor the organophosphates, which motivated or triggered the substitution. It was the changed measure of DDT along the one of the evaluation criteria of utmost importance to farmers and entomologists: toxicity towards the target insect species.

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[11] Brooks (1974, vol II, p 4)

Also note that the "fact" being made here about the toxicity of DDT is not a difficult one to make, really. Evidence for it is painfully obvious and immediate: the target species is not killed. But nonetheless, users' initial reactions are those of *disbelief*. Even with evidence before their very eyes, users revised their incumbent beliefs only with difficulty, suspecting that they had purchased a fraudulent batch of insecticide or that they had somehow misapplied it[12].

> *"With the postwar prospect that DDT would be the panacea for all insect problems, it will be appreciated that the impact of resistance was somewhat painful, and* ***it was at first difficult to accept the fact*** *that failure to control a particular pest might be due not to some defect in the quality of the insecticide or in the application technique but to an alteration in the pest itself."*
>
> (Brooks, 1974, vol II, p 31)

But ultimately, this new belief that of the higher LD50 of DDT towards the codling moth (a higher LD50 means that it takes more insecticide to kill half the insect population) came to replace - *to substitute for* - the users' incumbent belief re DDT's LD50.

Stated another way, when the problem of resistance arose and was recognized, then in that particular spatial and temporal context, **the belief of apple orchard farmers that "DDT is effective" was substituted for by the belief that "DDT is not effective".** This led apple growers to substitute organophosphate insecticides for DDT.

How exactly this change or substitution of beliefs occurred for individual farmers likely varied from person to person. Many growers may have changed their beliefs in isolation from others soon after applying DDT, upon seeing the evidence before their eyes; the insects had not died. Those who sprayed prophylactically (i.e. in order to *prevent* rather than *control* or *eradicate* an infestation) would have been forced to wait a bit.

But the views of others were no doubt important as well. My interviews indicate that growers made their pest control decisions based on a number of different inputs: (1) what

[12] Glass interview; also in Brooks (1974, vol II, Chapter 2)

they had heard about (neighbours, friends, agricultural research station people, industry people), (2) what they had read about , and (3) their own experience. *"Farmers learn who gives them the right information"* and *"friends and neighbours are important."*[13], so one can imagine the news of resistance spreading quickly through a growing region.

Certainly the official recommendations of extension entomologists served as vectors for transmitting "beliefs", diffusing them out to farmers until they had become widely held and hence "facts". They developed and communicated "local" recommendations annually. Their recommendations were "local" or "specific" to particular geographic regions because variations of all sorts of factors can affect the killing power of insecticide formulations. Along with the genetic makeup of the target pest population (which affects resistance), humidity, temperature, rainfall, the presence of other insect species, and other factors can all influence which particular active ingredients and formulations thereof are recommended. At the start of each growing season, and then later at appropriate times throughout it when annual infestations of different species began to arrive, *"the fruit entomologists would draw up their recommendations each year, and these official recommendations were communicated to growers"*[14]. These were mostly followed, given that these stations *"had great credibility"*[15]. The system of tight cooperation that existed between growers and experiment stations helped to speed the transmission of these new "beliefs" about the efficacy of DDT. The agricultural system was *organized* so as to attend and respond quickly to problems which affected farmers' yields and productivity acutely.

Claims as to DDT's loss of efficacy due to a resistance problem also lend themselves to relatively immediate and unambiguous tests. For species already present in their crops, farmers could indeed test the efficacy of DDT. The absence of delay and ambiguity in the production of evidence for these particular claims meant that there was not a lot of

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[13] Glass interview
[14] Glass interview
[15] Glass interview

margin for *contesting* them. Neither did farmers have an obvious interest in contesting these new facts; if they were "true", their use could only help farmers.

It must be admitted that, with the example of problems of resistance, the changes in actors' beliefs followed and tracked changes to the underlying physical reality. For this example, we could credit these "real" changes in target insects' genetic makeup with triggering our focal phenomena of substitution, rather than crediting the subsequent changes to actors' beliefs. Farmers and entomologists *adapted* to their changed circumstances. Their beliefs about the efficacy of DDT - and therefore their choice of insect control technological artifacts - *coevolved* in a lagged manner along with the genetic makeup of target insect populations.

But there are, in this case study of the history of DDT, examples of changes to actors' beliefs which subsequently led to substitution and which were not coevolving with an underlying shifting physical reality. Rather, these beliefs *evolved* and became more consistent with an underlying reality that was complex but which had not changed fundamentally. In other word, actors *learned*. These were substitution processes caused by the problems of secondary pests and primary pest resurgence.

7.3 Substitution Because of the Problems of Secondary Pests and Resurgence

Without being forced or coerced through legislative action, users of DDT in a number of markets switched to alternative active ingredients because of the problems of secondary pests and primary pest resurgence. I treat these problems together here because of their many similarities; they both involve a worsening of insecticide users' pest problems subsequent to the use of a particular active ingredient.

Problems of secondary pests arise from the use of insecticides because all active ingredients have different toxicities to different insect species. Hence, situations arise frequently where the initial use of an insecticide kills the targeted primary insect species as desired, but that in so doing it raises the status of what was once considered a secondary or "nuisance" species to full pest status. This is especially the case if the insecticide is not toxic to the nuisance species but is toxic to its predators, parasites and competitors. If this occurs, the unaffected species' population increases, filling the biological void left by the killing power of the insecticide. As the nuisance insect population increases, at some point it passes the economic threshold which defines a full-fledged pest and ceases to be just a nuisance: it begins to cause damage to crops serious enough to warrant more insect control intervention by farmers. Recall an important point made early in our case study description - "pest" is not a scientific category but is rather defined contingently and economically.

Problems of primary pest resurgence on the other hand arise from the use of insecticides not because different species are differentially affected by the active ingredients' killing power but rather because the primary pest species is able to rebuild its population faster than its predators, parasites and competitors and hence quickly refills the biological void. In other words, farmers' initial pest infestation problems return quickly and with more severity. This is also called "flare-back". By as early as 1964, resurgence problems had been recorded for over 50 species of plant-eating insects and mites, with the majority of these species being *"serious pests now found widely in comparable crop types throughout the world."*[16]

DDT has been implicated in a number of serious secondary pest and resurgence problems:

> *"Instances are now legion in which DDT and parathion unfavourably depressed predator and parasite populations."*
>
> (Rudd, 1964, p 274)

[16] Rudd (1964, p 270)

This is unsurprising considering that DDT, like parathion, is a broad-spectrum insecticide and, by definition, is toxic to many species of insects. Let's consider again the case of apple growers who learned after their initial experiences with DDT against the codling moth (carpocapsa pomonella) that *"red spider outbreaks followed DDT applications."*[17]

> *"There are also unfortunate cases where the use of DDT has led to new pests developing. The best documented case relates to the fruit-tree red spider mite, Panonychus almi. This mite has, during the last 50 years, become an important pest of apples and fruit in Britain and in parts of North America. ...However with the successful use of DDT to control the codling moth Cydia pomonella, huge outbreaks of red spider mite occurred. This only happened where DDT was used - in neglected orchards the many predators present kept the mite in check even if the fruit was severely damaged by other pests."*
>
> (Mellanby, 1992, p 64)

> *"A characteristic of DDT which was soon noticed is its selective toxicity towards certain pest predators. It frequently happens that the pest is imperfectly controlled while the predators are mostly destroyed, resulting in a later damaging increase in the pest population. When for example, DDT is used in orchards for the control of the codling moth, mite predators are destroyed and mite infestations frequently follow because the mite eggs are not affected by DDT. The nymphs and adults may be killed by the treatment, but the life cycle is very short and the unharmed eggs quickly give rise to more individuals which proliferate rapidly in the absence of natural biological control."*
>
> (Brooks, 1974, vol I, p 29)

As with the problem of resistance, problems of secondary pests and resurgence do not *necessarily* lead to the substitution of the implicated active ingredient with another. In fact, a common response is to use a combination of active ingredients such that what one might first think of as competing substitute products actually become used in the field as complements:

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[17] Rudd (1964, p 271)

"The codling moth is a very serious pest of apples in Europe and the USA. It proved easy to control with DDT, but the red spider mite, on the same trees, was not so easily eliminated and became even more common. This made it necessary to use parathion or one of the newer acaracides in addition to DDT"

(Mellanby, 1992, p 38)

" ... the use of DDT has been accompanied by applications of mite ovicides to restore the population balance."

(Brooks, 1974, vol I, p 29)

But this strategy does not always work and full-fledged replacement of active ingredients giving rise to problems of secondary pests and resurgence is sometimes necessary. In other words, demand for the active ingredient falls as users switch to alternatives. In other words, **the focal phenomena of substitution was a common response to the problems of secondary pests and resurgence.** Consider the case of citrus fruit growers in a number of growing regions in the United States, like Florida:

"Citrus red mite increased so drastically in Florida after DDT applications that all recommendations for DDT in citrus orchards were withdrawn"

"One of the most dramatic examples implicating pesticides as destroyers of the natural enemies of pests occurred with the advent of DDT use in citrus orchards in 1946 (DeBach & Bartlett, 1951). The singular success of the vedalia beetle, imported from Australia to control cottony cushiony scale, is one of the classic tales of biological control. For almost 60 years this scale had been kept in check, at low numbers, by its introduced adversary, but with widespread applications of DDT the scale increased sufficiently to become a serious pest once more. DDT was much more toxic to the coccinellid predator than it was to the scale. Only the uniform withdrawal of DDT from citrus orchards restored the former balance."

(Rudd, 1964, p 271 & 273)

Or California:

"Mite and aphid populations increased noticeably after DDT use in California orchards."

(Rudd, 1964, p 271)

"When DDT was used in citrus orchards in California to control mosquitoes, this led to an outbreak of the cottony cushy scale (icerya purchasi) which for a hundred years had been biologically controlled by the ladybird (Rodolia cardinalis). It was found that the Rodolia was much more susceptible to the chemical than the Icerya. When the use of DDT was stopped, the ladybird once more took control."

(Mellanby, 1992, p 64)

How did this "uniform withdrawal of DDT" take place in these markets? What was the process involved by which DDT came to be replaced by other active ingredients in citrus orchards? As above with the problem of resistance, **the primary trigger, I argue here, was fact-making by extension entomologists, scientists and farmers.** The fact that was "re-made" had to do with the *efficacy* of DDT as an economic poison.

Problems of secondary pests and resurgence were identified and addressed using precisely the same criteria as were used to identify and address the original insect control problem that resulted in the use of DDT: did the level of crop damage justify spraying with an active ingredient or not? The only difference was, whereas prior to their knowledge of the problems of secondary pests and resurgence that appear as consequences of using DDT growers opted for DDT, once they appreciated these outcomes they opted for alternative active ingredients. Substitution due to problems of secondary pests and resurgence came about because of changes to the "facts" about the consequences of using DDT related to the actual costs of spraying with it once all unintended consequences were accounted for. Individual switching behaviour away from DDT to alternative substances, that when aggregated gives us the phenomena of substitution, was driven by changes to users' beliefs about the economic outcomes which would be obtained through the continued use of DDT.

Note that the citrus growers who switched away from DDT did so by employing the **exact same set of evaluation criteria and decision logics** they used when they were choosing and using DDT. They also faced **the same choice menu of alternatives** as when they originally chose DDT. It was not the appearance of a better substitute product which motivated or triggered the substitution, but rather the appearance of more "facts" -

the identification and attending to of a problem - that in turn made an existing alternative "better".

Stated another way, when the problems of secondary pests and resurgence arose and were attended to, then in that particular spatial and temporal context, **the belief of citrus growers that "DDT is effective" was substituted for by the belief that "DDT is not effective".** This led them to substitute alternative insecticides for DDT.

As with substitution due to resistance, initially it was difficult to believe that DDT had been the cause rather than the solution of insect control problems. But ultimately, through discursive struggle and debate among economic entomologists, "facts" about the link between DDT and secondary pests and resurgence got made, and diffused out to growers. Once the entomologists had reached consensus, then their official recommendations and the system of tight cooperation that existed between growers and experiment stations helped to speed the transmission of these new "beliefs" about the economic unsoundness of using DDT.

> *"Upon my return after this work in the south of California, the fame of DDT had spread. It was found to be a rather effective control for the citrus thrips in the Central Valley of California, and it was enthusiastically applied in 1945. In 1946, they found that the cottony cushy scale, which had been the first great example of biological control in the world, had become the major pest in this whole valley ... We were called up there. We found that citrus groves were literally encrusted in some cases with the cottony cushy scale to the extent that the trees were actually killed. I don't know how many of you have had experience with how difficult it is to kill a citrus tree. It's not easy because, particularly with any kind of an insect, you can get a tremendous infestation [which]may kill twigs or branches. But to kill an entire tree, it really has to be an enormous infestation. But this is what we had. I saw entire large groves defoliated by the cottony cushy scale due to the killing of the predacious lady beetles by DDT. ... The situation was so serious among the growers up there then, that they were actually trying to buy, and were buying when they could get them, these beetles for one to two dollars apiece. ... It was obvious to anyone at this time what the cause and effect were. At first it wasn't you see, because at that time people didn't have experience with this phenomena [of secondary pests and resurgence], they really didn't realize that insecticides ... like DDT could do this. And their*

first answer, their first thoughts among the entomologists were: Gosh, it must be something in the climate, something must have changed to do this. But soon it became obvious to everyone that there wasn't any other explanation. We were able to prove, by experimental tests in which DDT was put onto plots and not put onto other plots that this great upset occurred due to the use of DDT. So we introduced the beetle into the valley in 1947 and modified and, in fact, essentially dropped the use of DDT up there."

(De Bach, 1969, cited in Henkin et al, 1971, p 131).

It is interesting to note that these problems of resistance, secondary pests and resurgence often pitted economic entomologists who favoured and promoted biological or integrated controls against their counterparts who favoured and promoted chemical controls. The former were able to win a few isolated battles against DDT because of just these sorts of problems. Their "beliefs" about the economics of chemical controls, and especially the economics of the use of broad-spectrum insecticides like DDT, carried the day and got made into "facts", *in specific field situations* as with this famous case of the California citrus growers in the late 1940s. But their beliefs about the economics of chemical controls *in general* did not become widespread. Indeed, they were vociferously contested by the majority of economic entomologists throughout most of this century and only recently, after all the problems of chemical controls surfaced and DDT, other organochlorines and many other pesticides had been banned, could one say that they had become "facts" and point to the widespread adoption of the philosophy of integrated pest management (IPM), currently the dominant paradigm in insect control, as evidence.

7.4 Substitution Because of Problems of Compliance with Residue Rules Mandating "Zero tolerance"

In this section I recount and analyze the exit of DDT from uses on dairy cattle farms as it was substituted for by other active ingredients, frequently the organochlorine methoxychlor. As I describe how this occurred, I wish to draw readers' attention to a few key points characterizing the situation both before (i.e. when DDT was the insect control tool chosen) and after (i.e. when methoxychlor was the insect control tool chosen) the substitution process. First, in making their insect control decisions, the evaluation criteria and decision rules invoked by users were the same at both points in time; and second, the alternative substance, methoxychlor, had been around for almost as long as DDT and hence was not a new addition to users' choice menus. The change that triggered the change in substance chosen, from DDT to methoxychlor, was one of users' beliefs about the outcomes and consequences of using these substances. Specifically, the belief that DDT could be used around dairy cattle without contaminating milk was falsified.

As discussed in Chapters 4 & 5, the presence of insecticide residues on food was one of the earliest problems encountered during the rise of chemical controls as the technology of choice for achieving insect control. Recall, in 1906, the Pure Food Act placed responsibility for public health considerations related to insecticide residues with the USDA, which implemented an informal system of tolerances[18]. In 1938, the Federal Food, Drug and Cosmetic Act (FFDCA) gave the Food and Drug Administration (the FDA, soon transferred to the forerunner to the U.S. Department of Health, Education and Welfare in 1940) the right to set standards for maximum residue levels which would act as binding tolerances, but only after public hearings and which could be appealed. These hearings proved to be long, cumbersome and expensive, and in 1954 this was remedied by the Miller Amendment which provided for the establishment of tolerances in or on raw agricultural commodities based on scientific evidence provided by firms bringing new molecules to market.

As DDT was being introduced at the end of WWII, the FDA established provisional tolerance levels for DDT residues on food, pending the necessary public hearings and further research (ultimately, public discussion of the safety of DDT would not come until the 1950 and 1951 hearings of the House Select Committee to Investigate the Use of Chemicals in Food Products). It set an "action level" of 7 ppm on fruit, above which it communicated to the USDA and others that it would prosecute growers. The FDA also established a "zero tolerance" level for DDT in milk because of the centrality of this food

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[18] USDA (1963)

in the diet of infants and invalids. It also warned against the use of DDT on feed or forage crops for dairy cattle.

As DDT was being introduced into agriculture, its uses in and around dairy barns, as well as on feed and forage crops like alfalfa, were some of those to which promoters reacted with the most enthusiasm. But it was not long before DDT residues began to show up in milk. This is not surprising and easily understandable now once one considers the particular combination of physical properties that characterizes DDT: incredible persistence *and* high solubility in fats. But at the time, it was surprising and unsettling, leading USDA officials and agricultural scientists to initiate efforts to track down and to understand its sources. Experiments were devised and executed, with their results disseminated. Eventually, "facts" about the consequences of using DDT around dairy cattle got made, as evidenced by these summaries of research carried out in the late 1940's:

> *"DDT occurs in the milk of cattle soon after spraying. Scientists at the Oklahoma Agricultural and Mechanical College discovered that in 1947. Immediately the Department of Agriculture began a study of samples of milk taken weekly from dairy herds that were sprayed once a month with 0.5 percent DDT. All the samples contained 0.1 to 2.0 ppm (parts per million) of DDT. ..."*
>
> (Radeleff et al, for the USDA, 1952, p 278)

> *"The excretion of pesticides in milk after cattle have consumed forage treated with pesticides can also be a problem. Cows fed DDT in their diet at rate of 0.5, 1.0, 2.0, 3.0, and 5.0 p.p.m. DDT in alfalfa exhibited DDT in their milk at all feeding levels except 0.5 p.p.m. At 1.0 p.p.m., residues of 0.01 to 0.03 p.p.pm. were consistently present in milk after 19 days. As the DDT feed levels increased, the DDT contamination in milk increased. At a feeding rate of 5 p.p.m. DDT, significant DDT levels appeared in the milk from a Guernsey cow. The milk concentration during the feeding period ranged from 0.16 to 0.32 p.p.m."*
>
> (USDHEW, 1969, p 139)

The FDA and USDA issued a joint statement warning farmers not to use DDT around their cattle. The USDA recommend alternative active ingredients, as evidenced by this extract from their 1952 Yearbook of Agriculture, which was accompanied by a colour glossy photograph to help farmers to identify the pest:

> *"The horn fly is a small bloodsucking fly about one half as large as the housefly. It lives on cattle, usually resting and feeding on the back and shoulders. ... Large numbers of the flies can reduce milk production of dairy cattle by 10 to 20 percent and prevent weight gains of beef cattle by as much as one-half pound per day. ... Sprays containing toxaphene, or at least a 0.5 percent concentration of TDE, methoxychlor, or DDT are recommended for controlling the insect on beef cattle. ... Methoxychlor is recommended as most economical and effective on dairy cattle. Use as suggested for beef cattle. DDT, toxaphene, and TDE are not recommended for use on dairy cows because the chemicals may appear in milk.*
>
> "(USDA, 1952, plate XXV)

The focal phenomena of substitution was the almost universal response of dairy farmers to problems of residues for which there was "zero tolerance". By far the most popular substitute was methoxychlor. Indeed, this particular market became one of the most significant for this substance.

> *"Methoxychlor has some advantages over DDT from an environmental standpoint: the oral LD50 for rats of 6,000 mg/kg compares favourably with 113 mg/kg for DDT and, unlike DDT, it shows little tendency to store in the body fat of animals or to be excreted in the milk. Thus one application of methoxychlor is as a replacement for DDT for fly control in dairy barns."*
>
> (Brooks, 1974, vol II, p 16)

> *"At an early stage of its development, it was discovered that DDT tends to be stored in body fat and is excreted in cow's milk. In contrast, methoxychlor shows little tendency to store in adipose tissue and the plateau levels achieved in tissues following high dietary exposure decline rapidly when exposure ceases. For this reason the compound provides a favourable replacement for DDT for fly control in dairy barns. It is less toxic than DDT toward many insects and nearly four times as expensive ($0.66/lb) so that its use has been somewhat restricted. By 1961, only 81 agricultural uses had been registered in contrast to 334 uses for DDT."*
>
> (Brooks, 1974, vol I, p 34)

> *"Currently, about 75 percent of the methoxychlor sold is used for fly control on cattle and in farm buildings, ..."*
>
> (USDHEW, 1969, p 51)

By what mechanism or process did methoxychlor come to replace DDT in dairy barns? It was not the sudden appearance of methoxychlor that triggered switching, as it was not at first viewed as an obviously superior product for use in dairy barns. Indeed, it was much more expensive than DDT. Switching to methoxychlor occurred at the end of the 1940s; the substance had been available since 1944. Nor was it a regulatory change that prompted the switch. The "zero tolerance" rule had been in effect since 1946, and dairy farmers went on choosing and applying DDT. They simply believed that DDT could be used effectively without resulting in residues in milk. **The primary trigger, I argue here, was fact-making by government officials, scientists and farmers.** The fact that was "re-made" had to do with the *consequences of contamination of milk* from the use of DDT as an economic poison towards flies and other pests of dairy cattle.

Stated another way, when the problem of DDT residues in milk arose and was attended to, then essentially **the belief of USDA officials, scientists and dairy farmers that "DDT used in dairy barns will not appear in milk" was substituted for by the belief that "DDT used in dairy barns will appear in milk".** To be an effective chemical insect control technology in the context of dairy farms, a substance could not leave traces in milk for which the rules were clear and mandated "zero tolerance".

Note that this change or substitution of beliefs occurred for individual farmers largely as a result of communication from the USDA and workers at the agricultural experiment stations. Farmers could not "see" the DDT in their own or others' milk, but instead had to rely upon officials. That DDT residues were present, or that they would appear if DDT was employed, they took on faith, trusting the scientists and government personnel that they had come to cooperate closely with.

As I end this Chapter, it is interesting to note that this phenomena of fact-driven substitution - the supplanting of one product for another in performing a particular function for a buyer *due to a substitution of beliefs* - was recognized, implicitly, by actors in the case study. Over and over again, defenders of DDT reiterated that *"if the facts warranted"*, DDT would be substituted for. Indeed, the particular case of methoxychlor for DDT in dairy barns was invoked as an example of how substitution could be effected *without changes to the rules*. The USDA, which throughout the post-Silent Spring political debate argued and lobbied hard to maintain the pesticide regulatory framework of the time, drew upon this example:

> *"For as long as persistent organic pesticides have been used, there has been concern about their presence in human food. The primary objective in regulating pesticide use has been to keep residues in food supplies at minimal and safe levels, because food is the principal route by which pesticides normally reach man. Increasing effort has been devoted to inspecting food supplies, and supplies in which residue levels were found to exceed legal tolerances have been condemned. As a result, residues in the food supplies of the United States have been maintained at remarkably low levels during a time of great increase in pesticide use. The Committee believes that, at present, pesticide chemical residues are being maintained at safe levels. The interaction of inspection and enforcement with research on agricultural practices has resulted in the discontinuance of some uses that were once approved. For example: DDT was once used to control flies and other insects on dairy cattle, but this practice was found to result in unacceptable residues in milk."*
>
> (NRC, 1969, p 10)

They went on to recommend *"that the present system of regulation, inspection, and monitoring to protect man and his food supply from pesticide contamination be continued."*[19]. The USDA did not want to lose responsibility for pesticide registration - its monopoly on rule-making in the domain - although it ultimately did, in 1970, to the newly created Environmental Protection Agency.

7.5 Substitution as a Consequence of Fact-Making

[19] NRC (1969, p 30)

This Chapter has drawn examples from the case study which illustrate the phenomena of substitution to be a consequence of "fact-making", a process that takes place largely though not wholly in this particular case study, in the scientific arena of society. In the examples described and analyzed, what prompted the disappearance of DDT from a particular market was not the sudden appearance of an obviously superior alternative, nor the coercion of users into a change through a ban or other regulations. Rather, alternatives replaced DDT in the economy primarily because the beliefs or expectations about the effect of using DDT had changed. In other words, substitution of one artifact for another followed - and was triggered by - the substitution of one belief for another. Scientists, along with farmers and government officials, searched for, developed or "made" descriptive assertions, knowledge claims or "facts", along with arguments and evidence for their adoption. The monopoly or quasi-monopoly of competing incumbent claims was challenged and contested, essentially, with appeals to and demonstrations of "**Truth**".

New beliefs *substituted* for older incumbent ones, which led different products to substitute for incumbent ones. Stated in terms of the conceptual language we are advocating, the dominance of incumbent "facts" was overturned subsequent to the appearance of competing beliefs. In the examples discussed here, at the time of substitution, the array of alternative artifacts (i.e. available active ingredients) on actors' choice menus remained constant, as did the decision rules (i.e. evaluation criteria) invoked to select from them. But actors' expectations about outcomes of using the various products come to be changed as these new claims came to be widely adopted, triggering substitution.

Analogous to the institutionalization of artifacts and the emergence of dominant designs in the physical world, as a competing belief becomes more and more widespread, it becomes *institutionalized* and when contestation ceases it has become a "fact" and part of the dominant paradigm. This was the case here: subsequent to these instances of substitution, it has became unthinkable to use DDT against the codling moth in apple orchards, in citrus groves, and certainly not to kill flies around dairy cattle. Everyone knows that DDT will show up in the milk!

SECTION III

Discussion & Conclusion

In this Section of the dissertation, I execute the final stage in case study research, which is that of *"enfolding the literature"* into findings, because *"an essential feature of theory building is comparison of the emergent concepts, theory or hypotheses with the extant literature. This involves asking what is this similar to, what does it contradict, and why."* (Eisenhardt, 1989, p 544).

I begin first with a recap of the three distinct types of substitution phenomena described in prior Chapters. I then explore the close relationship between these and categories of substitution events that can be derived from simple economics-inspired models of individual and collective choice, suggesting that there are three "ideal types" of substitution processes.

I conclude by arguing that my findings, especially when considered in combination with those of Garud & Rappa (1994), suggest that substitution phenomena *in general* are comprised of aspects of these idealized processes, all present to some degree and interconnected with the others. In other words, it is very difficult to disentangle winning artifacts in the material realm from winning arguments in the ideational (or "representational" or "symbolic") realm.

Tools and talk coevolve.

8 Substitution - Towards an Empirically Supported Typology of Ideal Types

In this section, I explore the close relationship between identified types of substitution phenomena from the case study with those categorizations of substitution events that can be derived from models of individual and collective choice. I argue that my research has revealed three "ideal types" of substitution processes that are supported by longstanding and well-accepted theory.

8.1 Recap: Distinct Types of Substitution Phenomena from the Case Study

Substitution is a more complicated phenomena than has been suggested to date in the theorizing about it which predominates in the strategy literature. Previous Chapters have demonstrated that historically, in the agricultural chemical industry, competing active ingredient products have substituted for alternatives in markets for a diverse set of reasons and through distinct processes. I identified and described three clearly distinct types of substitution found in the case study. I named them in terms of the events and processes which preceded and triggered them:

(1) substitution as a consequence of tool-making,
(2) substitution as a consequence of fact-making, and
(3) substitution as a consequence of rule-making.

Table 8.1.1 recaps the ten examples discussed in the case study (i.e. entry and exit of DDT in five different markets), as well as important components of these broad categories of substitution phenomena.

Table 8.1.1 - Three Empirically Supported Types of Substitution

	Substitution as a consequence of ...		
	tool-making	**fact-making**	**rule-making**
Examples from case study:	- DDT replaces arsenicals and botanicals for cotton - DDT replaces arsenicals and botanicals for apples - DDT replaces arsenicals and botanicals for dairy barns - DDT replaces biological controls for citrus crops - DDT replaces cultural controls for containing Dutch Elm disease vectors	- organophosphates replace DDT for apples - methoxychlor replaces DDT in dairy barns - biological controls replace DDT for citrus crops	- methyl parathion and EPN replace DDT for cotton - methoxychlor replaces DDT for containing Dutch Elm disease vectors
Generic principle, expressed in terms product "performance"	**REACH & SURPASS PERFORMANCE** actors must build a product with a performance/price ratio superior to that of incumbent products	**REMEASURE or RE-EVALUATE PERFORMANCE** actors must demonstrate that performance/price ratios of incumbent products are not what they are perceived to be	**REDEFINE PERFORMANCE** actors must redefine acceptable and desired "performance"

Table 8.1.1 (continued) - Three Empirically Supported Types of Substitution

	Substitution as a consequence of ...		
	tool-making	**fact-making**	**rule-making**
key arena:	Commerce	Science	Politics
discourse:	marketing	scientific	public/political
key actors:	firms	scientists	politicians, government, NGOs, firms, public
competition between:	rival products (i.e. artifacts, tools, technologies)	rival descriptive claims (i.e. beliefs, "is" statements)	rival normative claims (i.e. values, preferences, "ought" statements)
trigger:	generation & promotion of new artifact	generation & promotion of new descriptive claim	generation & promotion of new normative claim
institutionalization as contestation ceases:	artifacts become *dominant designs*	beliefs ("is" statements) become *facts* in *dominant discourse*	values ("ought" statements) become *rules* in *dominant discourse*
dominant realm:	material	ideational/discursive	ideational/discursive
actors appeal to:	Efficiency	Truth	Justice ("Rightness")

With tool-driven (or "artifact-driven") substitution, a new product appears on the choice menu of customers, along with information indicating that it has an obviously higher performance/price ratio, therefore making it a more efficient choice and causing customers to switch with the result being a gain in market share at the expense of incumbent products. To promote their tools, actors appeal to and make arguments of Efficiency, attempting to have their tool widely adopted and institutionalized as a dominant design. The entry of DDT into markets discussed in this dissertation is a good example of substitution as a consequence of tool-making; Muller specifically sought an insecticide like DDT that had superior performance along the dimensions of relevance to users at that time - wide spectrum and persistent insect killing power combined with low acute toxicity to humans.

With fact-driven substitution, products on customers' choice menus do not change, but rather actors' beliefs about the consequences of using different products change because of "learning". Because of changes to the facts, and without anyone's decision rules, decision logics, goals, values, or preferences changing, an incumbent product that had been available to customers all along but which had low market share suddenly gains market share at the expense of formerly dominant products. To promote their beliefs, actors appeal to and make arguments of Truth, attempting to have their belief widely adopted and institutionalized as a "fact". The exit of DDT from apple orchards due to the problem of resistance and from citrus groves due to problems of resurgence and secondary pests are good examples of substitution as a consequence of fact-making. In both cases, claims of DDT's efficacy were "falsified"[1]. In addition, the exit of DDT from dairy barns is another example of substitution as a consequence of fact-making. Recall, claims that DDT would appear in cows' milk and render it unusable given the "zero tolerance" rule, which was already in effect when many dairy farmers adopted DDT, were at first discounted, marginalized and even ignored but then eventually prevailed and became dominant; the counter-claims that DDT would not affect cow's milk were marginalized.

With rule-driven substitution, neither the products on actors' choice menus nor the facts about the consequences of using these products changes. Rather, facts are processed through a different logic because the evaluation criteria employed, values, preferences, utility functions - or, in the limit, "rules" and hierarchies of rights - have changed. Because of this invoking of different goals and new or changed evaluation criteria, an incumbent product that had been available to customers all along but which had low market share suddenly gains market share at the expense of formerly dominant products.

To promote their values, actors appeal to and make arguments of Rightness or Justice, attempting to have their belief widely adopted and institutionalized as a "rule". This was the case with the exit of DDT from the Dutch elm disease control programme market where methoxychlor, which did not leave so many dead robins on homeowners' lawns, triumphed once bird values were given more weight. In the limiting case of a product ban, changes to rules go beyond the mere disfavouring of a particular product by explicitly removing it from customers' choice menus. This was the case with the exit of DDT from the cotton market.

8.2 A Derived Typology of Substitutions

In this section, I explore the close relationship between identified types of substitution phenomena from the case study with those categorizations of substitution events that can be derived from models of individual and collective choice. I argue that my research has revealed three "ideal types" of substitution processes.

8.2.1 Different types of substitution, as derived from rational models of decision-making

A consideration of rational models of decision-making and microeconomic theory yields insights into substitution processes which are entirely consistent with our findings. To illustrate this, I revisit the conceptual building blocks of such models and ask what would happen if "constants" considered "exogenous" and "given" were less fixed and static than is commonly assumed? The models themselves tell us: each of these conceptual building blocks, if changed, can serve as the trigger for a different type of substitution event.

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[1] The reasons for placing this term in italics will become clear a few paragraphs later when I define what I mean by a 'fact".

Rational models of decision-making are essentially optimization models at the level of individuals: they posit an idealized actor - Economic Man - engaging in an act of choice and always maximizing his "subjective expected utility". Central to this conceptualization and theorizing is a rational actor's "choice menu", which can be decomposed into three parts according to Simon (1983):

(1) a well-defined set of alternatives (i.e. the actor's options or possible choices),

(2) the expected utility of each possible action obtained from a joint probability distribution linking actions to outcomes (i.e. the actor's beliefs or expectations), and

(3) a well-defined utility function which means that the actor can assign a cardinal number as a measure of relative preference to all the future outcome scenarios (i.e. the actor's goals or desires or values).

Let us consider the impact of simple discrete changes to these building blocks of rational choice, using comparative statics. Imagine a system made up of a single actor (i.e. a user or consumer of some technological tool or artifact) at some initial point in time. Within the theoretical framework of rational choice, this system is assumed to have equilibrated: the actor would be purchasing and using the "optimal" or premier technological alternative on his current choice menu, which is the artifact ranked first on an ordinal scale that ranks all alternatives. He would be using the tool which, according to his expectations, maximized the attainment of his preferences. We can now examine the impact of subsequent discrete changes to the building blocks of rational choice: (1) alternatives (i.e. possible choices: competing products or "artifacts" or "tools"); (2) expectations (i.e. beliefs); and (3) preferences (i.e. values).

Discrete changes to any of these act as "shocks" to our system which then re-equilibrates.

If the shock results in a reordering of alternatives such that a *different* tool or technological artifact is now ranked first, then substitution (i.e. switching) occurs through the optimizing force posited in this framework. For the sake of simplicity, assume for the moment that switching costs are zero, but of course this comparative statics analysis could be easily modified to include those and other *process costs* (i.e. cost of generating a shock or change to alternatives, expectations or preferences + cost of attending to, perceiving and processing information about this change + cost of switching to a different alternative). In other words, the incumbent premier alternative can be dethroned by any of three distinct mechanisms - changed alternatives, changed expectations, or changed preferences. Hence we have derived three possible idealized substitution processes at the level of the *individual*:

(1) substitution as a consequence of changed alternatives on choice menus

(2) substitution as a consequence of changed expectations, and

(3) substitution as a consequence of changed utility functions.

(1) Alternative-driven substitution is triggered by the appearance of a new alternative on the choice menu of actors. In terms of substitution of physical products, these competing "alternatives" would represent competing tools or artifacts, hence we can talk about "tool-driven" or "artifact-driven" substitution. In rational models of individual choice, the appearance of a new product or technological artifact for performing a function would trigger information processing and (re-)deciding behaviour. The consequences of using the new product would be assessed using existing beliefs about the state of the world and cause-effect relations. These consequences would be evaluated by invoking existing goals, evaluation criteria and decision rules. If as a result of this information processing the rational actor concluded that use of the new artifact would lead to higher utility or functionality, the actor would switch to the new product from the old incumbent one. One would say that the new product had substituted for the incumbent, having *supplanted* [it] *in performing a particular function or functions for a buyer* (Porter, 1985, p 273). Hence, changing the products available on an actor's choice menu is one important mechanism for bringing about substitution events.

Changing the products available on an actor's choice menu is certainly the most obvious mechanism for triggering and bringing about substitution, and it has been well-researched and extensively theorized in the literature on technological evolution and substitution.

Firms conduct research and development in order to innovate, invent or discover new artifacts which are superior to the incumbent products along evaluation criteria that matter to customers and other relevant evaluation constituencies such as regulators. They then bring them to market. As recounted in his Nobel lecture, Muller and his company, Geigy, were working with a clear sense of both what constituted an "ideal" insecticide, as well as what were the problems and inadequacies of the incumbent arsenical and botanical products when contrasted with this ideal. They searched for, discovered, then brought to the marketplace a product, DDT, with a superior performance/price ratio which substituted for the arsenicals and botanicals.

(2) Belief-driven substitution (or "expectations-driven" substitution) is not triggered by the appearance of new alternatives on actors' choice menus, but rather by a change in actors' "descriptive logics" - their expectations of the consequences of using existing alternatives, still evaluated along existing performance criteria. If an individual actor's beliefs about cause-effect relations or the state of the world change, then their expectations and predictions of the outcomes of using different competing products can change as well. Formerly second-best or even lower ranked products can become elevated to premier status by such shifts in beliefs if, as a result of information processing using these new beliefs, the actor concludes that continued use of the incumbent product is no longer optimal. The actor would switch away from the incumbent product to whichever other product on the choice menu had been elevated to the highest rank by the change in beliefs. One would say that the formerly lower-ranked product had substituted for the incumbent, having *supplanted* [it] *in performing a particular function or functions for a buyer* (Porter, 1985, p 273). Hence, changing the beliefs of actors is another important mechanism for bringing about substitution events.

Changing actors' beliefs is a less obvious mechanism for triggering and bringing about substitution phenomena. Certainly it is a mechanism that has received little attention in the literature on technological evolution and substitution. In the bulk of that literature, inspired as it is by models drawn from microeconomics, beliefs are assumed to change only in an uninteresting and trivial manner; along with a new artifact on actors' choice menus comes accompanying information about the new artifact's superior performance/price ratio. This information is assumed to be objective, undisputed and easily incorporated into actors' existing mental models. In other words, the bulk of the literature contends that, along with new artifacts, actors are provided with *more* information about the world - information which can be added cumulatively in an unproblematic way to the previous information they have received - but not information which *conflicts with* - and hence enters into a contest with and potentially displaces - current understandings.

To date, substitution of artifacts has not been conceived of as a consequence of a process of substitution of one belief for another. Yet it has been demonstrated in our case study how the struggle for dominance between competing physical artifacts can be seen in just these terms: as the physical trace of a struggle for survival and dominance between competing beliefs. This was made possible by the choice of an extreme and transparent case for study and the investigation of substitution phenomena where the incumbent products were replaced by artifacts which were *already* available on the choice menus of actors but which had formerly not been judged optimal. Examples include: the substitution of various organophosphates for DDT in apple orchards once "facts" about the problem of insect resistance got made and actors' beliefs about the efficacy of DDT changed; the substitution of biological controls for DDT in citrus groves once "facts" about the problems of secondary pests and resurgence got made and actors' beliefs about the efficacy of DDT changed; and the substitution of methoxychlor for DDT in dairy barns once "facts" about the problem of accumulation of DDT in milk got made and actors' beliefs as to whether the continued use of DDT would allow their operations to remain within the law changed.

I have italicized "facts" to underline my sociological interpretation of this term: not the inevitable outcome of a teleological process of scientific discovery, a "fact" is a descriptive claim that has gained widespread acceptance in a society and whose validity or truth actors have ceased to contest. Because they can change (and lots of evidence of that has been presented), one can view "facts" as simply "beliefs that people have stopped fighting over". At the time of DDT's entry into the economy, what would later come to be "facts" about the problems of DDT were mere "beliefs", certainly not absent nor unimagined, but held by just a minority of entomologists, mostly those who were uncomfortable with the dominant "magic bullet" approach to insect control and its emphasis on chemical as opposed to cultural or biological methods. Similarly, "beliefs" that DDT would show up in cows' milk were present but not dominant; they became "facts" later. Marginalized within the discourse of economic entomology at the time of DDT's entry, as their claims gained acceptance they came to occupy a more central role. The dominant paradigm or discourse in insect control today, Integrated Pest Management (IPM), would not be imaginable without the shifting power that accompanied the shift in thinking within the discipline of economic entomology. Returning now to "falsification", it can be viewed in its essential form - as the substitution of once widely-held and uncontested incumbent "True" claims by rival claims.

(3) Finally, value-driven substitution (or "preference-driven" substitution) is not triggered by the appearance of a new alternatives on the choice menus of actors, but rather by a change in the "normative logics" used by actors to weigh and evaluate the consequences associated with existing choices. Changes to such things as individuals' evaluation criteria and routines, their tastes, their sense of right and wrong, as well as the goals they invoke to frame decisions can change actors' normative logics. The application of a new normative logic to an existing set of alternatives and beliefs can lead to a reshuffling of the ordinal ranks of competing products. In other words, if measured along different performance criteria, once-rejected alternatives can suddenly become elevated above once-optimal incumbents. The actor would switch away from the incumbent product to that product on the choice menu which had been elevated to the highest rank according to the new normative logic, and one would say that that product had substituted for the incumbent, having *supplanted* [it] *in performing a particular function or functions for a buyer* (Porter, 1985, p 273). Hence, changing an actor's values is a third important mechanism for bringing about substitution events.

Changing an actor's values is a less obvious mechanism for triggering and bringing about substitution. Certainly it is a mechanism that has received little attention in the literature on technological evolution and substitution. In the bulk of that literature, inspired as it is by models drawn from microeconomics, values and preferences are considered to be given and exogenous: they just *are*.

To date, substitution of artifacts has not been conceived of as a consequence of a process of substitution of one value for another. Yet it has been demonstrated in our case study how the struggle for dominance between competing physical artifacts can be seen in just these terms: as the physical trace of a struggle for survival and dominance between competing values. This was made possible by the choice of an extreme and transparent case for study, and the investigation of substitution phenomena where the incumbent products were replaced by artifacts which were already available on the choice menus of actors but which had formerly not been judged optimal. A good example is that of the substitution of methoxychlor for DDT in spray programs against Dutch elm disease once wildlife and bird values were incorporated into municipalities' decision rules.

A brief discussion of terminology is required here in order to clarify the connections between the three categories of substitution identified in our research and the three derivable from rational models of decision-making. Notice how the categories of substitution derivable from rational models of decision-making (i.e. tool-driven, belief-driven, and value-driven substitutions) do not match exactly the categories of substitution we identified in our case study (i.e. tool-driven, fact-driven, and rule-driven). This is because a distinction between beliefs and facts as well as values and rules has been drawn in the following manner. At the level of individuals, descriptive statements and claims (that when aggregated into the individual's system of beliefs give rise to a "descriptive logic") are termed "beliefs". I reserve the term "facts" for the level of the domain and applying it to only those beliefs that have become widely held, weakly contested (if at all) and are hence dominant and institutionalized. Similarly, at the level of individuals, normative statements, claims and preferences (that when aggregated into the individual's system of values gives rise to a "normative logic") are termed "values", reserving the term "rules" for the level of the domain and applying it to only those values which have become widely held, weakly contested (if at all) and are hence dominant and institutionalized. Because my research investigated outcomes at the macro-level of the domain - I documented changes in "facts" and "rules", but did not track the micro-level of individuals and their beliefs, values, and decision-making - I named the identified categories of substitution by drawing upon the domain-level terminology.

This may seem like conceptual hairsplitting, especially in discussions of comparative statics and analysis of *outcomes*. But the distinction is important when it comes to discussing issues of process. I conceptualize fact-making as a contest between promoters of competing beliefs, each seeking to institutionalize their mere "belief" into a widely-accepted and undisputed "fact". Similarly, rule-making is viewed as a contest between promoters of competing values, each seeking to institutionalize their preferences and "values" into a widely-adhered to "rule".

8.2.2 Different types of substitution, as derived from microeconomic theory

The discussion of beliefs versus facts and values versus rules has pointed to the distinction between individual-level and domain-level phenomena. Readers may legitimately question as to whether or not "switching" by a single individual from one alternative to another - which is what I have described above by focusing on rational models of decision-making - constitutes our focal phenomena of "substitution". Typically, this latter term is used when discussing outcomes at the level of industry or domain. Once a large set of actors has switched from one product to another, then we would say that substitution has occurred. At this higher level of analysis, the appropriate framework is microeconomics.

Rather than predicting outcomes and technological choices at the level of an individual, microeconomic theory predicts outcomes at the macro-level of the economy. It predicts the "choices" made by an economic system. It is essentially an optimization model at the level of the collectivity, predicting that economic outcomes are optimal in the Pareto sense. This means that all actors' subjective expected utilities have been maximized, not absolutely, *but to the extent possible given the current distribution of rights and resources.* This is an important distinction between optimization at the level of individual and optimization at the level of collectivity: at Pareto optimal equilibria, there are no subsequent changes which can be made to the system which raise the utility of one actor *without lowering that of others.* This differs a bit from our thought experiment above where, with a single technology chooser, no problems of actor interdependence arose and no *social* constraints were placed on choosing. To deal with interdependence, societies create rights, laws, regulations, and rules that constrain "free" actors by dictating how potential conflicts in values and preferences are resolved. Rules dealing with hierarchies of rights as well as the distribution of resources to actors in an economy determine *whose* preferences economic outcomes will reflect. One cannot simply aggregate across the utility functions of individuals to generate the utility function of the system; rules must be invoked during aggregation to arbitrate between conflicts in individuals' preferences. Hence another construct - rights - must be added to the buildings blocks of rational choice in order for microeconomic theory to generate *precise* predictions about economic outcomes, especially in a world of non-zero transaction costs (Coase, 1960; Spulber, 1989):

> *"In the presence of external diseconomies, such as environmental pollution, the creators of external damages may be identified as the injurers, while the consumers of external damages may be identified as victims. From a legal standpoint, either side of the transaction may possess certain rights. The producer of an externality may have the right to pursue the economic activity that creates the diseconomy as a by-product. Further, the producer may have the right to discharge pollutants into the air, water or ground. Alternatively, the consumer of the externality may have the right to clean air or water or to be free from the harm caused by air or water pollution.* ***The legal definition of these property rights has profound implications for resulting market equilibria, particularly for those goods that entail pollution as a by-product."***
>
> (Spulber, 1989, p 336)

Microeconomic theory, with its optimizing force, can predict that the quality of Pareto optimality (i.e. efficiency) will apply to collective outcomes but, in and of itself, cannot predict which of the infinite number of points on a *Pareto frontier* will be the specific collective outcome, as this depends upon the distribution of rights. Analysts must invoke a particular mix of property rights to determine particular outcomes (Coase, 1990; Spulber, 1989). Obviously, the economics of a polluting technology - and hence the outcomes one would expect in the economy - differ drastically in a society in which the hierarchy of rights obligates injurers to pay for the reparation of damage as opposed to one in which the injured must pay.

Applying comparative statics to a simple neoclassical microeconomic model of the economy - a population of rational actors faced with choices between competing tools and transacting in free markets, all embedded within a system of rules and regulations - we can therefore derive four possible idealized categories of substitution:

(1) substitution as a consequence of changed tools

(2) substitution as a consequence of changed facts,

(3) substitution as a consequence of changed rules that are held and enforced at the level of individual (i.e. changes to preferences that are institutionalized informally into a collectivity's "norms"), and

(4) substitution as a consequence of changed rules that are held and enforced at the level of the collectivity (i.e. changes to preferences that are institutionalized formally into a collectivity's "regulations").

Notice here that I have distinguished between two classes of "rules" that together make up the normative logic of an economic system comprised of more than one actor. They differ as to how they get made and how they are then later enforced; substitutions can be triggered by "top-down" as well as "bottom-up" processes of rule-making, a distinction that is meaningless when considering a single actor.

Recall, "rules" refer to dominant and institutionalized values which provide direction to or in the limit "control" parts of a social system. Sociologists often conceive of rules being enacted through two basic mechanisms of control: (a) internally and informally, by actors themselves, through a process of self-regulation implying bottom-up "normative" control, or (b) externally and formally, by the collectivity, through a process of regulation involving rewards and punishments implying top-down "coercive" and "remunerative" control (Etzioni, 1961). With the former, the "rules" that must be changed to trigger domain-wide substitution are "norms" (i.e. change the preferences of individuals, across an economic system, which act as "internal" constraints on choosing). With the latter, the "rules" that must be changed to trigger domain-wide substitution are "regulations" (i.e. change the preferences of the collectivity which act as "external" constraints on choosing).

With regards to (1), (2) and (3), because microeconomic theory is built upon the rational model of decision-making presented in detail above, I do not need to repeat my discussion of how changes to artifacts, beliefs (which, if widespread and uncontested at the level of domain can be termed "facts") and values (which, if widespread and uncontested at the level of domain can be termed "rules") invoked by evaluators and choosers of tools in an economy can lead to substitution. If one repeats the thought experiment described above except this time with a population of actors instead of just a single actor, then one sees that aggregating actors' switching behaviour across the population indeed yields three idealized types of substitution resulting from "shocks" to these parameters: tool-driven, fact-driven, and rule-driven (i.e. norm-driven).

The final idealized type, (4) regulation-driven substitution, is also easy enough to demonstrate. A regulatory shock changes the distribution of rights in the economic system, and can force actors to explicitly include the preferences of others in their decision-making calculus. This can result in disfavouring the incumbent technology, especially if that technology was generating negative externalities and the regulatory change created or redistributed rights to those who bore the costs of those externalities. Products with fewer negative externalities would be advantaged. For example, consider the case recounted by Spulber (1989, p 336) above. Clearly, a switch in property rights regimes from (a) one which priorizes the right to pollute whilst earning a living above the right of others to clean air to (b) a regime in which the hierarchy of these rights is reversed, would advantage cleaner technologies. Whereas prior to the regulatory change the Pareto optimal outcome would see victims forced to pay the injurer to not pollute (or, euivalently, to pay for remediation of their own injuries), subsequent to the regulatory change, the injurers would be forced to compensate those victims whose rights to clean air had been violated, and this would obviously raise the cost of the polluting technology they were using. If this increase in cost is substantial enough, it can lead to the incumbent technology being dethroned from its premier position among the alternatives on the choice menu of the injurers.

Hence changing the formal "regulations" of a social system within which economic activity is embedded is another mechanism for triggering and bringing about substitution. If one considers fiscal policy (i.e. taxes and subsidies) as a form of regulation, then this mechanism has received much attention certainly in the economics literature where the notion of a "Pigouvian tax", a regulatory technique which makes use of markets and price signals, has been around for a long time (Pigou, 1932). A Pigouvian tax is set so as to force the internalization of formerly-externalized social costs (i.e. public bads), raising the nominal cost of a technology enough to correct for the externalities caused by its use. Obviously, if the Pigouvian tax is set high enough, switching and substitution could result. This is the logic behind so-called "Green taxes". Similarly but conversely, economists have long recommended the subsidy (or, in the limit, state provision) of technologies with public goods properties.

But beyond these basics of fiscal policy, the use of regulation as a trigger for substitution has not received much attention, although this is beginning to change with the growing significance of environmental problems and the debate over whether "it pays to be green" - whether setting high environmental and health standards hurts a country's competitiveness. Recent writings on national competitiveness address technological evolution and substitution indirectly. In their discussions of "appropriate" environmental regulation by governments (see, for example, Porter, 1990; Porter & Van der Linde, 1995), authors frequently stress how stringent regulations can spur innovation and the substitution of cleaner tools for dirtier ones.

But all in all, to date the substitution of artifacts has not been conceived of as a consequence of a process of substitution of one value for another. Yet it has been demonstrated in the case study how the struggle for dominance between competing physical artifacts can be seen in just these terms: as the physical trace of a struggle for survival and dominance between competing values. This was made possible by the choice of an extreme and transparent case for study and the investigation of substitution phenomena where the incumbent products were replaced by artifacts which were *already* available on the choice menus of actors but which had formerly not been judged optimal. A good example is that of the substitution of methyl parathion and EPN for DDT in the cotton market once the incorporation of wildlife and bird values into law resulted in the ban on DDT and forced cotton growers into switching.

8.3 Recap: Ideal Types of Substitution Expressed in terms of Product Performance

Hence there is theoretical support for the different types of substitutions we have identified in our research. Using elementary models drawn from economics along with simple comparative statics analyses, we have demonstrated qualitatively that discrete exogenous changes to (a) the tools available, (b) the facts employed or (c) the evaluation rules invoked during decision making - be they at the level of individual or collectivity - could each serve as the trigger for switching behaviour and substitution.

For those seeking to dislodge a product from the economy, our typology suggest four idealized fronts of "attack", presented in Table 8.3.1 which recaps the ten examples (i.e. entry and exit of DDT in five different markets) discussed in the case study.

Table 8.3.1 - Four Fronts of Attack to Trigger Substitution

Front of Attack	Examples from case study	Generic principle, expressed in terms of "products" and their "performance/price" ratios
change the tools	- DDT replaces arsenicals and botanicals for cotton - DDT replaces arsenicals and botanicals for apples --DDT replaces arsenicals and botanicals for dairy barns - DDT replaces biological controls for citrus crops --DDT replaces cultural controls for containing Dutch Elm disease vectors	**REACH & SURPASS PERFORMANCE** actors must build a product with a performance/price ratio superior to that of incumbent products
change the facts	--organophosphates replace DDT for apples - biological controls replace DDT for citrus crops --methoxychlor replaces DDT in dairy barns	**REMEASURE PERFORMANCE** actors must demonstrate that performance/price ratios of incumbent products are not what they are perceived to be
change the norms	- methoxychlor replaces DDT for containing Dutch Elm disease vectors	**REDEFINE PERFORMANCE from users' point of view** actors must redefine acceptable and desired "performance", **from users' point of view**
change the regulations	- methyl parathion and EPN replace DDT for cotton	**REDEFINE PERFORMANCE from society's point of view** actors must redefine acceptable and desired "performance", **from society's point of view**

Two qualities of the case study of DDT have made it particularly useful for isolating and illustrating all three ideal types: (1) the controversial, pathological and extreme nature of the case has highlighted and made *"transparently observable"* (Eisenhardt, 1989) processes and events that are likely much more subtle, nuanced, entangled, and leaving of fewer traces in cases of a more mundane nature; and (2) the nature of the technology studied, both highly technical and highly politicized, meant that quite distinct actors and arenas were involved in each of the three idealized processes.

In the next Chapter, I suggest that the three idealized substitution processes revealed by our case study should be interpreted as three dimensions of *all* substitution phenomena. The choice of an *extreme* case study has simply made these dimensions *"transparently observable"*. In other words, the findings in this dissertation have pointed to extreme instances of substitution where one dimension clearly dominated over the other two.

9 Winning Artifacts or Winning Arguments? The Coevolution of Technology and Discourse

In this Chapter, I continue to address the generalizability of my findings and the potential utility of my ideal types for researchers and practitioners. This Chapter is necessarily more *suggestive* than earlier Chapters which were *demonstrative.* I say "continue" because the prior Chapter, by relating my empirically substantiated types of substitution to those that can be derived from longstanding and widely-used theoretical tools, has in some way already spoken to this issue of generalizability.

Substitution is a more complicated phenomena than has been suggested to date in the theorizing about it which predominates in the strategy literature. It has been demonstrated in this dissertation that, historically in the agricultural chemical industry, competing active ingredient products have substituted for others in various markets for a diverse set of reasons and through distinct processes. The success and fate of particular insecticides has depended not only upon *material struggle* within the institutions of the marketplace, but also *discursive struggle* within the institutions of science and politics. In other words, this research has demonstrated clearly how particular *artifacts* presuppose and are predicated upon particular *arguments.* Their fates are inextricably intertwined; the success of particular artifacts is always contingent upon the success of particular descriptive and normative claims. Restated more holistically and systemically, *technologies* and *technological systems* are predicated upon *discourses* and *systems of ideas* or *paradigms.*

Because discourses and technologies coevolve, strategy should be conceived of as both *patterned talk* and *patterned action.* Besides adopting *positions* in the system of *exchanges* which is the economy (as per Porter and IO researchers), firms also adopt *positions* in the system of *conversations* which is society.

9.1 The Coevolution of Tools, Facts and Rules

9.1.1 "Efficient" Tools are Contingent upon "Truth" and "Justice"

For a product to make sense to an individual or a collectivity, let alone to be "optimal" in terms of performance/price as claim microeconomic models, certain descriptive claims must be accepted and held as *true* while certain normative claims must be accepted and held as *right* and *just*. Microeconomic theory, very influential in the strategy literature and theorizing about the focal phenomena of substitution, views the three important arenas identified from the case study as being independent. Positing equilibrium outcomes in the arena about which it speaks (the economy), it is forced therefore to assume equilibria in those arenas about which it is silent. Hence, theorizing about substitution in the strategy literature has tended to ignore the activities in these other spheres of social life. If it turns out that in the real world, as this case study would indicate, rules and facts are not as stable as assumed, then the economy cannot be either. In the limit, as in our case study, discontinuities in the facts or the rules can trigger substitution, dislodging incumbent products from their privileged place in the economy. In other words, achieving technical "Efficiency" within the economy, in the Pareto optimal sense, implies that issues of "Truth" and "Rightness" or "Justice" have been settled and closed.

Note that "settled' is the operative word here: in Western society, what are accepted and operationalized as "Truth" and "Justice" emerge out of processes of struggle and contestation, as indicated in Table 9.1.1, which reproduces and extends Table 8.1.1.

Table 9.1.1 - Substitution Types & Arena Myths

Substitution as a consequence of ...

	tool-making	**fact-making**	**rule-making**
key arena:	Commerce	Science	Politics
discourse:	marketing	scientific	public/political
key actors:	firms	scientists	politicians, government, NGOs, firms, public
competition between:	rival products (i.e. artifacts, tools, technologies)	rival descriptive claims (i.e. beliefs, "is" statements)	rival normative claims (i.e. values, preferences, "ought" statements)
trigger:	generation & promotion of new artifact	generation & promotion of new descriptive claim	generation & promotion of new normative claim
institutionalization as contestation ceases:	artifacts become *dominant designs*	beliefs ("is" statements) become *facts* in *dominant discourse*	values ("ought" statements) become *rules* in *dominant discourse*
dominant realm:	material	ideational/discursive	ideational/discursive
actors appeal to:	Efficiency	Truth	Justice ("Rightness")

Arena Myths re Progress

process by which "progress" ensured:	free market	scientific method	democracy
"heroic" individuals capable of transforming system:	entrepreneurs	discoverer-scientists	concerned citizens; political leaders
"teleological pull" in legitimating myth	Efficiency	Truth	Justice ("Rightness")

Interestingly, each of the three arenas in which contestation takes place is governed by a strikingly similar popular legitimating "myth" of how the arena operates and what sorts of outcomes it generates[1]. Efficiency, Truth and Justice are the outcomes of processes in these arenas *by definition* specifically because of the *contestation* that occurs and the freedom granted actors to initiate and to pursue their struggles. "Free" markets in the economic sector, the "free" play of ideas in science along with academic "freedom", as well as the "free" play of ideas put forth by "free" citizens, political parties and other actors in a functioning democracy ensure, as it goes in the legitimating myths, that Inefficiencies are eliminated through competition, Untruths are revealed as such through falsification, and Injustices are corrected through the assertion and adjudication of rights.

It should be noted that the examples in this case illustrated instances of contestation and conflict that were "head-on". The tools, beliefs and values we described to be in competition were such that only one could survive. In reality, competition is much more likely to occur "at an angle" (Latour, 1987) such that "negotiation" is possible. For example, instead of falsifying a descriptive claim, an opponent might just try to circumscribe its domain of validity, limiting its application. Similarly, instead of replacing an incumbent rule with a completely different one, one might add another rule that qualifies and circumscribes the jurisdiction of the incumbent rule. Indeed, as with the recognition of "technological discontinuities" by the arrival of tools with order of magnitude improvements to their performance/price ratios and distinguishing these from "incremental improvements" (Anderson & Tushman, 1990), I suggest that the ideational or discursive dimension of a firms' technological environment can be usefully characterized in a similar manner.

Discontinuities in facts could be measured by the degree of reversal of the fact implied by the categorizations or concepts opposed, ranging from falsification to minor nuancing. In other words, competition might occur not just between statements like "DDT is a carcinogen" and "DDT is not a carcinogen", but also between statements like "DDT is a possible carcinogen", "DDT is a probable carcinogen" and "DDT is a probable carcinogen, with human evidence". Discontinuities in rules could be similarly measured by the degree of reversal of rights, goals, and outcomes implied by changes to them.

Anderson & Tushman's cyclical model of evolution in technological *tools* appears to be paralleled by ones for *beliefs* and *values*. Systems of ideas - systems of facts and systems of rules - evolve similar to other complex systems, with periods of stasis punctuated by discontinuous changes (see Kuhn, (1970) on "ideas"; see Kauffman (1993, 1995, 1996), Bak & Chen (1991), and Bak (1994) on "complex systems"; see Tushman & Anderson (1986), and Anderson & Tushman (1990) on "technologies"; see Gunderson, Holling & Light (1995) on "rule sets"). "Eras of ferment" (i.e. debate, struggle) follow the arrival of new ideas which conflict head-on with incumbent ideas. Once a dominant design (i.e. paradigm) crystallizes, incremental changes occur as struggle is confined to that at a sharp angle, to use Latour's (1987) term, with the core relatively unchallenged.

Certainly the case study calls into question assumptions of relative independence and autonomy of these three spheres of society. In terms of *content*, at any given point in time dominant artifacts, beliefs and values mutually validate each other, each conferring on the others a certain "obvious superiority" and legitimacy that comes from being part of an internally consistent logic, as per Garud & Rappa's (1994) sociocognitive model of technological evolution. In terms of *process*, facts and rules are not handed pre-made and black-boxed to economic actors who then go away to make some tools. For not only are these other two processes going on simultaneously with tool-making, but firms also monitor and participate in the processes by which both of these are constructed. It is also apparent from the case study that *coalitions* or *alliances* linking actors in each arena are formed.

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[1] I use the term "myth" here in its sociological sense; the use of this term does not mean that I consider the metanarratives used to legitimate activities in these arenas as false. But nor do I consider them necessarily true. These *are* the stories that participants in these domains and in wider society tell themselves.

9.1.2 Firms are Involved in the Making of Rules and Facts

Challenges to prevailing notions of what is True and what is Right or Just are simultaneously *indirect* challenges to what is Efficient. Because the viability of products can be dramatically affected by the outcomes of these struggles, such challenges represent threats to some firms but opportunities to others. Unsurprisingly, as in the case study, firms often get directly involved in these contests and take sides.

That firms get involved in the political arena and attempt to influence rule-making to their favour has long received attention in the strategy discipline, and I do not wish to dwell on it here. Business-government relations is a longstanding sub-discipline of strategy. But the role of firms in fact-making has been largely ignored. **One conclusion that I wish to draw as a result of this dissertation is that there is a significant need for more serious study of Business-Science relations in the strategy discipline.**

Consider a few examples of fact-making from the case. In the struggle over the facts about DDT, the agricultural chemical industry did not hesitate to get involved in highly technical methodological critiques. For instance, they consistently promoted a particular methodology for estimating cancer risk over a substitute one. Whereas extrapolation from toxicological tests on rodents yielded equivocal results as to the carcinogenicity of DDT, epidemiological studies on overexposed populations such as workers in DDT manufacturing plants and feeding studies on "volunteer" prisoners consistently indicated an absence of increased cancer incidence. Listen to Max Sobelman of the Montrose Chemical Corporation, in his statement before the Interim Committee on "DDT and the Environment" of the Nebraska State Legislature:

> *"The usefulness of DDT is based on its differential toxicity among various species as vast amounts of data in the literature indicate. Extrapolation cannot be made, therefore, from one species to another.* ***It is a well-***

established rule of toxicology that effects on human beings should be measured with human beings as experimental subjects."

(statement made 1970 01 06, transcribed and reprinted in Sobelman (1970, p 239))

In addition, the work of Dr. Wayland J. Hayes Jr., who favoured the latter methodology, was supported and widely publicized by industry. In the same statement, Sobelman describes him as *"the world's leading authority on the toxicology of DDT"*.[2]

Or, to get a sense of just what constitutes "discursive struggle" by firms, consider the following examples of hair-splitting.

When confronted with toxicological studies that showed DDT leading to tumours in mice, industry replied with the argument that because these tumours were not malignant, DDT could not be termed "carcinogenic". In other words, the very definition of cancer was contested. Referring to that research, Sobelman made clear:

*"The **facts** are these: The Bionetics researchers admittedly did not consider **the reversibility of the hepatomas (these are liver tumours)** that were produced in some of the mice."*

(Sobelman, 1970, p 246)

Definitions and the criteria for inclusion and exclusion for various categorizations are fiercely contested sites of struggle, especially for concepts that straddle scientific, political and economic discourse. Recall a point made much earlier about how difficult it is to isolate the terminology of these three domains from influences flowing from the others: "pesticide" is not a purely scientific term but has an economic and anthropocentric dimension to it. "Biocide" - a substance harmful to "life" or "living things" is actually a more accurate term and was promoted by Rachel Carson[3], and it was fiercely fought against by industry. Indeed, the history of DDT is in many ways of history of *categorizations* with *consequences*: DDT was an "economic poison" so its sale was subject to FIFRA (a claim uncontested by industry); DDT was a "biocide", a term

[2] Sobelman (1970, p 246)

with no legal standing but which has a bad ring to it among the public (industry contested the meaningfulness of the category); DDT was a "pollutant" according to Wisconsin water quality legislation (industry contested the categorization); DDT was a "possible human carcinogen" (one a series of compromise categories between "carcinogen" and "non-carcinogen" that emerged within the discourse of toxicology; contested nevertheless); etc. The categorizations result from fact-making. The consequences result from rule-making. Witness the discursive struggle currently underway over the inclusion and exclusion criteria - the *definition* - of a "persistent organic pollutant". The stakes are high; depending upon the definition settled upon, products other than the original twelve substances on the UNEP list could be forced out of the economy.

When confronted with evidence that DDT was ubiquitous in the environment, bioaccumulating and appearing in the body fat of mammals, birds and humans all over the world, again industry made methodological arguments. They pointed to the (real) difficulty of distinguishing DDT from PCB residues using standard gas chromatograph (GC) techniques, because the molecules yield very similar "printouts" from these machines. Of course we now know that the distinction was in many cases moot. DDT *and* PCBs are each "persistent organic pollutants" found everywhere on the planet; most organisms were likely contaminated with both.

Indeed, when confronted with almost any piece of evidence that DDT was having a negative impact on the environment, industry consistently generated a myriad of alternative hypotheses (i.e. rival claims or beliefs hoping to harden into facts). I suggest to you that this case study indicates that organizations, in contrast to the oft-repeated mantra in strategy and organization theory which holds that firms seek to reduce uncertainty, do not hesitate to manufacture uncertainty and ambiguity when their interests dictate, which is when the particular "certainty" that is crystallizing in society threatens them.

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[3] Carson (1962, p 8)

I wish to underline here that my choice of the label "fact-making" for one of my ideal types of substitution was not an attempt to build "grand" social theory and was not made lightly. Talk of "facts" and "truth" versus "non-facts", "untruths" and "fiction" is everywhere in the data. Indeed, a big part of the inspiration for the label "fact-making" on one of my ideal types comes from industry itself. For not only was NACA's response to *Silent Spring* a document entitled *Fact & Fancy*, but individuals who spoke out in defense of DDT, like Montrose's Max Sobelman for example, consistently framed their formal statements as a structured comparative series of points under the titles of "Facts" (their beliefs) and "Non-Facts" (those promoted by opponents of DDT)[4]. Of course, DDT opponents reversed the labels.

9.1.3 Which Facts get Made?

Note also that, in the case study, facts with a public goods dimension to them were consistently undersupplied, appearing late in the life of the focal molecule. Let's face it, facts get made about things that those with resources care about. If not for the special status of birds in society in general (for instance, consider that we do not have "frogwatcher" organizations) and of the bald eagle in the United States in particular, fact-making about that aspect of DDT would have been delayed even further. Had DDT not appeared, awkwardly, in sites with much emotional import - pristine Antarctica, breast milk, and the bird-symbol of the greatest nation on earth - it would have enjoyed a longer life.

Existing *organizations* and *institutions* structure the bias of fact-making. If malaria was not confined to the poorest and most marginalized regions of the globe, it is possible that the current fight over DDT could have been long settled by the pursuit and discovery of a cure for that disease. However, with the incredible scientific and financial resources of the North's pharmaceutical companies concentrated on making facts and tools for the Earth's real "problems" - erectile dysfunction, male pattern baldness - the South's sense

[4] Sobelman (1970, p 223)

of Injustice is understandable, and the struggle over which rules will apply to DDT at a global level continues. One cannot "blame" Business for the state and direction of Science, but a better appreciation of how these spheres of social life coevolve would surely be of benefit to those concerned about strategy and sustainable development, not to mention Efficiency, Truth, and Justice.

Notice how changes to the organization of the fact-making and rule-making domains were critical. After *Silent Spring*, more interdisciplinary "environmental" and ecological research got done. The disciplines of "environmental health" and "ecotoxicology" also grew in size and importance. Within different structures, different facts get made and at different rates. Similarly, the creation of the EPA and transfer of responsibility for pesticide registration away from the USDA spelled doom for DDT. That organization went on to develop organizational routines for *eliminating* old products from the economy, analogous to those of firms for bringing new products *into* the economy!

9.1.4 The Domain's Dominant Coalition, and Disruption by New Entrants

If we think of the pesticides domain as having three sub-domains as per the arenas I've described, then it becomes clear that as a clear domain emerges and becomes more "organized" and stable (Hardy, 1994), the interests of those who dominate in each sub-domain become aligned over time. Just as there is mutual interdependence amongst tools, facts and rules, there is mutual interdependence between tool-makers, fact-makers and rule-makers. It really couldn't be any other way especially given that each arena is premised on *competition* and *contestation*. The "core" of each arena becomes allied with the "core" in the others in their *ongoing* struggle to keep the peripheries at bay. Witness the alliance between the agricultural chemical industry (and producers of DDT and other persistent organochlorines in particular), economic entomologists favouring chemical controls, and the USDA which had the solid support and protection of Congressmen from farm states. The struggle over DDT was not *just* the struggle to substitute one product for another in the marketplace and hence a threat to the firms producing it, it was simultaneously a huge threat to the power, authority and legitimacy of the (a) advocates of chemical controls, and (b) the USDA and farm state politicians. Each had "monopolized" their respective arena. The struggle over DDT was a struggle for the "core" in each of the three arenas. The coalition of economic entomologists favouring biological controls and IPM along with wildlife biologists and ecologists from science, partnered with those politicians and government agencies making their careers as environmentalists in the political arena eventually overcame.

Of course for other goods and services, these alliances may be tacit or implicit in everyday life, but they sure become explicit quite quickly once an effort to remove a product from the web of goods and services is made.

Note also the importance of new entrants into the arenas. Prior research on technological evolution has demonstrated how technological discontinuities initiated by new entrants into the tool-making arena (i.e. into the industry) tend to be more "competence-destroying" than those initiated by incumbents which is more often than not "competence-enhancing" (see Tushman & Anderson, 1986). The case study suggests that a similar phenomena occurs with respect to the fact-making and rule-making arenas.

Just as firms must monitor the R&D activity of rival firms (i.e. keep an eye on "tool-making" in the domain) they must also monitor activities of fact-making and rule-making as well. Certainly at any given point in time, dominant designs (i.e. artifacts) would tend to be coherent and consistent with dominant paradigms (i.e. beliefs and evaluation routines), as per Garud & Rappa (1994). But notice that I say "tend"; this is because the "fit" between the material and ideational worlds is never guaranteed. Just as discontinuities can originate from processes of tool-making (Tushman & Anderson, 1986), so can they appear from processes of fact-making and rule-making. Firms must especially monitor these arenas for new entrants, because this case suggests that "competence-destroying" changes to facts and rules came from and were promoted by relative outsiders to each of the arenas. Wildlife biologists and marginalized economic entomologists (who favoured biological and cultural insect controls) led the struggle to change the "facts" promoted for so long by the dominant economic entomologists (who favoured and had built careers upon chemical controls) who had dominated the scientific (i.e. descriptive) discourse on pesticides. Similarly, it was politicians from non-farm states (who were building careers as "environmentalist" politicians) and government agencies traditionally viewed as less being less authoritative on pesticides who led the struggle to change the "rules" promoted for so long by politicians from farm states who had built careers defending the interests of farmers and the agrichemical industry and who had dominated agricultural committees and political (i.e. normative) pesticide discourse prior to DDT controversy

I wish to say a few words here about the stability of the dominant coalition (talker/actors) and how this relates to the dominant paradigm (discourse) and dominant design (technology), as well as why this might be so. Why are things stable so long then suddenly there's a "revolution"? Well, in short, it is due to "increasing returns" (Arthur, 1994). This concept has been used to explain how certain tools rise to dominance in an economy, not due to their inherent performance features or efficiency, but by getting just slightly ahead (perhaps by chance even) and then tending to stay ahead or increase their lead due to "lock-in". They become the "standard", then maintain a hegemonic dominance. The classic example given is usually VHS over Beta (Arthur, 1994), or Microsoft software. In a nutshell, everything else being equal, its when "winning in one time slice *increases* the probability that you will win in the next time slice".

Increasing returns exist when this simple condition holds. One explanation is that this effect is more likely when there are "positive network externalities". For technologies, this is when the benefits that result from a customer's particular technological choice increase with each and every additional customer making the same choice. Who wants to convert documents from one format to another all the time; of course I'll adopt Word for Windows!

I suggest that this is precisely the case in instances where beliefs crystallize into the dominant "facts", as in science. It is easier to go with the flow. The "cost" of being a biological control proponent was marginalization and ridicule within economic entomology. Who would pay it? It is natural that Ph.D. students in that discipline did more research on chemical controls when they saw the research money, publications and industry jobs going to those who did. Dissidence has costs, but for the health of the system, is so vital. Radicals, heretics, deviants - they all produce public goods.

Increasing returns also occur whenever what is being contested in one time slice can be recycled and reused in the next. I suggest that economic, political and scientific power all have this feature. The "elite" seek to retain their status in their respective arena. In industry, profits earned in one time slice can be reinvested in the search for improvements to processes and products in the next. Firms without cash lose at these tool-making races. Cash is both stake and weapon in these battles.

In discursive struggle over "facts" and "rules", I suggest that a similar phenomena occurs; *credibility* is simultaneously stake and weapon. Those who had monopolized pesticide discourse continued to do so, and when challenged they consistently questioned the *discursive legitimacy* and *right to voice* of "new entrants". What did bird-and-bunny-huggers know about insect control? What did city folk and their elected representatives know about cotton farming? How dare laypeople question the wisdom of the nation's scientists? Dominant incumbents in the discursive arenas harnessed their own credibility to snuff out the efforts of anyone who sought to establish their own.

"Silence! Miss Carson."

9.2 Strategy as Patterned Talk and Patterned Action

I wish now to turn my attention to more mundane substitution events - those involving artifacts which are less science-intense and less politically-charged.

For such artifacts, it is possible and indeed likely that *a smaller set of actors* (for example, just industry rivals and their customers) would be significantly involved in each of "artifact-making", "fact-making", and "rule-making" (rules as norms, at least) about their products. But I suggest that the *activities* still occur.

Imagine any substitute-producing firm attempting to dethrone an incumbent product with its own. Besides (a) bringing the artifact to market and to the attention of potential customers, this firm will also attempt to *convince* and *persuade* customers that its product (b) *is* better than the incumbent and that it is so (c) along evaluation criteria that *are* or *ought to be* important to the customer. In other words, along with the material or physical *artifacts* that they bring into the world and promote, firms also bring into the world and promote ideational or discursive *arguments* for adoption - a structured set of declarative statements (i.e. beliefs; "is" statements) and normative statements (i.e. values; "ought" statements) - that support their artifacts. These arguments may draw upon and reinforce existing beliefs and values, or they may be aimed at undermining them - substituting them with new beliefs and values. Just as a product can have complements in the physical world (i.e. other products or technologies, the sale and use of which enhances demand for the focal product), it can also have complements in the ideational world. The fate of technological artifacts inevitably depends not only on the fate of other technological objects, but on that of ideational objects - descriptive claims and normative claims - as well.

Of course, the relative importance of firms - and their arguments - in the creative destruction of beliefs and values will vary from industry to industry, depending upon the products concerned. Different products have different *relevant evaluation constituencies*, and hence different sets of beliefs and values that hold them in place in the economy. The specific *discourses* relevant to the utility value of a given product therefore differ according to product.

Consider fact-driven substitution. The important actors are those who are relevant to the process by which customers change their beliefs, and for different products these will be different. Firms promoting artifacts will also promote beliefs that help the cause of those artifacts. Firms intend and hope that the descriptive claims contained in advertisements, promotions and other marketing communications will become the beliefs of targeted buyers. But in addition, other actors may also play central roles in the shaping of beliefs of buyers and other important evaluation constituencies. **In general, we would expect that technically sophisticated products whose performance is difficult for users to observe and measure would be particularly vulnerable to fact-driven substitution.** This is the case with both agricultural and pharmaceutical chemicals. Economic entomologists and other agricultural scientists, especially those working at extension stations, influence beliefs about different agricultural chemical products, as in our case study. Doctors' claims about products influence not only their patients' ideas about pharmaceutical and medical products, but those of other doctors as well; pharmaceutical companies regularly target recognized disease specialists and opinion leaders when making claims about new products attempting to dislodge older ones. Indeed, many substitution events involving pharmaceutical products resemble our idealized fact-driven substitution. Doctors represent a relatively homogeneous and tightly connected *epistemic community*. The appearance of a strongly positive or negative article in an influential medical journal like the *New England Journal of Medicine* can change the fate of pharmaceutical products very quickly.

Consider norm-driven substitution. The important actors are those who are relevant to the process by which customers change their understanding of the desirability of various outcomes and for different products these will be different. Firms promote the use of specific evaluation criteria along which their products score well relative to other products. When allocating all the resources that they do to marketing, advertising, promotions and other communications, firms intend and hope that the dimensions of performance that they herald in their normative claims of product superiority will become the dimensions of product performance that are invoked by targeted buyers when they evaluate competing products. But in addition, other actors may also play central roles in the shaping of buyers' objectives, goals and notions of what constitutes desirable product performance. **In general, we would expect that products whose performance is**

difficult to define and to evaluate except subjectively but with input from peers would be particularly vulnerable to norm-driven substitution. Products with much cultural significance which are subject to shifting tastes and fads, like clothing for example, fit into this category. Just as pharmaceutical companies target influential opinion-leading doctors, firms marketing "cultural" products target consumers whose tastes are influential for the masses: the "early adopters" of marketing textbooks. Should hemline be an evaluation criteria for skirts? If so, what is desirable? These questions are decided in the discourse of fashion. The substitution of tight miniskirts for flowing floor length maxiskirts certainly cannot be interpreted as the outcome of a generic innovation process involving search, discovery and then bringing to market. The superior performance/price ratio of miniskirts in consumers minds arose because they changed their evaluation criteria, not because firms looked for and discovered the miniskirt along with its obviously superior performance along the dimension of length.

Consider regulation-driven substitution. Once again, the important actors are those who are relevant to the process by which other actors' change their understanding of the desirability of various outcomes and for different products these will be different. The difference here is with whose understanding is changed. With norm-driven substitution, it is users and consumers of the product whose values and decision rules shift and cause substitution. With regulation-driven substitution, other stakeholders affected by the manufacture, sale and use of a product come to change their understanding of the desirability or acceptability of various outcomes, become politically active and are successful at formally changing the rules governing what constitutes acceptable and desirable products in a society. Again, for different products these actors may be very different, although in general **we would expect that products whose manufacture, sale and use affects many stakeholders through "externalities" would be particularly vulnerable to regulation-driven substitution.** With norm-driven substitution, it is "internalities" that come to be evaluated differently by users once newer values substitute for old ones. With regulation-driven substitution, "externalities" are reevaluated as values and priorities shift, and especially as new stakeholders identify themselves as such, perhaps with the discovery of some impact upon them due to a particular product, and insist that their concerns be included in the calculus of design decisions. Chemical products, because many of them are not "used up" or transformed as they are consumed, are especially vulnerable, and empirically, in North America, it is been organizing around externalities that has led to the regulation-driven demise of a number of industrial (ex. CFCs, PCBs, lead in gasoline, lead in paint) and agricultural (ex. DDT and other organochlorines like aldrin, dieldrin, toxaphene, mirex) substances.

That the beliefs/facts and values/rules which dominate in a society are also relevant to the fate of a firm's products and technologies seems obvious, yet surprisingly these variables and their dynamics have been largely ignored, at least in most theorizing about substitution and technological evolution. But they have certainly not been ignored by firms in the real world, judging by the amount of resources they devote to such things as marketing, communications, dissemination of particular scientific findings, public relations, and lobbying. All of these activities are aimed at influencing ideas or, in other words, at shaping beliefs and values. Firms are quite aware that ideas matter. When particular ideas upon which their fates are contingent are threatened, they do not hesitate to enter into debates, make public their views, and actively promote those ideas. In other words, besides being *actors*, firms are also *talkers*. They take part not only in *exchanges*, but also in *conversations*. Within these conversations, they act - or rather, talk - strategically. They make *character-defining commitments* (Selznick, 1957) to particular *positions*, defending some descriptive statements and some normative statements while seeking to dislodge others, much like they commit to particular technological positions.

I suggest therefore that a more complete view of firm strategy would include *patterned talk* in addition to *patterned action* (Mintzberg, 1987). Table 9.2.1 summarizes two ways of looking at social systems and shows how a firm's strategy might be treated in both perspective. Clearly the "exchange" view on the right has dominated historically within the strategy discipline. The strategy discipline could benefit from more research work done from the "communications" perspective on the left, as has the field of organization theory recently. I suggest that future work investigating the *coevolution* of discourses and technology - of the worlds of ideas and energy-matter - would also be fruitful.

Table 9.2.1 - Two Views of Social Systems

	information system representation (communication paradigm)	**material system representation (exchange paradigm)**
key concept:	"information"	"resources"
entities:	talkers	actors
entity activity:	exploit stocks & flows to accomplish thought, deciding, intuiting, calculating	exploit stocks and flows to accomplish production, consumption (metabolism)
stocks:	beliefs, values, mental maps, etc.	assets, technologies, equipment
flows:	talk, signals, texts, etc.	products, cash
"strategy" identified as:	character-defining commitment to particular stocks and flows (patterned talk)	character-defining commitment to particular stocks and flows (patterned action)
interactions (micro-events):	conversations	exchanges
aggregated interactions (macro-phenomena)	discourses	industries
nature of contests:	discursive struggle	material struggle
static, equilibrium view:	reproduction of social life: talk reinforces existing paradigm, beliefs, order	reproduction of economic life: revenues from product flows spent on existing portfolio of raw materials &/or reinvested to maintain existing portfolio of fixed assets
dynamic, far-from-equilibrium view:	conceptual entrepreneurship possible - discursive "innovations" can change conversations and beliefs through "creative destruction"	material entrepreneurship possible - material "innovations" change product flows and investment in asset stocks through "creative destruction"

Paul Muller from Geigy was a traditional entrepreneur, acting in the material realm; his artifacts changed the world. Rachel Carson and the EDF were discursive entrepreneurs, acting in the realm of ideas; their arguments changed the world.

9.2.1 Conclusion

What is the process by which one product substitutes for another one?

Whereas most research aimed at understanding our focal phenomena of substitution - the process by which new technological products replace incumbent products - has had a clear focus on the physical realm of *action* and *artifacts*, I found myself, in order to understand that process, also investigating the ideational or discursive realm of *talk*. In order to understand and track competition between rival products, I found it necessary to describe and track competition between rival *beliefs*. Was DDT safe and effective? Many believed it was, but many others held the exact opposite views. I also found it necessary to describe and track competition between rival *values* as well. Should the rights of citizens to a clean environment outweigh those of chemical companies and farmers to earn a living? Were dead robins found on people's lawns a fair exchange for warding off Dutch Elm disease on tree-lined suburban streets? Different actors valued these potentially conflicting rights differently.

In resolving these two sorts of questions, one *descriptive* and the other *normative*, actors engaged in discursive struggle. That is, they entered into the social arenas in which the fate of beliefs and values were decided. There, they made and promoted their claims, offering evidence, justification and reasons why their beliefs and values should prevail over competing ones. Through this process, certain beliefs became widespread and institutionalized until finally, in the absence of further contestation, they had become hardened into "facts". Similarly, the values, preferences and decision rules promoted by some actors became, through contestation and clashes with rival values, the "rules" as particular tradeoffs and preferences became institutionalized and applied in a widespread manner, informally as norms or formally as regulations.

And so from my study of the phenomena of substitution, of struggle for dominance in the marketplace, has come a description of three parallel, simultaneous and entangled processes: struggles over "Efficiency", struggles over "Truth", and struggles over "Justice".

BIBLIOGRAPHY

Amit, R. & Schoemaker P., 1993, "Strategic Assets and Organizational Rent", *Strategic Management Journal*, 14, 33 - 46

Anderson P., & Tushman, M., 1990, "Technological Discontinuities and Dominant Designs: A Cyclical Model of Technological Change", *Administrative Science Quarterly*, 35, 604 - 633

Andrews, K.R, 1971, *The Concept of Corporate Strategy*, Homewood, IL, Dow Jones-Irwin Inc.

anonymous, 1962, "The Desolate Year", *Monsanto Magazine*, (Oct 1962) 4 - 9

Ansoff, H.I., 1965, *Corporate Strategy*, New York: McGraw Hill Book Company

Ansoff, H.I., 1991, "Strategic Management in a Historical Perspective", *International Review of Strategic Management*, 2, 1, 1991, p. 3–69.

Arthur, W.B., 1989, "Competing technologies, increasing returns and lock-in by historical events", *The Economic Journal*, March, 116 - 131

Arthur, W.B., 1994, "Positive feedbacks in the economy", *The McKinsey Quarterly*, no 1, 81 - 95

Aspelin, Arnold L., 1999, *Pesticide Usage in the United States: A Survey of Current Levels and Past Trends*, Office of Pesticide Programs, United States Environmental Protection Agency, Washington, DC [unpublished draft as of time of writing]

Avial, J.A., & Whitehead, B.W., 1993, "What is Environmental Strategy?" *The McKinsey Quarterly*, 4, 53 - 68

Bak, P. & Chen, K., 1991, "Self-Organized Criticality", *Scientific American*, 246, 1, 1991, 46–53

Bak, P., 1994, "Self-Organized Criticality: A Holistic View of Nature" in *Complexity: Metaphors, Models and Reality*, edited by G.A. Cowan, D. Pines and D. Meltzer, Proceedings Volume XIX of Santa Fe Institute Studies in the Science of Complexity, Reading MA, Addison-Wesley Publishing Company, 477–495

Barney, J.B., 1986, "Strategic Factor Markets: Expectations, Luck and Business Strategy", *Management Science*, 42, 1231 - 1241

Barney, J.B., 1991, "Firm Resources and Sustained Competitive Advantage", *Journal of Management*, vol 17, no 1, 99 - 120

Benedick, R.E., 1991, *Ozone Diplomacy: New Directions in Safeguarding the Planet*, Harvard University Press, Cambridge, MA

Benson, S., Arax, M. & Burstein, R., 1997, "A Growing Concern", *Mother Jones*, Jan-Feb, 33 - 43 & 66 - 68

Berger, P.L. & Luckmann, T., 1967, *The Social Construction of Reality: A Treatise on the Sociology of Knowledge*, Garden City, NY, Anchor Books

Bishop & Philip, 1952, in USDA [United States Department of Agriculture], 1952, *Insects: The Yearbook of Agriculture for 1952*, Government Printing Office, Washington, DC

Blodgett, John E., 1974 "Pesticides: Regulation of an Evolving Technology" in Epstein, Samuel S. & Grady, Richard D., (eds.), *Legislation of Product Safety*, MIT Press, Cambridge, MA, 197 - 287

Bloom S.C. & Degler S.E., 1969, *Pesticides and Pollution*, Bureau of National Affairs, Washington, DC

Boardman, Robert, 1986, *Pesticides in world agriculture : the politics of international regulation*, St. Martin's Press, New York, NY

Borror, Donald J., De Long, Dwight, M., & Triplehorn, Charles A., 1981, *An introduction to the study of insects*, College Publications, Philadelphia, PA

Bosso, Christopher J., 1987, *Pesticides and Politics: The Life Cycle of Public Issue*, University of Pittsburgh Press, Pittsburgh, PA

Bregha, F., Greene, G., Ruitenbeek, Wright, D., 1990, *A Sustainable Development Framework for CIDA*, CIDA Policy Branch, Hull

Briggs, Shirley [Rachel Carson Council], 1992, *Basic Guide to Pesticides: Their Characteristics and Hazards*, Taylor & Francis, Washington, DC

Brooks, G.T., 1974, *"Chlorinated Insecticides: Volume I - Technology and Applications"*, CRC Press, Cleveland, OH

Brooks, G.T., 1974, *"Chlorinated Insecticides: Volume II - Biological and Environmental Aspects"*, CRC Press, Cleveland, OH

Brooks, G.T., 1977, "Chlorinated Insecticides: Retrospects and Prospects", in Plimmer, J.R. (ed.), *Pesticide Chemistry in the 20th Century*, American Chemical Society, Washington, DC

Brooks, Paul (editor), 1972, *The House of Life: Rachel Carson at Work, with selections from her writings published and unpublished*, New York, Houghton Miflin, New York, NY

Brown, A.W.A., 1971, *Insecticide resistance in arthropods*, World Health Organization, Geneva, Switzerland

Brown, L, et al, 1998, *State of the World: A Worldwatch Institute Report on Progress Toward a Sustainable Society*, W.W. Norton & Company, New York, NY

Brown, L.D., 1989, *Bridging Organizations and Sustainable Development*, paper presented at Conference for Social Innovations in Global Management, Boston University

Buckley, John, 1986, "Environmental Effects of DDT", in Committee on the Application of Ecological Theory to Environmental Problems, Commission on Life Sciences, National Research Council, (ed.), *Ecological Knowledge and Environmental Problem-Solving: Concepts and Case Studies*, National Academy Press, Washington, DC, 358-374

Burn, A.J., Coaker, T.H., & Jepson, P.C. (eds.), 1988, *IPM: Integrated Pest Management*, Academic Press, London, UK

Busvine, J.R., 1946, "New Synthetic Contact Insecticides", *Nature (London)*, 158, 22

Cairncross, F., 1992, *Costing the Earth: The Challenge for Governments and The Opportunities for Business*, Harvard Business School Press, Boston

Carson, Rachel, 1951, *The Sea Around Us,* Oxford University Press, London, UK

Carson, Rachel, 1962, "Silent Spring - I" [A Reporter At Large], *New Yorker*, June 16, 35 - 99

Carson, Rachel, 1962, "Silent Spring - II" [A Reporter At Large], *New Yorker*, June 23, 31 - 89

Carson, Rachel, 1962, "Silent Spring - IIII" [A Reporter At Large], *New Yorker*, June 30, 35 - 67

Carson, Rachel, 1962, *Silent Spring*, Houghton Mifflin Company, New York, NY (page numbers cited refer to a 1994 paperback edition)

Casida, John E. & Quistad, Gary B., 1998, "Golden Age of Insecticide Research: Past, Present or Future", *Annual Review of Entomology,* 43, 1-16

CBS News Archives, 1963, *The Silent Spring of Rachel Carson* (VIDEOTAPE: documentary aired 1963 04 03), CBS News Archives, 1988

CCPA [Canadian Chemical Producers Association], 1994, *Responsible Care 1994: A Total Commitment*, annual report/brochure, CCPA, Ottawa, ON

Chengelis, C.P., Holson, J.F., & Gad, S.C. (eds.), 1995, *Regulatory Toxicology*, Raven Press, New York, NY

CMA [Chemical Manufacturers Association], 1994, *US Chemical Industry Statistical Handbook*, CMA, Washington, DC

CMA [Manufacturing Chemists Associaton, later to become Chemical Manufacturers Association], 1940 (ed. 1), 1946 (ed. 2), 1950 (ed. 3), *Chemical Facts & Figures*, which became in 1955 (ed. 4), 1960 (ed. 5), 1966 (ed. 6), 1971 (ed. 7) *The Chemical Statistics Handbook*, CMA, Washington, DC

Coase, R.H., 1960, "The Problem of Social Cost", *Journal of Law and Economics*, 3, 1 - 44

Colborne, T., Dumanoski, D., & Myers, J.P., 1997, *Our Stolen Future*, Plume Books of Penguin Press, New York, NY

CONSAD Research Corp [Bernstein, A., Stewart, D., & Lowrey., R.], 1976, *Study of the Short Term Agricultural User Adjustment Problems Associated with Major Pesticide Regulatory Restrictions - Executive Summary,* CONSAD Research Corp., Pittsburgh, PA and Environmental Protection Agency, Washington, DC, Criteria and Evaluation Division (Report Number: EPA-68-01-1917; EPA/540/9-77/014)

Cort, D., 1958, "The Pesticide That Came to Dinner", *The Nation*, April 12, 316 - 319

Cottam, Clarence & Higgins, Elmer, 1946, "DDT and its Effect on Fish & Wildlife", *Journal of Economic Entomology*, 39 (Feb 1946), 44 - 52

Cremlyn, 1991, in Pimentel, David (ed.), 1981, *CRC Handbook of Pest Management in Agriculture*, CRC Press, Boca Raton, FL

Curl & White, 1952, in USDA [United States Department of Agriculture], 1952, *Insects: The Yearbook of Agriculture for 1952,* Government Printing Office, Washington, DC

Cyert, R.M., & March, J.G., 1963, *A Behavioural Theory of the Firm*, Englewood Cliffs, New Jersey, Prentice-Hall Inc.

Dangerfield, W.G., 1946, "Toxicity of DDT to Man", *British Medical Journal*, 1 : 27

Darby, William J., 1962, "Silence, Miss Carson", *Chemical and Engineering News*, Oct 1, 1962, 60 - 63

Davis, Kenneth S., 1971, "The Deadly Dust: The Unhappy History of DDT", *American Heritage*, 22 (Feb 1971), 44 - 47 & 91 - 92

Deloitte & Touche, 1991, *Politiques et attitudes des industriels face à l'environnement*, DRT International

Dent, David, 1995, *Integrated Pest Management*, Chapman & Hall, New York, NY

Dietz, F.J., & van der Straaten, 1992, "Rethinking Environmental Economics: Missing Links Between Economic Theory and Environmental Policy", *Journal of Economic Issues*, vol 26, no 1, 27 - 51

Douglas, William, O., 1962, "Review of *Silent Spring*", *Book-of-the-Month Club News*, September, 2 - 4

Doutt, R.L., & Smith, R.F., 1971, "The Pesticide Syndrome: Diagnosis and Prophylaxis" in Huffacker, C.B. (ed.), *Biological Control*, New York, Plenum Press, 5

Draize, John H. et al, 1944, "Summary of Toxicological Studies of the Insecticide DDT", *Chemical and Engineering News*, 22 (10 Sept 1944), 1503 - 1504

Dunbar, Paul A., 1949, "The FDA Looks at Insecticides", *Food, Drug, Cosmetic Law Journal*, 4 (June, 1949), 233 - 239

Dunlap, Thomas R., 1978a, "The Triumph of Chemical Pesticides in Insect Control, 1890 - 1920", *Environmental Review*, 5 (1978), 38 - 47

Dunlap, Thomas R., 1978b, "DDT on Trial: The Wisconsin Hearing, 1968-1969", *Wisconsin Magazine of History*, Autumn 1978, 2-24

Dunlap, Thomas R., 1978c, "Science as a Guide in Regulating Technology: The Case of DDT in the United States", *Social Studies of Science*, 8, 265-285

Dunlap, Thomas R., 1981, *"DDT: Scientists, Citizens and Public Policy"*, Princeton University Press, Princeton, NJ

Dupree, A.H., 1957, *Science in the Federal Government : a history of policies and activities to 1940*, Arno Press, New York, NY

Edwards, Clive A., 1973 (first edition) & 1975 (second edition), *Persistent Pesticides in the Environment*, CRC Press, Cleveland, OH

Ehrenfeld, D, 1997, "A Cruel and Transient Agriculture", lecture given at Marist College, Ploughkeepsie, NY, reprinted in *Harper's Magazine*, Oct, 13 - 17

Eichers, Theodore Raymond, Jenkins, Robert, & Fox, Austin Schultz, 1969, *DDT used in farm production*, U.S. Dept. of Agriculture, Economic Research Service, (for sale by the Supt. of Docs., U.S. Govt. Print. Off.,)

Eisenhardt, K., 1989, "Building Theories from Case Study Research", *Academy of Management Review*, 14, 4, 532 - 550

Elliot, M. (ed.), 1977, *Synthetic Pyrethroids*, American Chemical Society, Washington, DC

Emery, F., & Trist, E., 1965, "The Causal Texture of Organizational Environments", *Human Relations*, 18, 21 - 35

EPA [Environmental Protection Agency], 1972, "Consolidated DDT hearings, opinion and order of the Administrator", Washington DC, *Federal Register*, 37, 13369 - 13376

EPA [United States Environmental Protection Agency - DDT Advisory Committee], 1971, *Report of the DDT Advisory Committee to William D. Ruckelshaus, Administrator, Environmental Protection Agency*, United States Environmental Protection Agency (Report Number: EPA/540/5-71/004), Washington, DC

EPA [United States Environmental Protection Agency], 1975, *"DDT: A Review of Scientific and Economic Aspects of the Decision to Ban Its Use as a Pesticide"*, United States Environmental Protection Agency (Report Number: EPA-540/1-75-022), Washington, DC

Epstein, Samuel S. & Grady, Richard D., 1974, *Legislation of Product Safety*, MIT Press, Cambridge MA

Epstein, Steven, 1996, *Impure Science*, University of California Press, Berkeley, CA

Etzioni, Amitai, 1961,*A comparative analysis of complex organizations*. New York: Free Press of Glencoe

Ewing, 1952, in USDA [United States Department of Agriculture], 1952, *Insects: The Yearbook of Agriculture for 1952*, Government Printing Office, Washington, DC

Fagin, D., Lavelle, M., & The Center For Public Integrity, 1996, *Toxic Deception: How the Chemical Industry Manipulates Science, Bends the Law, and Endangers Your Health*, Carol Publishing Group, Secaucus, NJ

FAO [Food and Agriculture Organization], 1975, *Report of the Panel of Experts on Integrated Pest Control, 5th meeting, Oct15 - 25, 1974*, FAO, Rome, Italy

Fernald, H.T., & Shepard, H.H., 1955, *Applied entomology : an introductory text-book of insects in their relations to man - 5th edition*, McGraw Hill, New York, NY

Fernald, H.T., 1935, *Applied entomology : an introductory text-book of insects in their relations to man - 3rd edition*, McGraw Hill, New York, NY

Fisher, J. & Pry, A., 1971, "A Simple Substitution Model of Technological Change", *Technological Forecasting and Social Change*, 3, 75 - 88

Flippen, J. Brooks, 1997, "Pests, Pollution and Politics", *Agricultural History*, 71, 4, 442-456

Folsom, J.W., 1914, *Entomology, with special reference to its Biological and Economic Aspects - second revised edition*, P. Blakiston's Sone & Co., Philadelphia, PA

Fronk, W.D., 1962, "Chemical Control" in Pfadt, Robert E. (ed.), *Applied Entomology*, MacMillan Company, New York, NY, 159 - 190

Garud, R., & Rappa, M.A., 1994, "A Socio-cognitive Model of Technological Evolution: The Case of Cochlear Implants", *Organization Science*, 5, 3, 344 - 362

Geier, P.W. & Clark, L.R., 1961, "An Ecological Approach to Pest Control", *Proceedings of Technicla Meeting of the International Union for the Conservation of Nature and Natural Resources, 8th meeting, Warsaw, PO,* E.J. Brill, Leiden, 10 - 18

George, J.L., & Frear, D.E.H., 1966, "Pesticides in the Antarctic", *Journal of Applied Ecology* (supplement), 3, 155 - 167

Ghemawat, P., 1991, *Commitment: The Dynamic of Strategy*, New York, The Free Press

Gillette, Robert, 1971, "DDT: In Field and Courtrooom, a Persistent Pesticide Lives On", *Science*, 174 (10 Dec, 1971), 1108 - 1110

Gladwin, T., 1993, "The Meaning of Greening: A Plea for Organizational Theory", in *Environmental Strategies for Industry: International Perspectives on research Needs And Policy Implications*, edited by Fischer, K. & Schot, J., Island Press, Washington, DC, 37 - 61

Goudie, A., 1991, *The Human Impact on the Natural Environment - third edition*, The MIT Press, Cambridge, MA

Graham, Frank, Jr., 1970, *Since Silent Spring,* Houghton Mifflin Company, Boston, MA

Gray, B., 1985, "Conditions Facilitating Interorganizational Collaboration", *Human Relations*, 38, 911 - 936

Gray, B., 1989, *Collaborating: Finding Common Ground for Multiparty Problems*, Jossey-Bass, San Francisco, CA

Gunderson, L.H., Holling, C.S., & Light, S.S., 1995, *Barriers and bridges to the renewal of ecosystems and institutions*, Columbia University Press, New York, NY

Gunter, Valerie J. & Harris, Craig K., 1998, "Noisy Winter: The DDT Controversy in the Years before *Silent Spring*", *Rural Sociology*, 63, 2, 179-198

Hagen, K.S., & Franz, J.M., 1973, "A History of Biological Control", in Smith, R.F., Mittler, T.E., & Smith, C.N., *History of Entomology*, Annual Reviews Inc. & the Entomological Society of America, Palo Alto, CA, 433 - 476

Hardy, C., 1994, "Underorganized Interorganizational Domains", *Journal of Applied Behavioural Science,* 30, 3, 278 - 296

Hayes, Wayland J. Jr., 1956, "The Effect of Known Repeated Oral Doses of Chlorophenethane (DDT) in Man", *Journal of the American Medical Association*, 162 (27 Oct, 1956), 890 - 897

Hayley, Denis, 1983, *The Catalyst: The First Fifty Years of NACA*, National Agricultural Chemicals Association (NACA), Washington, DC

Henkin, Harmon, Merta, Martin, & Staples, James, 1971, *The Environment, the Establishment, and the Law*, Houghton Mifflin Company, New York, NY

Higdon, Hal, 1969, "Obituary for DDT (in Michigan)", *New York Times Magazine*, (6 July 1969), 6

Hill, S.B., 1990, "Pest Control in Sustainable Agriculture", *Proceedings of the Entomological Society of Ontario*, 121, 5 - 12 (reprinted by McGill University Ecological Agriculture Projects, no. 32)

Hilton, James G. (Chair, writing a report for Ruckelshaus., William D.), 1971, *Report of the DDT Advisory Committee*, Environmental Protection Agency, Office of Pesticide Programs, Washington, DC, Sept 1971, (Report Number: EPA/540/5-71/004)

Hitchner, Lea, 1952, in USDA [United States Department of Agriculture], 1952, *Insects: The Yearbook of Agriculture for 1952*, Government Printing Office, Washington, DC

Holling, C.S., 1986, "The Resilience of Terrestrial Ecosystems: Local Surprise & Global Change", in *Sustainable Development of the Biosphere*, edited by Clark, W.C. & Munn, R.E., Cambridge University Press, 292 - 320

Holling, C.S., 1989, "Integrating Science for Sustainable Development", *Journal of Business Administration*, vol 19, no 1&2, 73 - 83

Holling, C.S., Berkes, F., & Folke, C., 1997, "Science, Sustainability and Resource Management", in *Linking Social and Ecological Systems*, edited by Berkes, F., & Folke, C., Cambridge University Press, UK, 346 - 366

Hoskins, W.M., Borden, A.D., Michelbacher, A.E., 1939, "Recommendations for a more discriminating use of insecticides", *Proceedings of 6th Pacific Scientific Congress*, 5, 119 - 123

Howard, L. O., 1933, *Fighting the insects*, MacMillan, New York, NY

Howard, L.O., 1931, *The Insect Menace,* The Century Company, New York, NY

Hurst et al, 1991, in Pimentel, David (ed.), 1981, *CRC Handbook of Pest Management in Agriculture*, CRC Press, Boca Raton, FL

Hynes, H. Patricia, 1989, *The recurring silent spring*, Pergamon Press, New York, NY

IARC [International Agency for Research on Cancer], 1999, at www.iarc.fr

Itami, H., & Numagami, T., 1992, "Dynamic Interaction Between Strategy and Technology", *Strategic Management Journal*, 13, 119 - 135

Jones, D. Price, 1973, "Agricultural Entomology", in Smith, Ray F., Mittler, Thomas E., & Smith, Carroll N. (eds.), *History of Entomology*, Annual Reviews Inc with the Entomological Society of America, 307-332

Kallett, A, & Schlink, F.J., 1933, *100,000,000 guinea pigs; dangers in everyday foods, drugs, and cosmetics*, Vanguard Press, New York, NY

Kauffman S.A., 1993, *Origins of Order: Self-organization and Selection in Evolution*, Oxford University Press, New York

Kauffman S.A., 1995a, *At Home in the Universe: The Search for Laws of Self-organization and*

Complexity, Oxford University Press, New York

Kauffman S.A., 1995b, "Escaping the Red Queen Effect", *The McKinsey Quarterly*, no 1, 119 - 129

Kiss, A., & Meerman, F., *Integrated Pest Management and African Agriculture*, World Bank Technical Paper 142, Africa Technical Department Series, World Bank, Washington DC

Knipling, E.F., 1948, "Insect Control Investigations of the Orlando, Florida Laboratory During World War II", in the *Annual Report of the Smithsonian Institution*, Government Printing Office, Washington, DC

Knipling, Edward F., 1953, "The Greater Hazard: Insects or Insecticides", *Journal of Economic Entomology*, 46, 1 - 7

Kogan, Marcos, 1998, "Integrated Pest Management: Historical Perspectives and Contemporary Developments", *Annual Review of Entomology*, 43, 243-270

Kuhn, T.S., 1970, *The Structure of Scientific Revolutions - second edition*, Chicago: University of Chicago Press

Latour, B., 1987, *Science in Action*, Harvard University Press, Cambridge, MA

Lear, Linda, 1992, "Bombshell in Beltsville: The USDA and the Challenge of *Silent Spring*", *Agricultural History*, 66, 2, 151-170

Lear, Linda, 1997, *Rachel Carson: Witness for Nature*, Henry Holt & Company, New York, NY

Leary, James C., Fishbein, William I, & Salter, Lawrence C., 1946, *DDT and the Insect Problem*, McGraw-Hill Book Company, Inc. New York, NY

Lippman, S.A., & Rumelt, R.P., 1982, "Uncertain imitability: an analysis of interfirm differences in efficiency under competition", *The Bell Journal of Economics*, 13, 418 - 438

Lyle, Clay, 1947, "Achievements and Possibilities in Pest Eradication", *Journal of Economic Entomology*, 40 (Feb 1947), 1 - 8

Lyle, Clay, 1952, in USDA [United States Department of Agriculture], 1952, *Insects: The Yearbook of Agriculture for 1952*, Government Printing Office, Washington, DC

Macintyre, Angus A., 1980, *The Politics of Nonincremental Domestic Change: Major Reform in Federal Pesticide and Predator Control Policy*, PhD dissertation, University of California, Davis, CA

MacIntyre, Angus A., 1985, "Administrative Initiative and Theories of Implementation: Federal Pesticide Policy, 1970-1976", in Ingram, Helen M. & Godwin, R. Kenneth (eds.), *Public Policy and the Natural Environment*, JAI Press, Greenwich, CT, 205-238

MacIntyre, Angus A., 1987, "Why Pesticides Received Extensive Use in America: The Political Economy of Pest Management to 1970", *Natural Resources Journal*, 27, no 3, 533 - 578

MacIntyre, Angus, A., 1980, *The Politics of Nonincremental Domestic Change: Major Reform in Federal Pesticide and Predator Control Policy*, Ph.D. diss., Univ. of California, Davis, CA

Mackenzie, D., & Wajcman, J., 1985, "Introductory Essay: The Social Shaping of Technology" in *The Social Shaping of Technology: How the Refrigerator Got Its Hum*, 2 - 25, Open University Press, Philadelphia, PA

MacNeill, J., Winsemius, P., & Yakushiji, T., 1991, *Beyond Interdependence: The Meshing of the World's Economy and the Earth's Ecology*, Oxford University Press, New York

Magretta, J., 1997, "Growth Through Global Sustainability: An Interview with Monsanto's CEO, Robert B. Shapiro" *Harvard Business Review*, Jan - Feb, 79 - 88

Mahoney, J., & Pandian, J.R., 1992, "The resource-bsed View within the Conversation of Strategic Management", *Strategic Management Journal*, 13, 363 - 380

Marco, Gino J., Hollingworth, Robert M., & Durham, William, 1987, *Silent Spring Revisited*, American Chemical Society, Washington, DC

Mellanby, Kenneth, 1970, *Pesticides and Pollution*, Collins New Naturalist, London, UK (this is the second edition of a 1967 book)

Mellanby, Kenneth, 1992, *The DDT Story*, British Crop Protection Council, Farnham Surrey, UK

Metcalf, Robert Lee, 1955, *Organic insecticides: their chemistry and mode of action*, Interscience Publishers, New York, NY

Metcalf, Robert Lee, 1972, "Agricultural Chemicals in Relation to Environmental Quality: Insecticides Today and Tomorrow", *Journal of Environmental Quality*, 1 (1), 10

Michelbacher, A.E., & Bacon, O.G., 1952, "Walnut insect and spider mite control in Northern California", *Journal of Economic Entomology*, 45, 1020 - 1027

Miles, M., & Huberman, A.M., 1984, *Qualitative Data Analysis*, Sage Publications, Beverly Hills, CA

Miles, R.E. & Snow, C.C. 1978, *"Organizational Strategy, Structure, and Process"*, New York: McGraw Hill

Miller, D., 1986, "Configurations of Strategy and Structure: Towards a Synthesis", *Strategic Management Journal*, vol 7, 233 - 249

Mintzberg, H., & McHugh, A., 1985, "Strategy Formation in an Adhocracy", *Administrative Science Quarterly*, 30, 160 - 197

Mintzberg, H., & Waters, J.A., 1982, "Tracking Strategy in an Entrepreneurial Firm", *Academy of Management Journal"*, 25, 3, 465 - 499

Mintzberg, H., 1979, "An Emerging Strategy of Direct Research", *Administrative Science Quarterly*, 24, 580 - 589, reprinted in Van Maanen, J., 1983, *Qualitative Methodology*, Sage Publications, Beverly Hills, CA, 105 - 116

Mintzberg, H., 1987, "The Strategy Concept: 5 P's for Strategy", *California Management Review*, 30, 1, 11 - 24

Mintzberg, H., 1988, "Generic Strategies: Towards a Comprehensive Framework", in *Advances in Strategic Management*, vol 5, Greenwich CT, JAI Press, 1 - 67

Mintzberg, H., 1990, "Strategy Formation Schools of Thought" in *Perspectives on Strategic Management*, editted by J.W. Fredrickson, Harper & Row, 105 - 235

Montgomery, C.A., 1995, "Of Diamonds and Rust: A New Look at Resources", in *Resource-based and Evolutionary Theories of the Firm: Towards A Synthesis*, edited by Montgomery, C.A., Norwell MA, Kluwer, 251 - 268

Moore, N.W., 1967, "A Synopsis of the Pesticide Problem", *Adv Ecol Res*, 4, 75

Moriarty, F., 1975, *Organochlorine Pesticides: Persistent Organic Pollutants*, Academic Press, London, UK

Munn, R.E., 1989, "Towards Sustainable Development: An Environmental Perspective", *Development*, 2, 3, 70 - 80

NACA [National Agricultural Chemicals Association], 1958, *Open Door to Plenty*, NACA, Washington, DC

Newall, J.E., 1990, "Managing Environmental Responsibility", *Business Quarterly*, Autumn, 90 - 94

Newton, Commissioners report, 1865

Norgaard, R.B., 1988, "Sustainable Development: A Coevolutionary View", *Futures*, 12, 606 - 620

NRC [National Research Council, National Academy of Sciences] 1965, *Report on 'No Residue and Zero Toleranceof the Pesticides Residues Committee*, National Academy of Sciences, Washington, DC

NRC [National Research Council, National Academy of Sciences], 1980, *Regulating Pesticides; A Report prepared by the Committee on Prototype Explicit Analyses for Pesticides, Environmental Studies Board, Commission on Natural Resources*, National Academy of Sciences, Washington, DC

NRC [National Research Council, National Academy of Sciences], 1987, *Regulating Pesticides in Food; The Delaney Paradox*, National Academy Press, Washington, DC

NRC [National Research Council, National Academy of Sciences], 1966, *Scientific Aspects of Pest Control*, National Academy of Sciences - National Research Council, Washington DC (National Research Council Publication no. 1402)

NRC [National Research Council, National Academy of Sciences], 1985, *Ecological Knowledge and Environmental Problem Solving: Concepts and Case Studies*, Environmental Protection Agency, Washington, DC

OECD, 1971, *The Problems of Persistent Chemicals: Implications of Pesticides and other Chemicals in the Environment*, Report of the Study Group on Unintended Occurrence of Pesticides, OECD, Paris, France

Ordish, George, 1976, *The Constant Pest: A Short History of Pests and Their Control*, P. Davies, London, UK

OTA [Office of Technology Assessment], 1979, *Pest Management Strategies: Volume I, Summary*, OTA, Washington, DC

Perkins, John H., 1978, "Reshaping Technology in Wartime: The Effect of Military Goals on Entomological Research and Insect Control Practices", *Technology and Culture*, 19, no 2 (Apr 1978), 169 - 186

Perkins, John H., 1980, "The Quest for Innovation in Agricultural Entomology, 1945-1978, in Pimental, David & Perkins, John H., (eds.), *Pest Control: Cultural and Environmental Aspects*, AAAS Selected Symposium 43, Westview Press, Boulder CO, 23 - 80

Perkins, John H., 1982, *Insects, Experts, and the Insecticide Crisis: The Quest for New Pest Management Strategies*, Plenum Press, New York, NY

Perkins, John H., 1983, "Insects, Food and Hunger: The Paradox of Plenty for U.S. Entomology", *Environmental Review*, 7 (spring 1983), 71 - 96

Perry, A.S., Yamamoto, I., Ishaaya, I., & Perry, R.Y., 1998, *Insecticides in Agriculture and Environment: Retrospects and Prospects*, Springer, Berlin, Germany

Pesticide Handbook, 1951 (ed. 1) - 1964 (ed. 16), College Science Publishers, State College, PA [in 1965 (ed. 16), this merged with *Entoma* to become *Pesticide Handbook - Entoma*; all issues were reviewed up to 1981-82 (ed. 29)

Peteraf, M.A., 1993, "The Cornerstones of Competitive Advantage: A Resource-based View", *Strategic Management Journal*, 14, 179 - 191

Pfadt, Robert E., 1962, *Fundamentals of applied entomology*, MacMillan, New York, NY

Pigou, A.C., 1932, *The economics of welfare*, MacMillan, London, UK

Pimentel, David & Perkins, John H., 1980, *Pest Control: Cultural & Environmental Aspects*, Westview Press, Boulder, CO

Pimentel, David (ed.), 1981, *CRC Handbook of Pest Management in Agriculture*, CRC Press, Boca Raton, FL

Pimentel, David (ed.), 1991, *CRC Handbook of Pest Management in Agriculture: Second Edition*, CRC Press, Boca Raton, FL

Pimentel, David, 1972, *Ecological Effects of Pesticides on non-target species*, Office of Science and Technology, US Government Printing Office, Washington DC (June 1972)

Pimentel, David, 1987, "Is Silent Spring Behind Us?", in *Silent Spring Revisited*, edited by Marco, G., Hollingworth, R.M., & Durham, W., The American Chemical Society, Washington, DC, 175 - 187

Polanyi, Karl, 1944, *The Great Transformation*, Farrar & Rinehart, Inc., New York, NY

Popham, W.L., & Hall, David G., 1958, "Insect Eradication Programs", *Annual Review of Entomology*, 3 (1958), 335 - 354

Popham, W.L., 1952, in USDA [United States Department of Agriculture], 1952, *Insects: The Yearbook of Agriculture for 1952*, Government Printing Office, Washington, DC

Porter, M.E. & van der Linde, C., 1995, "Green and competitive: Ending the stalemate", *Harvard Business Review*, September-October: 120-134

Porter, M.E., 1980, *Competitive Strategy*, The Free Press, New York, NY

Porter, M.E., 1985, *Competitive Advantage: Creating and Sustaining Superior Performance*, The Free Press, New York, NY

Porter, M.E., 1990, *The competitive advantage of nations*, The Free Press, New York, NY

Princi, Frank, 1952, "Toxicology and Hazard Record of the Newer Pesticides", *Agricultural Chemicals*, 7 (Jan 1952), 44

PSAC [President's Science Advisory Committee: Weisner, J.B., chairman], 1963, *The Use of Pesticides - President's Science Advisory Committee Report*, Government Printing Office, Washington, DC (May 15, 1963)

Radeleff et al, 1952, in USDA [United States Department of Agriculture], 1952, *Insects: The Yearbook of Agriculture for 1952*, Government Printing Office, Washington, DC

Rainwater, 1952, in USDA [United States Department of Agriculture], 1952, *Insects: The Yearbook of Agriculture for 1952*, Government Printing Office, Washington, DC

Ravetz, J.R., 1986, "Usable knowledge, usable ignorance: incomplete science with policy implications", in *Sustainable Development of the Biosphere* editted by Clark, W.C. & Munn, R.E., Cambridge University Press, Cambridge, 415 - 434

Redclift, M., 1988, "Sustainable Development and the Market", *Futures*, 12, 635 - 650

Rissler, J., & Mellon, M., 1996, *The Ecological Risks of Engineered Crops*, The MIT Press, Cambridge, MA

Ritter et al, 1995, *Persistent Organic Pollutants: An Assessment Report on DDT, Aldrin, Dieldrin, Endrin, Chlordane, Heptachlor, Hexachlorobenzene, Mirex, Toxaphene, Polychlorinated Biphenyls, Dioxins, and Furans*, IPCS [International Programme on Chemical Safety], December 1995, available online at: http://irptc.unep.ch/pops/newlayout/infpopsalt.htm

Roark, R.C., 1935, "Insecticides and Fungicides", *Industrial and Engineering Chemistry*, 27, 5, 530 - 532

Rogers, E., 1982, *Diffusion of Innovations - third edition*, New York, NY, Free Press

Rogers, R.E., 1976, *Biocides and Birds: A Survey of the Efects of Biocides on Birds*, Alberta Environment Conservation Authority, Edmonton, AL (October 1976)

Rohwer, S.A., 1945, "Report of the Special Committee on DDT, with S.A. Rohwer as Chairman", *Journal of Economic Entomology*, 38, 144

Ruckelshaus, William D., 1972, "Consolidated DDT Hearings: Opinion and Order of the Administrator", *Federal Register*, vol 37, no 1331, Friday, July 7, 1972, 13369 - 13376

Rudd, Robert L., 1959a, "Pesticides: The Real Peril", *The Nation*, 28 Nov 1959, 399 - 401

Rudd, Robert L., 1959b, "The Irresponsible Poisoners", *The Nation*, 30 May 1959, 496 - 497

Rudd, Robert L., 1964, *Pesticides and the Living Landscape*, University of Wisconsin Press, Madison, WI

Ruggles, A.G., 1924, "Pioneering in Economic Entomology", *Journal of Economic Entomology*, 17, 34 - 41

Rumelt, R.P., 1984, "Towards a Strategic Theory of the Firm", in *Competitive Strategic Management*, edited by Lamb, R., Prentice-Hall Inc., Englewood Cliffs N.J., 556 - 570

Russell, Edmund p. III, 1996, "Speaking of Annihilation: Mobilizing for War Against Human and Insect Enemies", *Journal of American History*, 82 (March 1996), 1505 - 1529

Sailer, 1991, in Pimentel, David (ed.), 1991, *CRC Handbook of Pest Management in Agriculture: Second Edition*, CRC Press, Boca Raton, FL

Schmidheiny, S, & The Business Council for Sustainable Development, 1992, *Changing Course: A Global Business Perspective on Development and the Environment*, The MIT Press, Cambridge, MA

Schoemaker, P.J., 1990, "Strategy, Complexity and Economic Rent", *Management Science*, 35, 1178 - 1192

Schot, J., & Fischer, K., 1993, "Introduction: The Greening of the Industrial Firm" and "Conclusion: Research Needs and Policy Implications", in *Environmental Strategies for Industry: International Perspectives on Research Needs And Policy Implications*, edited by Fischer, K. & Schot, J., Island Press, Washington, DC, 3 - 33, 369 - 373

Schumpeter, J.A., 1943, *Capitalism, Socialism, & Democracy*, London: Unwin

Schwartz & Klassen, 1981, in Pimentel, David (ed.), 1981, *CRC Handbook of Pest Management in Agriculture*, CRC Press, Boca Raton, FL

Selznik, P., 1957, *Leadership in Administration*, Evanston, Illinois: Row, Peterson and Company

Shepard, Harold H., 1951, *The chemistry and action of insecticides*, McGraw-Hill, New York, NY

Simon, Herbert A., 1983, *Reason in Human Affairs*, Stanford University Press, Stanford, CA

Smith, Apple & Bottrell, 1976, in Apple, J.L., & Smith, R.F. (eds.), *Integrated pest management*. Plenum Press, New York, NY

Sobelman, Max (compilation), 1970, *Selected Statements from State of Washington DDT Hearings held in Seattle Oct 14, 15, 16, 1969,* published by the DDT Producers of the United States (Diamond Shamrock Corp, Lebanon Chemical Corp, Montrose Chemical Corp of California, Olin Corp in December, 1970)

Spooner, B., 1984, *Ecology in Development: A Rationale for Three Dimensional Policy*, The United Nations University, Japan

Spulber, D.F., 1989, *Regulation and markets,* MIT Press, Cambridge, MA

Standen, Anthony, 1946, "DDT: It will not rid the world of insect pests but it is still a wonder bug killer", *Life*, July, 47 - 54

Steingraber, S., 1997, *Living Downstream: An Ecologist Looks at Cancer and the Environment*, Addison Wesley Publishing Company Inc., New York, NY

Strong, M., 1988, "Environment and Economic Growth: Can They Be Reconciled?", *Business Quarterly*, spring, 32 - 36

Sutherland, W.W., 1952, "No More Legislation Needed", *Agricultural Chemicals*, 7 (April 1952), 41 - 43

Taylor, S.J., & Bogdan, R., 1984, *Introduction to Qualitative Research Methods: The Search for Meanings*, John Wiley & Sons, New York, NY

Thomson, W.T., 1994 [1994-95], *Agricultural Chemicals - Book I, Insecticides*, Thomson Publications, Fresno, CA

Tollison, R.D., 1982, "Rent Seeking: A Survey", *Kyklos*, 35, 575 - 602

Trist, E., 1983, "Referent Organizations and the Development of Interorganizational Domains", *Human Relations*, 36, 269 - 284

Tushman, M.L., & Anderson, P., 1986, "Technological Discontinuities and Organizational Environments", *Administrative Science Quarterly*, 31, 439 - 465

U.S. Congress, House, Committee on Agriculture, 1971, *Federal Pesticide Control Act of 1971*, Hearings before the Committee on Agriculture, 92nd Congress, 1st session, on HR-26, HR-1077, HR-1722, HR-4152, HR-4596, HR-5182, HR-6576, & HR-6761. Government Printing Office, Washington DC

U.S. Congress, House, Committee on Government Operations, 1969, *Deficiencies in Administration of the Federal Insecticide, Fungicide, and Rodenticide Act*, House Report 91-637, 91st Congress, 1st session, Government Printing Office, Washington, DC

U.S. Congress, House, Select Committee to Investigate the use of Chemicals in Food Products, 1951, *Chemicals in Food Products*, Hearings before the House, Select Committee to Investigate the use of Chemicals in Food Products, 81st Congress, 1st session, Government Printing Office, Washington, DC

U.S. Congress, House, Select Committee to Investigate the use of Chemicals in Food Products, 1953, *Chemicals in Food Products*, Hearings before the House, Select Committee to Investigate the use of Chemicals in Food Products, 81st Congress, 2nd session, Government Printing Office, Washington, DC

U.S. Congress, House, Subcommitee on Forests of the Committee on Agriculture, 1974, *Permit the Use of DDT*, Hearings before the Subcommitee on Forests of the Committee on Agriculture, on HR-10796, 93rd Congress, 1st session, Government Printing Office, Washington DC (Oct 23, 24, 25 1973)

U.S. Congress, Senate, Committee on Government Operations, 1966, *Pesticides and Public Policy*, Report of the Committee on Government Operations, U.S. Senate, 89th Congress, 2nd session, report 1379, Government Printing Office, Washington, DC

U.S. Congress, Senate, Subcommittee on Agricultural Research and General Legislation of the Committee on Agriculture and Forestry, 1971, *Federal Environmental Pesticide Control Act*, Hearings before the Subcommittee on Agricultural Research and General Legislation of the Committee on Agriculture and Forestry, 92nd Congress, 2nd session, Government Printing Office, Washington DC

U.S. Congress, Senate, Subcommittee on Reorganization and Internal Organization of the Committee on Government Operations, *Interagency Coordination on Environmental Hazards (Pesticides)*, Hearings before the , Subcommittee on Reorganization and Internal Organization of the Committee on Government Operations, U.S. Senate, 88th Congress, 1st session, Government Printing Office, Washington, DC (hearings ultimately resulted in Report 1379, *Pesticides and Public Policy*, published in 89th Congress, 2nd session)

UN [United Nations], 1991, *Consolidated List of Products Whose Consumption has been Banned, Severely Restricted or not Approved by Governments (fourth edition)*, United Nations Publications, New York, NY, USA

UNEP [United Nations Environment Program], 1996, *United Nations Environmental Program Survey on Sources of POPs*, report prepared for an IFCS Expert Meeting on Persistent Organic Pollutants, Manila, Philippines, 1996 06 17 (online at http://orptc.unep.ch/pops/indexhtms/manexp3.html)

USDA [United States Department of Agriculture], 1971, *DDT Used in Farm Production* [Report 158 of the USDA Economic Research Service], USDA, Washington, DC

USDA [Centennial Committee: Baker, G., Rasmussen, W.D., Wiser, V., & Porter, J.M.], 1963, *A Century of Service: The First 100 Years of the USDA*, Government Printing Office, Washington, DC

USDA [United States Department of Agriculture], 1952, *Insects: The Yearbook of Agriculture for 1952*, Government Printing Office, Washington, DC

USDA [United States Department of Agriculture], 1955, 1956, 1957 ...1965, *Pesticide Situation*, [in 1966, 1967, 1968 ..., this became *Pesticide Review*; all issues were reviewed up to 1978], USDA, Washington, DC

USDHEW [United States Department of Health, Education and Welfare], 1964, *Pesticides in Soil and Water*, United States Department of Health, Education and Welfare Washington, DC

USDHEW [United States Department of Health, Education and Welfare: committee chaired by Mrak., Emil M.], 1969, *Report of the Secretary's Commission on Pesticides and Their Relationship to Environmental Health - Parts I and II*, Environmental Protection Agency, Office of Pesticide Programs, Washington, D.C. (Report Number: EPA/540/9-69/001 - HEW)

Utterback, J. & Abernathy, W.J., 1975, "A Dynamic Model of Process and Product Innovation", *Omega*, 33, 639 - 656

Van de Ven, A.H. & Garud, R., 1993, "The Coevolution of Technical and Institutional Events in the Development of an Innovation", in Baum, J. & Singh, J. (editors), *Evolutionary Dynamics of Organizations*, Oxford University Press, New York, NY

Van de Ven, A.H. & Poole, M.S., 1990, "Methods for Studying Innovation Development in the Minnesota Innovation Research Program, *Organization Science*, 1, 3, 313 - 334

Van den Bosch, Robert, 1978, *The Pesticide Conspiracy*, Doubleday, New York, NY

Van Emden, H.F., & Peakall, D.B., 1996, *Beyond Silent Spring*, Chapman & Hall, London, UK

Wallace, George J., 1959, "Insecticides and Birds", *Audubon Magazine*, 61, (Jan-Feb, 1959), 10

Waller, Wilhelmine Kirby, 1958, "Poison on the Land", *Audubon Magazine*, 60 (Mar-Apr 1968), 68

Ware, George W., 1994, *The Pesticide Book*, Thomson Publications, Fresno, CA

Wargo, John, 1996, *Our Children's Toxic Legacy: How Science and Law Fail to Protect Us from Pesticides*, Yale University Press, New Haven, CT

Warren et al, 1998, "Spectacular Increases in Crop Yields in the United States in the Twentieth Century", *Weed Technology*, 12, 752 - 760

Watt-Cloutier, Sheila, 1998, "Northern Exposures: The Inuit Experience", *Persistent Organic Pollutants: The Need for a Strong Treaty, IPEN Public Forum, June 28, 1998*, Bibliotheque Nationale du Quebec, Montreal, QC

WCED [United Nations World Commission on Environment and Development], 1987, *Our Common Future*, Oxford University Press, Oxford

Wernerfelt, B., 1984, "A Resource-based View of the Firm", *Strategic Management Journal*, vol 5, 171 - 180

Wernerfelt, B., 1995, "The Resource-based View of the Firm: Ten Years After", *Strategic Management Journal*, 16, 171 - 174

West, T.F., and Campbell, G.A., 1950, *DDT and Newer Persistent Pesticides (revised second edition)*, Chapman & Hall, London, UK

West, T.F., Hardy, J.E., & Ford, J.H., 1951, *Chemical Control of Insects*, Chapman & Hall, Ltd., London, UK

Whitten, Jamie L., 1966, *That We May Live*, van Nostrand, New York, NY

WHO, 1996, *Persistent Organic Pollutants*, report prepared for IFCS Expert Meeting on Persistent Organic Pollutants, Manila, Philippines, 1996 06 17 (online at: http://irptc.unep.ch/pops/indxhtms/manexp12.html)

Whorton, James C., 1971, "Insecticide Spray Residues and Public Health: 1865-1938", *Bulletin of the History of Medicine*, 45, 3, 219-241

Whorton, James C., 1974, *Before Silent Spring*, Princeton University Press, Princeton, NJ

Wigglesworth, V.B., 1945, "DDT and the Balance of Nature", *Atlantic Monthly*, 176, 107 - 113

Williams, J.R., 1992, "How Sustainable is Your Competitive Advantage", *California Management Review*, spring, 29 - 51

Winsemius, P., & Guntram, U., 1992, "Responding to the Environmental Challenge", *Business Horizons*, 3-4, 12 - 20

Winter, S.G., 1995, "Four Rs of Profitability: Rents, Resources, Routines and Replication", in *Resource-based and Evolutionary Theories of the Firm: Towards a Synthesis*, edited by Montgomery, C.A., Norwell, MA, Kluwer Academic Publishers, 147 - 178

Woolgar, Steve, 1981, "Interests and explanations in the social study of science", *Social Studies of Science*, 11, 3, 365 - 397

Wurster, Charles F., 1975, *The Decision to Ban DDT: A Case Study*, prepared for Study on Decision Making for Regulating Chemicals in the Environment, Environmental Studies Board, National Research Council, National Academy of Sciences, at the request of the U.S. EPA, contract number 68-01-2262

WWF [World Wildlife Fund], 1998, *Resolving the DDT Dilemma: Protecting Biodiversity and Human Health*, WWF Canada, Toronto, ON

Yin, R.K., 1989, *Case Study Research: Design & Methods*, Sage Publications, Newbury Park, CA

Yuill et al, 1952, in USDA [United States Department of Agriculture], 1952, *Insects: The Yearbook of Agriculture for 1952*, Government Printing Office, Washington, DC

Zimmerman, O.T., and Levine, Irvin, 1946, *DDT: Killer of Killers*, Industrial Research Service, Dover, NH