THE EFFICACY OF STRATEGY IN THE COMPETITION FOR RESEARCH FUNDING IN HIGHER EDUCATION

by

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Abstract

This thesis is concerned with the strategic management of research in research intensive universities (RIUs). RIUs have a huge economic footprint and research is at their core. Competition for the funds that support research is fierce, and RIUs must increasingly engage in strategic activities to maximize their share of the available research funding.

Widely accepted portfolio theories underpin a quantitative model that exposes the research strategies of a group of 39 RIUs and measures the results of their strategies in terms of the change in the share of federally funded research expenditures they performed during the decade that ended in 2000. It was determined that there was a .62 correlation between the RIU research strategies and the corresponding change in their share of federally funded research expenditures. A modified specialization strategy was most closely associated with the greatest gain in share, and any RIU that does not pursue this strategy does so at its peril. The ideal strategy is the most efficient in the sense that it represents a research portfolio configuration that generated the highest rate of growth in the value of research performed among the 39 RIUs.

For the first time, an RIU can determine the exact dollar value of research that it should perform in each of its research portfolio components in order to achieve the ideal portfolio configuration. When all RIU portfolio configurations, or when a peer group of RIU portfolio configurations, are viewed, environmental opportunities or threats may become apparent. In addition, the new research-related performance indicators introduced in this thesis enhance the ability to measure research operations. Improved measurement capability enhances both research accountability and institutional accountability.

This thesis contributes to the literature pertaining to the management of research in higher education and, more generally, to the literature related to the efficacy of strategy.

Acknowledgement

Dear Professor Daniel Lang,

After every meeting with you I found myself so invigorated that I did not know what to do first. I craved these encounters despite the child-like trepidation that preceded them. I hold you in the highest esteem. I worked hard to meet your expectations. I shall not have met mine unless yours have also been met.

Your graduating student,

Jeffrey Litwin

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Dedication

Dear Lili,

You supported me every moment along a journey that began in the fall of 1998. But…you have supported everything I have done, no matter hard it was, or how long it took. The fact that you know that this is mutual is but another indicator of a relationship that is strong, passionate, and between two people that are in love with each other.

Chapter One: Letter of Introduction

I am writing this thesis because I have come to believe that the research performed in universities is a major economic stimulant from many perspectives. Research employs tens of thousands of researchers and technicians, it is a major support of the entire higher education system, and the act of conducting research trains new generations of researchers and legions of highly trained workers. Beyond these factors, academic researchers have the opportunity to think carefully about their topics and expand the edges of current knowledge. The impact of this exploration permeates the societies of all advanced industrialized countries, contributing significantly to our standard of living, to our spirit of creativity and innovation, to what we believe is right and wrong, and to wealth creation. University research is an important contributor to our way of life.

Am I being overly dramatic? Perhaps, but I see government policy in Western industrial countries explicitly, and over the long term, calling for increased participation in higher education because they know that this is the only way to support a technically advanced economy. Dare I ask what the quality of a university education might be if the teachers were not world-leading researchers, if, for example, the federal government in the United States had not pumped $30 billion of research funding into its higher education system in 2005 (National Science Foundation [NSF], 2007c). What equipment would students learn on? Who would make up the shortfall? What would be the lure and venue for the world's great thinkers? I am writing this thesis because I care about the place that Western civilization has in the world, and I view academic research as a point of high leverage that contributes to the advancement of this stature.

While it is argued that research intensive universities are transnational in nature, for reasons primarily concerned with establishing an identifiable market and because many of the issues confronting the research operations of America's higher education system mirror those in other highly industrialized jurisdictions, this thesis focuses exclusively on a select group of research intensive universities in the United States. In addition, partly because of the cultural and geopolitical history of the United States, America's research complex is the most successful on earth. At the core of this complex is one of the true manifestations of academic freedom, inquiry-based or basic research, which comprises more than 75 % of the research performed by universities (NSF, 2007c) and comprises more than 50 % of the basic research performed in the United States (Geiger & Sá, 2005). In order to maintain its preeminence in the face of rapidly developing international competition and competing domestic pressures, America and its citizens must recognize what should be done and act accordingly. Adding vast resources is an easy ideal, and even though it is undoubtedly necessary in the longer term, it is a naive expectation in the current context. Likewise, erecting trade barriers that might starve China of the resources it is investing in its higher education system is not a likely or even a desirable course of action.

Part of the answer to the question of how to help ensure that the American university research complex holds its leadership in the world lies in utilizing existing resources more efficiently. In higher education in the industrialized West, this story sounds like a broken record. Yet, when it comes to academic research, the impact of efficiency drives has been minimal. The nature of the work, the methods used to undertake it, to track it, to generate it, and to value it have changed little in the past 25 to

30 years, even while the measurement and drive for increased efficiency has grown enormously in every other part of universities.

In the face of an onslaught of demands from virtually every corner, which have forced universities to alter many of their behaviours, research seems to have somehow circumvented scrutiny of equal intensity. In research intensive universities, where most academic research is performed, the research activities of the professoriate are less measured than many of their other activities and, so long as teaching commitments are fulfilled, they are free to act at will in their research endeavours. It is not that most academic researchers do not feel pressure to conduct meaningful research in order to generate external research sponsorships and to publish, it is that they cannot guarantee that these outputs will result from their work. How can anyone provide assurances that they will win external funds or publish work when they are not in control of the decisions to grant awards or accept work for publication?

Given the significant contribution that university research makes to our way of life and to the higher education system, and its critical importance to the continuing operation of research intensive universities, it is surprising how few tools have evolved that can measure whether individual universities, or whether the system as a whole, is realizing the maximum benefit from the public resources being allocated to research. Other than perhaps comparing technology transfer statistics or publication data on some sort of per capita basis across institutions or countries, no one can answer whether the system is as productive as it could be, or if there is waste and where that might be. No one can even make an estimate based on any statistical measure. In contrast, there are certainly plenty of statistics about teaching. Without much effort, an administrator can determine which areas are more productive than others in significant detail, information that can be used to make decisions.

This thesis introduces new performance indicators and presents a model that is intended to expose the inefficiencies of the research programs of research intensive universities. The model is based on widely accepted portfolio theories and practices that are being applied in the context of university research for the first time. The model exposes the research strategies that research intensive universities actually realized and the outcomes they actually achieved in terms of performance against the academic research market.

The results of this study showed that there was a strong correlation between certain strategies realized by a selected group of research intensive universities and their performance in the academic research market. Notably, even if universities did not have a specific strategy, one might still have emerged a posteriori. Institutions that deviated from the strategy that was most closely associated with the best market performance were more likely to have inefficiency in their research operations. Even though this thesis presents only the basic version of the model, powerful insights are still revealed. For example, the model suggests that the degree to which the University of Michigan is investing in its Mechanical Engineering research activity is beyond the point of optimum efficiency and is probably stealing resources that could be redeployed to have a greater impact on its performance in the academic research market. The same situation exists for Physics research at the University of California at Berkeley.

At the institutional level, if the University of Michigan decided to deemphasize Mechanical Engineering by moderating future investments in research capacity in that discipline, it would be freeing up resources that could go into building on its strengths, which include Medical and Biological Sciences. If all research institutes followed this path, the entire system would be creating increased efficiency in the use of resources available for research.

While this thesis presents a model that is the first quantitative view of the research strategies of universities, it should be thought of as only a first step in the development of a series of management tools that can inform strategic decision-making relating to the management of research in research intensive universities. No single tool should be relied on to provide the right or complete answer. However, this model can at least shed some light on important questions, such as why a researcher should be hired in one area versus another.

I believe that the academic research market has matured to a point that demands that greater rigour be brought to bear in its management. This thesis is a step forward in providing management tools that provide new insights as to whether more can be done with the resources that support academic research.

This leads to the second reason that I am writing this thesis. When I began looking more closely at the nature of the strategic planning that universities undertake to advance their research programs, I was astounded at how shallow the effort seemed in relation to an operation that is ostensibly part of the institutional mission and in relation to the type of planning done in similarly sized industries in other sectors. From what I have seen, very few specific, forward looking commitments are ever made. I have yet to read what I would call a detailed strategic plan that specifies a future direction and describes the resources that are expected to be used to move a university's research program towards that direction. I have yet to see an assessment of the external competitive environment. In addition to the reality that there is very little literature on the subject of the strategic management of university research, comments by Derek Bok (2003) and Irwin Feller (2000) heighten my concern. Anecdotally, during the past several years and at recent academic conferences, I have spoken with dozens of people, including provosts and vice-presidents of research at major universities, who all confirm my suspicion. Their answers are inevitably similar: a lightly toned and slightly sarcastic "What Strategy?" This remark is taken to mean that there is little if any proactive, centrally initiated strategic activity in the research activities of their universities. Perhaps Mintzberg's remark is more reflective of the reality in which he suggests that, "A university of one thousand professors might be described as pursuing one thousand different research strategies…" (2003, p. 270).

The research operations of many research intensive universities generate revenues of hundreds of millions of dollars per year and at least this amount has been invested in supporting capacity. Competition for these revenues is intense. It is not responsible to have a strategic plan containing few if any specifics and, at least in my view, a plan that includes virtually no analysis of market threats or opportunities. I have thought a great deal about why this might be, and I think a cynical response would be counterproductive. I prefer to think that universities have only become economically significant enterprises in the last 30 to 40 years and that their operating metrics are still evolving. Large-scale research is an even younger aspect of university operations, and meaningful measures have yet to emerge. The very nature of research makes its economic impact difficult to measure. In addition, the federal government, as primary principal, has not yet demanded the type of accountability that permeates most other aspects of university operations. Perhaps it believes that the system itself ensures sufficient efficiency. It might even be correct, but who knows for certain?

From an institutional perspective, this thesis demonstrates that there is a specific research strategy that is more closely associated with strategic success than other strategies. I would think that every university would want to adopt such a strategy. At a minimum, they would want to know what that strategy is. The colloquial version of this question puts it into better perspective: "What would it be worth to know what strategy was most likely to yield success?" Every player in every competitive arena wants to know the answer to this question.

Does this thesis offer the ultimate answer to the question for what the winning strategy is for the research operations of research intensive universities? Definitely not! As earlier mentioned, this is not the panacea for the strategic planning of university research. It is only a first step, and an imperfect one at that. But it is also an important first step. This thesis is about informing the strategies, even if they are not actually called strategies, of research intensive universities. The objective is to help guide the investments that a research intensive university makes in research capacity so as to improve the likelihood that the value of the research it performs grows at a faster rate than other universities with which it competes. The time frames during which strategy unfolds span years and even decades. The consequences of today's decisions may not be felt for several years or even longer. Hiring a researcher today may result in increased research performance immediately, or never, and so the reason that research intensive universities were the subject of this study is that they have large enough research programs so that they can rely on the averages. That is, a researcher hired today will perform, on average, an expected value or volume of research over the course of his or her career. Hiring many researchers and buying a lot of equipment will, on average, result in a far greater value of research performance. How much investment to make, and in what areas, is the nature of strategy and the focus of this thesis.

This thesis poses the question of whether the research strategies of research intensive universities produce results that reflect those strategies. This should not be interpreted to indicate a search for trivial outcomes. On the contrary, this broaches the issue of whether significant institutional and system effects are the likely consequence of strategic adaptation in the research operations of research intensive universities. The question of the efficacy of strategy is an important question and one that has been asked in virtually every sector, in most industries, and at many times. The nature of the above thesis question suggests a causal relationship. Does a certain type of strategy produce a certain outcome? This is a tough question and one that I am not certain this thesis can completely answer since an experimental methodology is not employed. But it comes closer to answering it than many other efficacy of strategy studies, and does so quite definitively. In working towards answering this question, several corollary benefits emerge that can inform the strategic processes for research in which universities are, or ought to be, engaged. These include new methods of establishing competitive positioning and understanding strategic progress in the academic research market. While these new performance indicators will help guide resource allocation decisions by improving measurement capabilities, they also provide new opportunities for internal and external accountability. The need for this work is discussed in Chapter Two.

Yet again I caution the reader that this is the basic version of the model and not verified qualitatively. I view the main purpose for undertaking this work as laying the groundwork for further development. Laying the groundwork includes demonstrating a method and presenting performance indicators that are founded on generally accepted theories, that apply equally in all cases, that produce discrete and completely objective results, and as a consequence, might be acceptable as a standard method of measuring university research operations. This is formally presented in Chapter Four.

Laying the groundwork also includes demonstrating how this application can be used to generate powerful insights into the research operations of research intensive universities and of the total academic research market. This discussion is primarily in Chapter Five, Interpretation and Analysis.

Finally, and as noted, there is a conclusion. But more important is the work yet to be done. I am very excited that this thesis could stimulate many new ideas that would inform university research strategy and strengthen the management of university research. At a minimum, I hope that people who can make a difference accept the notion that the research enterprise in American universities has become so large, and is so important to the higher education system and to the current and future economy, that allowing it to unfold without more fully understanding it may be allowing ignorance to lead an important part of our economic future.

Chapter Two: Context and Rationale

This thesis explores the intersection of three major themes in higher education in the United States. The first of these themes is the tremendous growth of research in universities. This issue is important for all universities that conduct research and is a vital part of the operations of the most research intensive universities, the latter being the primary subject of this thesis and which are later defined and hereafter referred to as RIUs. Equally important is the significant role of research in supporting America's university system as well as the economic contribution made by university-based research.

The second major theme is the rise of accountability. In universities, accountability, to a wide variety of internal and external constituents, has created a seemingly unrelenting drive for improved efficiency and effectiveness, both of which are measured by a proliferation of performance indicators. The accountability movement has accompanied the resource dependence orientation of universities and market-facing behaviours are increasingly evident. Intensifying competition between RIUs is the third intersecting theme of this thesis. Intercollegiate competition has given rise to a priori and a posteriori strategies, the consequence of which can be observed and the outcomes of which can be measured.

While all of these themes are interrelated, they come together in this thesis in an exploration of how RIUs can locate themselves in the academic research market by asking, and attempting to answer the basic central question: Do the research strategies of the RIUs produce results that reflect those strategies? At this point, the academic research market should be taken to mean the value, in dollars, of all of the research that is conducted by colleges and universities in the United States. While the academic research market is more closely defined later in this thesis, the question remains as to whether there is a strategy or strategies that RIUs can adopt that are more likely to improve their research performance? Is there a relationship between strategy and performance in the academic research market? To answer these questions, a methodology is presented that exposes the research strategies of each RIU and identifies where, within their research operations, they can begin looking to improve their efficient use of the scarce resources that support their research programs and those of the academic research market as a whole. This method, which is most likely applicable to any university, also provides new insights into the external competitive landscape faced by RIUs, which they can use to undertake a process of strategic development that is both more informed and increasingly proactive. The answer to this question takes on even greater weight when the importance of research performance as a primary indicator of institutional quality and reputation is considered (Altbach, 2004).

Accountability

Accountability arises from the principal-agent problem (Ross, 1973). The principal cannot be certain that the agent's motivations and actions are aligned with its own. Misalignment often results in the production of outputs that do not meet the principal's expectations. From an economic perspective the principal interprets unmet expectations as a misallocation, an inefficient use, an ineffective use, or some combination thereof, of the resources that it has provided to the agent. At a certain point, which is often situation specific, the misalignment surpasses the principal's threshold of tolerance causing it to demand that the agent account for its behaviour. In this context, accountability can be viewed as a requirement that the principal places on the agent to demonstrate that it is allocating or using resources to produce outcomes that are satisfactory to the principal.

The principal-agent problem is complex. One reason is that the principal's expectations are often difficult to define and meaningfully represent, as is its threshold of tolerance, all of which are subject to change. As such, an agent that is successful in one set of circumstances may become unsuccessful without changing its relative performance. It is also important to note that the principal-agent problem permeates every aspect of society including, for example, the relationship between government and taxpayers, parent and child, or in the case of higher education, the intricate web that includes financiers such as governments, governance and academic structures, faculty, students, managers, and society generally. Each relationship is dynamic and differs in its intensity and maturity, in the degree to which an agent is directly or jointly accountable, in regard to the principal's expectations, and in exactly how accountability manifests to provide the principal with sufficient assurance.

In modern sophisticated organizations, accountability assurances are most often expressed in quantitative terms and, while accountability measurements are created to have relevance to specific issues and relationships, they are arbitrary from an external perspective. As measurements evolve and begin being used by a wide group (particularly for longitudinal or for interorganizational purposes, or both) they can become a standard in the sense that many organizations are using the same or similar measurements for the same or similar reasons (Grady, 1965). Among other things, standardization enables comparison.

The use of performance indicators has grown as organizations have become more complex and as technology has enabled the generation and assemblage of vast quantities of data and the presentation of them in meaningful ways. Consider the dramatic advances in marketing that have occurred in the last 20 years, whether in the area of consumer research or customer relationship management. Indeed, organizations are increasingly required to be aware of all aspects of their operations if they are to function. Tax laws and the Sarbanes-Oxley Act are two examples of this requirement. In the private and public sectors, any lack of transparency can create suspicions, causing a flight of capital or loss of public trust. From an internal perspective, organizations must have the most complete information possible so that their resource allocation decisions ensure long term survival. One question this raises is whether RIUs should be exempt from what has become a societal norm. The position taken in this thesis is that RIUs should be as obligated as any other large public or private institution that has special social responsibilities. To put it plainly, these institutions, which include hospitals for example, should be highly accountable to their direct constituents and to society generally.

While performance indicators have likely been produced and used at universities from the beginning, in the last 25 years a number of factors have contributed to a virtual explosion in the number of performance indicators generated, and in the number of purposes and people using them. One of these factors is the transformation of universities through, using Martin Trow's terminology (1973), the massification of higher education into a system whose contribution to the economic well-being of the nation is widely recognized and, as a consequence, in which public funds continued to be invested in an effort to ensure that participation rates kept rising. As higher education garnered an increasing share of state budgets, requirements for greater accountability grew. The 1980s witnessed declining confidence in governments as credible fiscal custodians and, when various scandals seemed to confirm existing suspicions, high officials in the public and private sectors lost a great deal of the trust of the general pubic. By the end of that decade, governments were being forced to curtail expenditures and faced increasing taxpayer scrutiny.

Perhaps because of the perception of universities as "ivory towers," where management is collegial and fiscal concerns are well down the list of priorities, or perhaps because this image was, at least in part, deserved (Bok, 1982), universities were disproportionately impacted by the wider social trends described above. State support per student at public colleges and universities declined in real terms and, in some cases, in absolute amounts. Furthermore, states demanded evidence that their higher education institutions were becoming more efficient. The need for information about the costs and benefits of higher education grew system wide and this need was supported by rapidly advancing technological capability. Before long, the quantities of data being generated and the number of performance indicators being produced expanded to such an extent that most large universities established offices of institutional research (or some version thereof) to manage these activities. As the Delaware Study demonstrates, the ability to compare certain aspects of performance improved as many performance indicators began to stabilize and standardize (Middaugh, 2001) and as the growth in the number of new indicators slowed. The principals of higher education can now make intra- and intercollegiate comparisons on a system-wide or peer grouping basis. Indeed, benchmarking against peer groups is the current state of the art in many aspects of higher education measurement (Lang, 2000).

Declining state support was, in part, offset by rising tuitions, which stimulated an increased need for a set of performance indicators that would assist students and their parents with the complicated and increasingly expensive choice of where to go to college. *U.S. News & World Report* is a significant influence on the decisions of potential students and their parents about the choices for postsecondary education. In response, universities have adjusted their behaviours in order to improve their standing in those rankings (Ehrenberg, 2002; Zemsky, Wegner, & Massy, 2005). Ironically, these adjustments can be at odds with institutional missions and priorities, raising important questions concerning the credibility, the use, and the impact of performance indicators in higher education (Burke, Minassians, & Yang, 2002). A major issue for this thesis is whether the research function is sufficiently understood in relation to the other major functions of RIUs. In other words, are current accountability practices and capabilities, as informed by performance indicators, able to expose the productivity, the efficiency, or the costs and benefits of research as well as they do for teaching or other major components of RIU operations? This question applies equally to RIUs' internal resource allocation decision-making, to governments and others who finance RIUs, and to society at large, which stands to benefit from increased efficiency.

In the case of higher education, the answer to this question is complicated by the notion that, in organizations where operating funds and activities are substantially intermingled (as is the case for RIUs), a lack of accountability in any single component translates to a lack of accountability for the entire organization. As an instance in point, the professorial activity of leading a group of doctoral engineering students can be considered to be research, teaching, or both. Likewise, a grant received to pay these students can be argued as being used for research or for their training (Rothschild & White, 1993). The issues of full accountability and intermingling are further exemplified by an event that occurred in Ontario, Canada in 1993 (Skolnik, 1994): the Provincial Auditor's ability to examine the accounts of the University of Guelph, Trent University, and the University of Toronto (all publicly funded institutions) was limited by the courts to only those monies that the Province itself had provided and only up until the point where Provincial funds began to be intermingled with funds derived from other sources (including tuition and research funds). Considering the classic tension between teaching and research (Massy & Zemsky, 1994), if it is not clear where teaching begins and ends, how can the financiers and other principals of teaching be certain that their resources are not being used to subsidize research, and vice versa? To use an old adage, a chain is only as strong as its weakest link. This thesis argues that, from an accountability perspective, the ability to understand the research function in RIUs is substantially less than the ability to understand other functions.

One approach to answering the functional accountability question is to examine the current capabilities for reporting on two major RIU functions, namely teaching and research. An excerpt from Lang's 2005 article helps illuminate the situation:

> Each of the two most referred to lists of strategic indicators for higher education in the United States comprises over 100 indicators. On one of the lists (Taylor, et al. 1993) research appears only once. On the other (Taylor and Massy, 1996), research appears twice. Both lists contain a "top 10" of indicators. Research appears on neither. Not one of the indicators that involve research could be construed as having anything to do with quality or productivity. (p. 23)

This evidence could suggest that research is not a strategically important component of RIU operations. Yet, the vital role of research performance as a determinant of institutional prestige (Brewer, Gates, & Goldman, 2002; Garvin, 1980), the large amount of research performed by RIUs (NSF, 2005a), and the significant proportion that research comprises of total RIU revenue makes it difficult to argue against its strategic importance. From this perspective, research is clearly more difficult to account for than teaching. This thesis responds to this gap by providing a methodology and a tool that informs accountability of the research function in RIUs. Notably, this thesis responds at the resource allocation level and is not intended to provide insight into the day-to-day activities of individual researchers. This qualification can be clarified by referencing the relationship that is created when a researcher, the researcher's resident university, and the sponsor of the research enter into the performance agreement that describes the parties' obligations and the proposed research activities. This performance document is, arguably, the primary accountability tool of the principals of research since it describes the intended actions and obligations the researcher and the researcher's home institution (the agents in this relationship), and the payments to be made for the described activities. This thesis does not attempt to inform this level of accountability. The question informed by this thesis is whether the researcher should have been hired in the first place or, more generally, which areas of an RIU's research capacity should be increased or de-emphasized. This is a question of resource allocation. This is a question of institutional strategy.

A very important assumption of this thesis is the recognition that there is a direct relationship between RIU investments in research capacity and the value of research performance that results from those investments. On average, when an RIU invests in research capacity, a corresponding amount of research will be performed. While it is likely that the actual value, however measured, of research performed as a result of investments in capacity varies by researcher and by discipline, and that these factors also impact the time lag between the investments and the research performed, it is possible to aggregate the data and determine the average amount of research performed for corresponding investments in capacity. This thesis assumes that all RIU research portfolios are broad enough that this average is universally operative. As such, the research activity of individual researchers is only important insofar as it impacts the relationship between investments in research capacity and research performed to an extent that is great enough to create an anomaly in any single RIU. However, this methodology does not test for such anomalies as they are considered low probability events. Finally, the exact value of the average is not important; the direct relationship between investments in capacity and research performance is the relevant assumption.

The literature often emphasizes the complexity of accountability in higher education, which partly results from the large number of performance indicators that attempt to inform the varied principals. One important set of performance indicators is that produced by colleges and universities generally and, with specific relevance to this thesis, by the RIUs. A review of publicly available performance indicators of 11 RIUs (Performance Indicators, 2002-2006) reveals that each publishes more then 150 different indicators. Of these indicators, research is underreported in proportion to the average 25 % that research performance represents of the total revenue or expenditures of the 11 RIUs. Research is also underreported in relation to faculty activity (Fairweather, 2005;

Higher Education Research Institute [HERI], 2004), in relation to investments in plant and equipment, and considering the importance of research performance as a primary indicator of institutional prestige (Geiger, 2004; Lang, 2005). For example, part of the University of Minnesota's collection of performance indicators is represented in its *2004-05 Accountable to U* report (University of Minnesota, 2004). Counting the list of figures and tables in this report (each of which displays a set of indicators) reveals that 22 of 128 are related to research. Of the 22 figures and tables related to research, 9 do not provide direct insight into the university's research performance, the composition of the research being undertaken, or the productivity of its research activities. Rather, the indicators measure the university's ability to manage research activity and technology commercialization activities. Only 7 of the remaining 11 research related indicators provide the value of research performance and national ranking for selected research areas. A longitudinal view of the latter data informs the relative performance in each of the 7 featured research areas.

More generally, a review of the nature of the research related performance indicators produced by the 11 RIUs reveals that up to half of them do not directly measure research productivity, either at the researcher level or the institutional level. Measurements relate to the institutions' efficiency in managing research with indicators such as the number of proposals submitted or processed by the research administration. Others measure historic submission success rates or potential for future research with statistics such as the number and average value of proposal submissions or the proportion of faculty who submitted proposals. Those indicators that measure research directly are most often in the form of currency values and percentages that describe the proportion that various components of an RIU's research represent of its total research. The divisions tend to distinguish federally funded from other externally funded research, or among NSF research fields (NSF, 2005a). Viewing these data longitudinally can help observers understand which research interests have become more or less important to an institution.

Most of the RIUs also produce research commercialization indicators, such as the number of invention disclosures, the number of license and related agreements and start-up companies formed, or the amount of revenue generated from technology commercialization activities. These indicators provide specifics about technology transfer but are mostly nonspecific gauges of research output, of the type of research that has been undertaken, of the nature of industrial relations, of the entrepreneurial culture on campus, or some combination thereof (Etzkowitz, Webster, & Healey, 1998; Tornatzky, 2005). These factors, coupled with the political motivations underlying the production of these measures (Geiger, 1992) and the real need to generate nongovernmentally sourced revenues, precludes the use of technology commercialization statistics in this study. The aim of this thesis is to use indicators that more directly reflect research performance and which are derived in the most objective possible manner.

Another type of indicator produced by most RIUs boasts special academic credentials of the professoriate by featuring Nobel and other prestigious academic awards. Listing faculty awards is intended to create the perception that teaching and research is high quality but says little about the quality or value of research actually being performed.

Most of the aforementioned research related indicators contrast a substantial array of teaching indicators that provide general and specific insights into the quality, productivity, and efficiency of teaching such as "Undergraduate Credit Hours Taught by Ranked Faculty and Other Instructors (1998 - 2000)" and "Average Number of Excess Credit Hours per Graduating Student" (University of Florida, 2002). It is also important to remember that, in addition to these indicators, there are performance indicators measuring nearly every aspect of RIU behaviour including extensive financial representations, state statutory reports, endowment operations, ancillary operations that can include hospitals, and many more. One example is described by Fink (2004) in which he states, "In contrast to classrooms and class laboratories...there is a general lack of reliable space allocation guidelines for predicting research space needs.... This is the result of a number of factors: the absence of empirical data on which to base research space needs, ..." (p. 11).

The final category of accountability indicators produced by RIUs is that resulting from peer group development. Peer groups are used for benchmarking purposes as part of a method that enables meaningful intercollegiate comparisons within an exceptionally diverse population of institutions (Lang, 2000). While benchmarking is useful and important from many perspectives, one concern regarding peer group development is that identifying peer institutions is inherently subjective (Lang, 2005), and those creating the groups have an incentive to try to ensure that their institution performs favorably in the future. This reality diminishes the objectivity and the universal applicability of the measurements that flow from these groups.

Benchmarking and other externally focused research indicators presented by RIUs have been advanced by Pennsylvania State University (2002), which is among the most transparent reporters of research activity. Pennsylvania State University uses NSF federally financed science and engineering field categories to produce currency and ordinal rankings in what is essentially a peer group for each of its areas of research. Pennsylvania State University (and similar reporters) has advanced the practice of strategic outcome measurement of research beyond a more subjective peer group method in that it ranks itself against the entire population of institutions that outperform it in each of the NSF fields in which it has chosen to report. This method enables a quantitative ranking where changes in the institution's relative market position can be tracked over time. By providing commentary as to these rankings, Pennsylvania State University is demonstrating that it considers that strategic success will be reflected in a higher ranking or fewer outperforming institutions. It also compares total and federally financed research performance using this method.

The University of Glasgow (2001a), which is one of the more sophisticated reporters in the United Kingdom, uses a method that, in many ways, is similar to the Pennsylvania State University's in that it ranks itself in each Unit of Assessment (Research Assessment Exercise [RAE], 2001) using an ordinal ranking. The Research Assessment Exercise is a process within which any university in England, Wales, or Scotland competes for unrestricted funds based on the aggregated research performance of faculty. Funds are awarded to the participating universities according to the peer adjudicated ranking of the research output of institution-selected faculty. The greater the number of highly ranked faculty, the more funds will be awarded to the university. Since the universities can allocate the awards however they please, including to nonresearch activities, the Research Assessment Exercise forces highly strategic behaviour among research intensive universities in the United Kingdom. In addition to ordinals, the University of Glasgow uses percentiles to describe its position relative to all institutions that submitted work in each Unit of Assessment; in effect, generating a national positioning for each research segment in which it operates. Interestingly, the University of Glasgow appears less interested in a national ranking of its total or federally financed research performance than its RIU counterparts (University of Glasgow, 2001b). The major factor that distinguishes rankings at the University of Glasgow from RIU rankings is that RIUs use currency as the basic unit of comparison whereas the University of Glasgow follows Research Assessment Exercise scores to underwrite its ranking system.

The reporting methodologies used by Pennsylvania State University and the University of Glasgow recognize the notion that measuring strategic performance requires comparisons with the performance of competitors. A successful strategic process will advance an enterprise's rank, whether expressed as an ordinal, a percentile, or in currency values. In the instance of benchmarking using currency values, the most common and current form of measuring strategic research performance among RIUs, the question must be asked as to the performance of the peer group in relation to the total market. If a university's ranking is rising among its peers and the group's collective performance is simultaneously rising compared with the market, then that university is experiencing real growth. However, if the peer group is declining compared with the market, even a university that is rising within its group may be experiencing real decline. Over the long term, the latter scenario can have a surprisingly adverse impact, much as inflation deflates the purchasing power of money. Without monitoring the performance of the market generally, benchmarking may create a false sense of security. In any event, the array of benchmarked performance indicators publicly presented by the 11 RIUs generally reflects the types and proportions of indicators presented elsewhere. Thus, these comparisons do not provide insights into research that significantly differ from other RIU produced measurements.

The evidence presented strongly suggests that the RIU produced set of performance indicators significantly underweights research quantitatively and qualitatively, and thus, research is not as accountable as teaching or other RIU functions. From the perspective of the principals of research, any improvement in the ability to equalize this shortcoming is desirable. This thesis contributes to accountability in higher education by introducing a series of research performance indicators that provide specific and general insights into the effectiveness of an RIU's research program and then uses the indicators in a tool that exposes the strategic emphases and inefficiencies of RIU research operations. By focusing attention on resource allocation questions, better informed decisions might improve the return on investments in research, both for individual institutions and for the system as a whole.

The other set of performance indicators is that which describes various attributes of higher education, generally in the form of rankings, for an audience that includes RIUs, colleges and universities, and others interested in this field, but which was not produced for any specific university. These widely used indicators are important because they are published by usually credible organizations whose work is derived from reliable sources, including the NSF (2007a), the Integrated Postsecondary Education Data Set

(2006), and the publication rating services of Thomson Scientific (Thompson Corporation, 2007). RIUs use them to inform their resource allocation decisions, they are used by those whose decisions ultimately impact resource allocations (such as governments), and they are used as the basis upon which many other indicators are produced.

In the case of the NSF, a rich collection of data has resulted from a reporting function that includes recording the amount of federal research funding received by all colleges and universities, data that it has published annually since 1972. These data are assembled into various reports, some of which segregate research performance by source of funds (federal, state, industry, and institutional), by type of research (basic and applied), and into 28 science and engineering disciplines and subdisciplines, which it calls *fields*. Importantly for the purposes of this thesis, the fields and the method used to inform them has not changed in any way that would materially impact the results of this study (NSF, 1992-2002). The NSF indicates research intensiveness by delineating the top 20 and the top 100 performers of federally financed research. Every RIU quotes from the NSF's data in their research performance reports, most use its field demarcations, and all RIUs cite its federally financed research statistics. The universal use of NSF data among RIUs provides increased assurance about the reliability of the research results of this thesis. When assembled in new configurations, including longitudinal views, significant insights into the research operations of RIUs and the Federal Government can be derived. This thesis uses NSF data in its methodology and, as described elsewhere, includes only those colleges and universities that were among the top 100 performers of federally financed research in each year from 1988 to 2002 inclusive when defining RIUs (see Chapter Four, Definition 9).

Other important sets of rankings include those produced by *U.S. News & World Report* (2005); Shanghai Jaio Tong University Ranking (2006), The Center (2005a), the Carnegie Foundation for the Advancement of Teaching (2000), and Thompson Corporation's Web of Science and other citation indexes (Thompson Corporation, 2007). Most of the performance indicators produced in these reports provide little direct insight into research productivity, although many include qualitative and quantitative research statistics in the amalgams upon which their rankings are based. The citation indexes provide quantitative data based on the frequency of work cited by others, but do not easily enable the aggregation of these data by NSF field or even by departments within institutions. Of particular interest is part of The Center's annual reports, which go beyond simply listing the values of various research attributes with accompanying ordinals by presenting the change in the values and ordinal positions that occurred during the specified period. The reports' statistics relating to changes in performance provide insight into the effectiveness of the strategy of each university's research program. For example, a higher ordinal ranking equates to an improved market share. Increased market share represents real growth, growth that exceeds the average competitor. A growth rate that exceeds the average represents the results of a strategy that was more effective than the opposite scenario.

A second point of interest regarding The Center's annual reports is in the breakdown in the value of research performed (as delineated by the NSF) into "Major Disciplines" (The Center, 2005b, pp. 58-65), such as Engineering or Medical Science.

Highlighting the research emphases of each university in this manner is a recognition that, at RIUs, research can be viewed as a portfolio of activities (Carter, 1997; Feller, Ailes, & Roessner, 2002; McGeary & Smith, 1996; NSF, 2003b; Pasek & Asl, 2002). The concepts of market share, strategy, and portfolio will be developed further and applied in this thesis to present a model that exposes the strategic emphases of individual RIUs which are then correlated with the changes in the shares of federally financed research funding actually realized by the institutions. Using this method, the relationship between strategy and institutional performance is observable and can then be used to inform the process of strategy formation.

Notwithstanding the part of The Center's ranking described above, the ranking's set of indicators does not provide direct or specific insights into the effectiveness, efficiency, or productivity of RIU research programs. However, they do help establish reasonable impressions as to the quality of faculty that resides in each university.

Lastly, the collegial nature of higher education has resulted in a plethora of associations of all types. Membership in the Association of American Universities (AAU) indicates a prestigious reputation and substantial research intensity. In order to qualify as an RIU in this study, an institution had to have been a member of the AAU for all years from 1988 to 2002 inclusive.

Research is less measured than teaching or other RIU operations. This adversely impacts institutional accountability. Any improvement in the ability to measure research also improves institutional accountability. Using NSF data, this thesis introduces several new performance indicators and applies a model heretofore not used in a higher education application that improves the ability to measure research performance from the perspectives of efficiency, strategic contribution, and competitive positioning. In the process, these performance indicators enable answering the research question which is whether the research strategies of RIUs produce outcomes that reflect those strategies.

Research

In many regards, research has been transformational for the United States higher education system in general and for RIUs in particular. It has changed the nature of graduate education, the mindset of a significant proportion of the faculty (HERI, 2004), the financing and management of fixed and human capital (Clark, 1992), and the way institutional quality and reputation is perceived (Brewer et al., 2002; Geiger, 2004; Lang, 2005). In the context of RIUs and their operations, it is vital to understand the central role of research in ensuring long-term institutional success. The two threads underlying this central role include a financial argument and a strategy oriented argument.

One approach to the financial argument is to compare the relative size and importance of the RIUs' major revenue streams: state appropriations, tuition, service and other revenue, philanthropy, and research (Rapoport, 1998). Comparing revenue streams is useful because it exposes the consequences of the fiscal challenges that have been confronting RIUs, and most other institutes of higher education, for decades (Geiger, 2004). As resource dependency intensified (Pfeiffer & Salancik, 1978; Slaughter & Leslie, 1997; Zemsky et al., 2005), RIU managers came under, and continue to experience, intense pressure to cut costs, create efficiencies, improve effectiveness, and prove to stakeholders that they are both actively pursuing and demonstrating results towards these objectives. In addition, all universities are compelled "to maximize their own sphere of activity by obtaining as much revenue as feasible" (Geiger, 1992. p. 10). In this environment, revenue generation becomes evermore critical and, as part of their planning, RIU management are obligated to measure which significant revenue streams are likely to grow at rates that are faster than others and which revenue streams are likely to be most profitable. Such an analysis informs resource allocation decisions.

From 1980 to 2006, state funding per full time equivalent (FTE) student for higher education declined in real terms (State Higher Education Executive Officers [SHEEO], 2006) and universities must continue to lobby their state benefactors to the greatest possible extent to ensure that they maximize their appropriations. Given funding trends, which are partially reflected in the current discussion as to whether the benefits of a university education accrue more to private individuals than to society at large, there are strong indications that dramatic increases in real funding are unlikely (Spellings Report, 2006). In addition, the intense competition for a pool of future students whose growth rate appears to be slowing is likely to further dampen the growth of state appropriations, as well as the potential growth of tuition revenue (Gerald & Hussar, 2002). When viewed in the context that higher education is not a top priority for state governments, public universities cannot always expect their appropriations to grow; indeed, they will be doing well to hold them constant.

Partially offsetting these realities in the case of public institutions, but also to the benefit of private universities, is the "high tuition, high aid" regime that did help increase net tuition revenue (Geiger, 2004). This model is likely to continue. Whether it generates continuing increases in net tuition revenue is questionable since student loan programs, one of the engines supporting this model, are not likely to be augmented on a per student basis (Greene & Baer, 2007). As well, rapid growth may be pushing tuition levels to their limit of price elasticity (Callan, 2006). The growing literature concerning the affordability of higher education in the United States further supports this position.

Tuition and state appropriations to public 4-year degree-granting institutions of higher education, when viewed as a single revenue stream, decreased as a proportion of total current-fund revenue from 59.4 to 53.7 % from 1980-81 to 2000-01. Despite this declining share, public Doctoral/Extensive universities' tuition and state appropriations still comprised 16.8 and 31.6 %, respectively, for a combined proportion of 48.4 % of total revenue in 2000-01 (National Center for Education Statistics [NCES], 2000-01). This is a large proportion and is used primarily to fund the principal function of these institutions, educational operations. As a consequence, this revenue must be protected at all costs and augmented whenever and however possible. As a point of contrast, in the 22 years ended 2004, total tuition and appropriations revenue per FTE student increased by only 17.1 % in real terms (SHEEO, 2006), whereas growth in externally funded research, in real terms, was greater than 230 % during the same period (NSF, 2006). Externally funded research is defined as the total value of research and development performed by the institutions, less that amount that was funded by the institutions themselves. All told, revenue generated by tuition in the case of private universities, and by tuition and state appropriations in the case of public universities, may be peaking. Furthermore, and despite the recent growth and profitability of continuing education (Gose, 1999), these revenue streams are nearly always an amount that is less than the cost of the operations that they are meant to support (Bok, 2003).

Endowment capital, and its resulting income, has grown rapidly for universities that have the strongest reputations, but in general, the benefits have been unequal, enriching only a few institutions. In addition, the demands on these funds are widespread and, while their benefit to the richest institutions is significant, the benefits to most universities are significantly diluted (Geiger, 2004). A signal that RIUs believe that philanthropy can be a more substantial revenue growth area is the vigorous effort being made to generate funds from philanthropic sources. Yet, despite efforts, its proportionate share of RIU total revenue has not grown significantly. Of 27 RIUs, philanthropy comprised only 6.3 % of their 2005, 2006, or 2007 total revenue and less than 3.5 % when the top five institutions are removed (Annual Reports and Budgets, 2005, 2006). At best, philanthropy must be considered to be speculative as a major revenue category.

Service revenues have grown rapidly, but the question arises as to how many hospitals and coffee shops the typical RIU can or should operate. In many cases, hospitals that are part of or that are affiliated with medical schools operate so autonomously from the rest of the university that there is little financial accretion. In addition, hospitals can be risky enterprises and, when the term *profitable* is used, it refers to whether the activity generates a margin contribution for the host university that is beyond its own direct and variable costs, or whether there are positive externalities that befall other parts of the institution. In this regard, affiliated hospitals can help an RIU generate research funding and enable physicians and other personnel to be cross-assigned. In these cases, affiliated hospitals can augment institutional reputation, the halo effect of which can positively impact the RIU. However, most arguments suggest that, on balance, hospital affiliations do not provide a net benefit to the host institution (Clark, 1998; Feller, 2000).

A somewhat similar story describes RIU sports programs, where revenue at some institutions is large and growing, especially in the cases where an RIU fields National College Athletic Association Division IA teams. However, "[a]lmost all inter-collegiate sports require a subsidy from the parent institution's discretionary funds" (The Center, 2003, p. 20). At the same time, alumni are attracted to the sports programs of their alma mater which often manifests in increased philanthropic activity. Finally, sports programs are not core to the mission of RIUs and, indeed, some argue that they conflict with or that they divert resources from core academic values and operations (Bok, 2003). In light of the type of intermingling that occurs between RIU sports programs and academic programs, a case can be made that sports programs do not contribute significantly directly or indirectly (reputationally) to the profit of RIUs. As such, the proportion that sports programs represent of an RIU's total revenue is not highly relevant to this argument.

One of the reasons that research revenue is important to RIUs is that it has grown continuously, in real terms, over the very long term. Between 1970 and 1997, the real annual rate of growth of research revenue in colleges and universities was 5.7 % and then accelerated to an even faster growth rate in the subsequent 6 years (Jankowski, 1999, 2005). Relatively constant long-term growth of research revenue increases the likelihood that this trend will continue in the future. Predictability is important for RIUs because it significantly mitigates the systematic risk (Bank for International Settlements, 2001) associated with investing in research capacity. In other words, an investment in an environment where the total value of potential revenue is unproven or unstable will be deemed riskier, ceterus paribus, than an investment in an environment where the market size is, based on long-term history, less volatile (Ross, Westerfield, Jordan, & Gordon, 1999). With systematic risk reduced, RIUs are more free to focus on operational excellence, which includes hiring the best faculty possible, buying the best equipment, and creating an environment that maximizes quality and celebrates achievement.

In order to describe the second reason that research revenue is important to RIUs, it is useful to acknowledge that universities operate in various markets. University involvement in markets is more thoroughly discussed elsewhere in this thesis; it is a topic that has been discussed in the literature for decades and it is a notion that is widely accepted in many circles in the study of higher education (Teixeira, Jongbloed, Dill, & Amaral, 2004). In the context of this argument, the *research market* is defined as the total value of research funds that are available to postsecondary institutions in the United States in any given year, or in an otherwise defined period. Likewise, the *market for students* can be described as the net value of all student dependant funds that are available to postsecondary institutions in any year, or in an otherwise defined period.

The research market provides a better opportunity for revenue growth than the other major markets in which RIUs are engaged. This is because markets that are the largest and fastest growing provide better opportunities for growth than markets that do not contain both of these attributes (Hedley, 1976; Henderson, 1972). The preceding revenue descriptions suggest that state appropriations, while continuing to be a large proportion of public university revenues, will not be a growth area. Tuition revenue growth rates are likely to slow if affordability increasingly constrains access and endowment revenues are, as yet, an unproven source of long-term revenue growth. In addition, endowment income remains a relatively small proportion of revenue for most RIUs (Annual Reports and Budgets, 2005, 2006). Service revenue, which at some RIUs is large and fast growing do not, on balance, generate net benefits to their host institutions, either financially or strategically. This should not be interpreted to suggest that tactical benefits are not important. That is, state-of-the-art residences and fitness facilities might help attract students, but ultimately they only contribute peripherally to the academic core, perhaps even detracting from it.

Research revenue represents a large and fast growing source of revenue for RIUs and comprises a large proportion of the revenue of all RIUs. Given this circumstance, the pursuit of research revenue must be a central goal of every RIU, and a review of their mission statements and strategy documents confirms this to be the case (Mission Statements, 2004-2007). Since the generation of increased research revenue is a central goal of every RIU, they are forced to compete with each other, and with every other university that is pursuing research revenue, for the available funds. As research revenue became increasingly central to the mission and strategy of universities, and as research revenue became a larger proportion of overall university revenue (Shackelford, 2004), the challenge for RIUs was to protect existing research revenue while finding new ways to enhance research revenue growth. This collective activity has contributed to an intensification in the level of competition in the research market. This intensification is well documented (Slaughter & Rhoades, 2004).

The third financial reason that research revenue is important to RIUs would be considered by some as controversial in that it broaches the question of whether research is a profitable or a money losing activity for RIUs. The position of this thesis is that, specifically in the United States, research can, and in many cases does, produce net gains for universities. The arguments supporting this position are first, that there is wide variability in the productivity of researchers, second, that economies of scale are available to universities engaged in research (Cohn, Rhine, & Santos, 1989; Patterson, 2000; Rothschild & White, 1993), and third, that this is not, from an economic perspective, a perfectly competitive market. While any of these conditions are sufficient to substantiate the claim that profits are available in this market, given that all conditions exist, the likelihood that profits are available to universities that operate in the research market is very high. The following example demonstrates variability of researcher productivity.

Comparing the variability of researcher productivity of the faculty at the University of Arizona and Ohio State University exemplifies one source of profit that universities can earn from conducting research. In fiscal 2004, the average value of federally financed research performed per full-time equivalent (FTE) faculty at Ohio State was approximately $88,900 (Ohio State University, 2005) and was $175,400 at the University of Arizona (2006). Given an indirect cost recovery rate of 50.5 % at the University of Arizona (2006) and a rate of 49.5 % at Ohio State University (2005), the University of Arizona collected $29,432 more per faculty than did Ohio State in that year. Since the University of Arizona has 1613 FTE faculty, it generated more than $47 million more in gross profit than it would have had it realized Ohio State's gross profit ratio. Compounding this difference is that Ohio State paid its professors, associate professors, and assistant professors $108,000, $72,000, and $60,000, respectively, for 9 months of the 2004-05 academic year, while the equivalent rates at the University of Arizona were $95,000, $67,000, and $60,000 (NCES, 2004-05). This means that the gross profit earned from research, expressed as a ratio of dollars of wages paid, was even greater than the ratio expressed in terms of the number of faculty. From the perspective of researcher productivity, it is likely that the University of Arizona's research business is more profitable than Ohio State's. Given that Ohio State had 2,992 FTE faculty, it lost potential earnings of several tens of millions of dollars.

A scenario that demonstrates how economies of scale in a university's research operations can generate profits is one in which the productivity of researchers across institutions is equated but where the relative cost of supporting research differs. Many universities, particularly RIUs, track process indicators such as the Number of Protocols Processed Per Full-Time Employee (FTE), 2004, (Pennsylvania State University, 2004); however, the measure that would more accurately describe the profitability of the research business is one that measures the actual indirect cost of research in a given period, divided by the number of funded research projects that occurred during this period. This calculation produces the average indirect cost of research per funded project. Either calculation demonstrates the point since, where the productivity of researchers is similar (i.e. in the instance where the gross profit earned per research project across institutions is similar), those universities that have a lower value of indirect cost per project are enjoying higher profits. For greater certainty, economies of scale are exhibited when the costs required to support operations is inversely proportional to the volume of operations undertaken. Studies indicate that this relationship exists (Cohn et al., 1989; Patterson, 2000).

The notion that the research market is not perfectly competitive is supported by Massy's (1990) assertion that the marginal revenue curve in this market is downward sloping. This is a consequence of excess capacity resulting from the reality that research capacity, once it has been put in place, is sticky (Massy, 1996), because it is not readily removed. The practice of selling pre-emptive rights to commercialize research is, in essence, a discount to or improved terms in favour of a purchaser of university research. Conducting research for a reduced price is a manifestation of the market attribute to which Massy refers. A declining marginal revenue curve also indicates a negatively sloped price curve. Since perfectly competitive markets display horizontal marginal revenue and price curves, this market is likely not perfectly competitive. All alternative economic market archetypes indicate that profits are available for the market participants.

Variability in researcher productivity, variability in relative indirect costs (economies of scale), and the notion that this is not a perfectly competitive market demonstrates that profits are available to universities that operate in the research market. This might explain part of the reason why RIUs are so anxious to build this part of their operations, but it is not the whole story.

The strategy oriented argument, demonstrating the central role that research plays in RIU success, is described by exploring a series of cascading events that began after World War II when "the federal government built on its wartime experience by providing the mechanisms and the money to support a massive program of basic research on the nation's campuses" (Bok, 1982, p. 63). One of these mechanisms was the establishment of panels of experts, or peers that reviewed and selected the projects that were funded. The peer review process was considered rigorous and only provided funds for the best proposals. As a consequence, winning research awards from the federal government was regarded as very prestigious, and it was presumed that only the best researchers won them.

The revenue associated with these awards was one of many benefits that befell the institutions that were so engaged. The best students soon began seeking out the most prestigious researchers with the expectation that the quality of their training would be superior and the resulting employment prospects after completing their program would be significantly enhanced. Indeed, this is what occurred. Graduates trained by prestigious researchers received more and better employment options than others, and this further enhanced the reputation of award winning researchers. Very often, researchers that were trained by the first generation of prestigious researchers became high achieving award winning researchers themselves (Garvin, 1980). Winning federally funded research became synonymous with prestige.

Other prestigious and aspiring researchers of like minds were drawn to departments that they perceived provided the best opportunities to pursue their interests. Departments that were developing clusters of successful researchers and robust graduate programs began attracting funding, which built significant research infrastructure that rapidly expanded capacity.

A virtuous cycle arose around individual departments, whereby groups of high performing researchers, the most promising and capable students, state-of-the-art infrastructure, increasing administrative enthusiasm, and an increasing inflow of research funds mutually reinforced to establish a prestigious reputation for the department. In parallel, institutions that housed these departments gained credibility with the federal funding agencies as capable managers of research, which, in turn, improved the prospects for researchers in other areas of those universities to win research awards. Successful departments set quality standards to which all faculty who were interested in winning research funding began to aspire.

The term *halo effect* is often used to describe how the rising reputations of individual departments washed over entire institutions; this undoubtedly explains part of the phenomenon. Another factor in the rise of the reputations of certain institutions unfolded as faculty noticed the prestige associated with winning federal research funds and the career benefits that accompanied that prestige. Many wanted to participate and it is significant that the professional reputation of university faculty is still based primarily on their research output. Furthermore, it seems reasonable to assume that the faculty movement to federally funded research must have happened more intensively at universities where this activity was already underway, since, by 1972, when the NSF first began reporting research performance for individual colleges and universities in the United States, there were clearly winners and losers. That is, there were wide variances in the value of research performed among universities, and the amount of research performed was not concentrated in a single discipline (NSF, 1972). The largest performers were also institutions where research was being done in many disciplines.

Institutional reputation became based, to a great extent, on the federally funded research performance of the faculty. This relationship has been continually reinforced, and many now believe that research performance is the best reflection of institutional reputation (Altbach, 2004; Geiger, 2004; Lang, 2005). To state this point explicitly, "The resulting marketplace for research was both very large and very competitive. In this market, research universities had to succeed if they were to enhance their reputations…" (Zemsky et al., 2005, p. 56).

Universities are prestige maximizing institutions because their reputations impact so many aspects of their current and potential success. The exemplar of this is the relationship between institutional reputation and student demand. In general, an institution with a prestigious reputation will receive a larger number of admissions applications in relation to its available places and a greater proportion of the applicants will be higher quality (Zemsky et al., 2005). Such an institution will become more selective about the students it admits which can further enhance reputation as well as contribute to increased tuition revenue (Ehrenberg, 2002). Greater selectivity also enables an institution to increase the quality of its student body, an attribute that attracts higher performing faculty and researchers, all of which tends to enhance institutional reputation. Higher performing faculty will perform more research, further strengthening reputation. Finally, the better an institution's reputation, the greater will be its philanthropic income (Caton, 1991).

Whereas a virtuous cycle initially arose that was both centered on and driven by research performance at the department level, a wider virtuous cycle grew out of the department to encompass the entire institution. In harmony with the halo effect, this is the mechanism that established research performance at the centre of the success of many colleges and universities engaged in research, but especially RIUs (Slaughter & Rhoades, 2004).

It is the objective of every RIU to generate as much revenue as possible. Revenue growth is stimulated by maximizing institutional reputation and, while it may be an exaggeration to state unequivocally that research intensity results in a prestigious institutional reputation, given the aforementioned mechanism, the widespread use of research performance as the primary indicator of institutional prestige, and that so many important authors reference this relationship, it should be the strategic priority of every RIU to generate as much research revenue as possible. As noted, this is the case. This thesis describes a method that informs the strategic processes that RIUs can use to increase their research revenue. This supports the arguments that help answer the central question of this thesis, that being, whether the research strategies of the RIUs produce outcomes that reflect those strategies. In the process, the inefficiencies of the research programs of the RIUs are exposed, provoking many types of accountability questions that were heretofore unaskable.

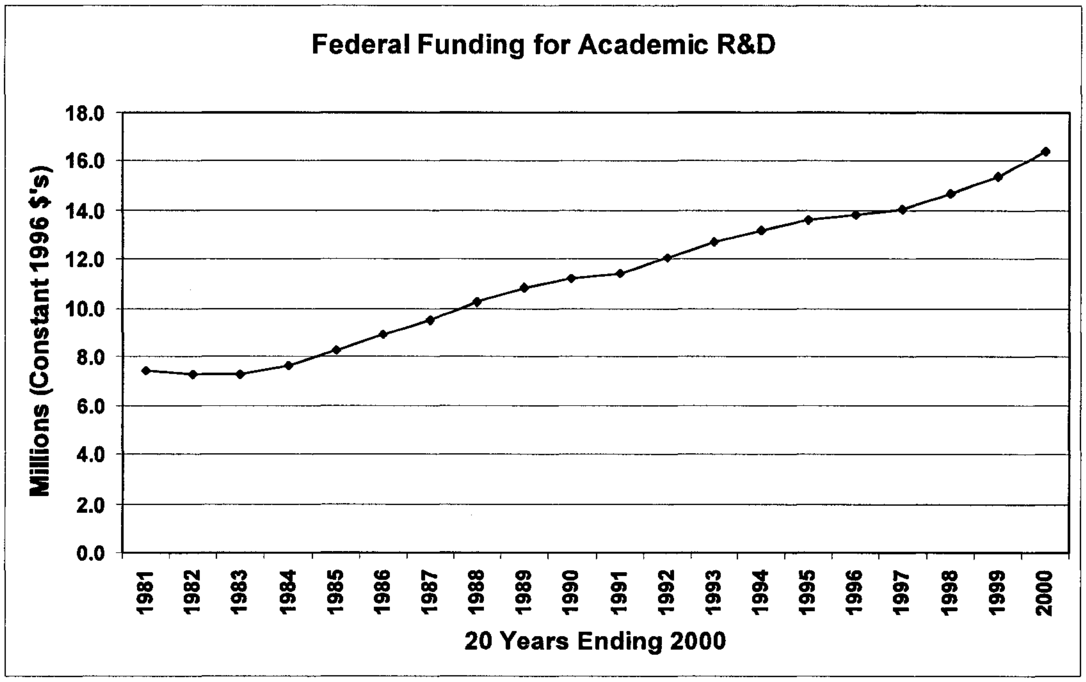
The financial and strategic arguments describe why research can be considered to be at the centre of long-term RIU success. However, research is financed by the federal government, by industry, by state governments, and by the institutions themselves (Lang, 2004a). This thesis argues that it is the federally financed component of research that is at the core of the financial and strategic arguments, since it meets all four of the following conditions.

The *first condition* relates to the degree of plurality in a system of research funding to the extent that it provides any researcher in any institution the ability to submit proposals for support through a national interinstitutional bidding process. Layered over this attribute is a structure in which all submissions receive equal consideration through what Massy (1996) refers to as "a powerful market mechanism, peer review…" (p. 43). Such a system promotes the widest possible range of exploration while creating intense competition, a combination of attributes that strengthens the system as a whole (Ben-David, 1972; Birnbaum, 1983). In addition, David Dill's (1997) article confirms the view that the market is highly informed, an attribute that enables full participation from a highly equitable base. The national open bidding condition is a market attribute that serves to strengthen the system by forcing each participant to continually improve. To compete in this environment, RIUs strive to create the best conditions for research and recruit the best students and the most prestigious, accomplished, or promising faculty that are within their capabilities (Clark, 1992). These are the factors that enhance research performance which, over time, results in strengthening an institution's reputation (Geiger, 2004; Lang, 2004b). This system most closely describes that segment of research funding that is provided by the federal government. Internally allocated resources are a source of research funding that does not meet the open bidding condition since these funds are rarely available to other than the home institution. Likewise, state sponsored research funds are almost never available to universities outside of the home state.

Industry funding is not a monolithic source of funds. A significant proportion of industry sponsored research is conducted by the largest companies close to their headquarters (Statistics Canada, 2000). The proximity factor disqualifies most RIUs from bidding on a large proportion of available industry sponsored contracts. In addition, industry sponsored research is almost entirely applied (Etzkowitz et al., 1998) and most faculty are not engaged in research of this type (NSF, 2003b). As such, the proportion of industry sponsored research that is open to national bidding is likely a small portion of total industry sponsored research funding, which, in turn, only represented 7 % of the entire value of research performed by academic institutions in 1996 (Jankowski, 1999). As a consequence, industry funded research does not meet the open market condition.

A commitment to long-term research is foundational to RIUs, and the *second condition* relates to the risk that universities have to take when they make investments in the capacity that supports their research, such as tenured faculty or fixed infrastructure that can take decades to yield a full return. As earlier described, long-term market predictability significantly reduces the risk of making these investments since the offsetting revenue can be reasonably estimated. With systematic risk substantially mitigated, the major challenge for RIUs becomes the more controllable operational risk, which relates to the set of actions and decisions that are made in an effort to earn a share of an existing market.

Federal financing of university research represents a very predictable and dependable source of research funding. Figure 1 demonstrates the constant growth of federal funding to colleges and universities during the 20 years ended 2000. With few exceptions, notably in 1982 where there was a slight decline and in 1996 where there was no growth, the federal government has continually and constantly increased funding for research at colleges and universities. This is why Robert Rosensweig remarked in 1992 that the federal government has been the sustaining source of funds upon which America's public research capacity and capability has been built and within which America's RIUs compete.



Source: NSF (2000b).
Figure 1. Trends in federal funding for research for academic institutions.

Funding from industry must be considered as volatile if for no other reason than businesses that supply the funds are themselves volatile. The stock markets exemplify this where corporate decisions are made from quarter to quarter and long-term planning is only valid as long as the short-term results support the plan. In addition, businesses are not likely to undertake research projects whose duration spans more than a couple of years (Feller & Roessner, 1995) and, as such, industry sponsored research funding is not sufficiently stable to enable RIUs to make long-term investments in research capacity of a substantial nature. This is not to say that some industry projects might satisfy an RIU's risk threshold for some types of investments or that some industry projects bridge such investment risk at the margins, but in general, industry sponsored research does not meet the second condition.

While the foci of state sponsored research funding can change abruptly, most often when new administrations come to power, these changes more often reflect the relatively slow evolution of local economies. For this reason, it can be argued that state sponsored research does meet the second condition. Finally, self-financed research, even with internal competitive pressures (Massy & Zemsky, 1994), should be regarded as meeting the second condition.

The *third condition* asks what proportion of an enterprise's revenue stream constitutes a strategic imperative. One method of approaching this issue is to speculate what might happen in a disaster scenario. That is, if a portion of an enterprise's revenue stopped flowing, what would be the consequences?

In 2000, research funding from industry was 6.9 % of all research performed by RIUs (NSF, 2000d). These funds were dispersed across a range of disciplines, although there was a degree of concentration in the life sciences fields. Notably, industrial sponsored research comprised a proportional maximum of 30.8 % of Duke University's research performance and as little as 0.9 % of the University of Chicago's in 2000. While this range makes it difficult to generalize, it can be suggested that, in a disaster scenario, an RIU losing not more than 10 % of its total research income would not have to make dramatic realignments to its total faculty complement or overhead structures. Thirty-two of the 39 RIUs meet this criterion. This threshold also seems reasonable in instances where industry sponsored research comprises not more than 10 % of research performance in several departments within an RIU. In cases where industrial sponsored research comprises more than 10 % of an RIU's research performance, the impact becomes a question of degree. In these cases, in the years 1988 to 2002, industrial sponsored research never exceeded 55 % of the amount of the federal research performed at any RIU.

A similar scenario can be described for state sponsored research, which comprised 8 % of total research expenditures in academic institutions in 1996 (Jankowski, 1999). As a consequence, it can be stated with a reasonable degree of confidence that neither of these two funding sources meets the third condition. However, at an average of 68 % of RIU 2000 research performance (NSF, 2000d), the same cannot be said for federally financed research. Indeed, if not for federal research funding, there would be no RIUs as we know them.

The *fourth condition* is an attempt to determine which research revenue streams contribute more directly, and to the greatest extent, to an RIU's virtuous cycle, to its strategic success. In other words, if one research revenue stream helps establish an RIU's national and international reputation to a greater extent than other streams, then it should be considered as more strategically important. Given that state sponsored and internally allocated research streams have already been disqualified from inclusion in the research market, they will not be considered at this point. The determination of whether federally financed or industrial sponsored research revenue streams meet the fourth condition relies on the criterion of whether the research is peer adjudicated, because this is the common denominator upon which international reputational comparisons are made (Liu & Cheng, 2005; O'Leary, 2004; The Center, 2003). Simply put, industry sponsored research does not meet this condition, and federally sponsored research, by virtue of the method used to award funding, is peer adjudicated.

A secondary confirmation that industry sponsored research does not contribute to the strategic success of an RIU to the same extent as federally financed research is that there is only a .33 correlation between the value of industrial sponsored research that was performed by RIUs in 2000 and the total value of research performed by the RIUs in that year. This contrasts with a .89 correlation between the value of federally financed research performed by the RIUs in 2000 and the total research they performed in that year (NSF, 2000d). Given that federally financed research expenditures comprised 58.2 % of all research performed by colleges and universities in 2000 (NSF, 2000d), the federally financed portion influenced overall performance substantially beyond its proportionate share.

While these four conditions are not meant to suggest that research income from all sources is not important or that investments in capacity do not enable competing for multiple income streams, the conditions do provide a basis upon which federally financed research should be considered to be at the core of the earlier described virtuous cycle. An expanding virtuous cycle will result in overall revenue growth, particularly in the areas of tuition, state appropriations, philanthropy, and research, and as a consequence, all institutions of higher education want to generate as much federally funded research revenue as possible. RIUs can establish long-term growth in revenue by ensuring that they are maximizing the amount of federally financed research that is being performed on their campuses at all times. Indeed, research intensity constitutes a competitive advantage that research intensive universities have over other colleges and universities. Their special status, or perhaps more appropriately stated, as elite status, in many important rankings recognizes their success in leveraging this advantage.

This study uses some of these rankings to define a subset of 39 of America's most research intensive universities, which have been and will continue to be referred to as *RIUs*. Specifically, RIUs are those universities that have been members of the Association of American Universities (AAU) continually from 1988 to 2002 inclusive (AAU, 2005), which, according to the NSF, were among the top 100 largest recipients of federal research funding from 1988 to 2002 inclusive, and which were categorized by the Carnegie Foundation as a Research University I in its 1987 and 1994 surveys and as Doctoral/Research University – Extensive in its 2000 survey (Carnegie Foundation for the Advancement of Teaching, 1987, 1994, 2000). The fourth and final condition that defines an RIU is a mathematical calculation that ensures that qualifying universities reported their research performance with sufficient consistency from 1988 to 2002. This calculation can be found in Chapter Four (see Definition 9) of this thesis. The list of RIUs can be found in Appendix A.

If the hypothesis that federally funded research is at the core of the long-term success of RIUs is correct, or even if it is mostly correct, then RIUs are strategically bound to generate as much federal research funds as possible. As a strategic imperative, it is of great concern that research is less well understood, as informed by measurements of performance, than teaching and other RIU operations. Compounding this concern is the reality that the amount of federal funds available for research at colleges and universities is less than the demand for those funds. Limited funding forces universities to increasingly compete with each other, and declining rates in the proportion of successful federal funding proposals is evidence of this trend (Newman & Couturier, 2001).

Competition for research funding is fierce and intensifying among universities in the United States (Feller, 2000; Geiger, 2004).

This thesis improves the understanding of the research function by presenting performance indicators that expose the research operations of individual RIUs and of the federal government in a heretofore unobserved manner. In addition, these performance indicators are used in a model that informs the resource allocation decisions of the RIUs. By applying the following principles and using them in the methodology described in Chapter Four, the research operations of individual RIUs will be more completely understood and, at the same time, institutional accountability will be enhanced. In addition, by using the results of this methodology, RIUs will improve the efficient use of their resources. If all universities use this methodology, the entire system will become more efficient.

Competition and Strategy

"...any organization with competitors, with aspirations to greatness, or with threats of decline has come to feel the need for a strategy..." (Keller, 1983, p. 75).

"...strategic planning is here to stay. [This] assertion is shared by most authors today on strategic planning for higher education" (Chaffee, 1985, p. 134).

"...where properly conceived and carried out, the application of the strategic concept leads to improved institutional vitality, which – in this report – is defined as a combination of success and prosperity: *Success* in the mission fulfillment with the acquisition of sufficient resources for *prosperity*" (Cope, 1987, p. 1).

"...objectives alone are insufficient...for guiding the firm's strategic reorientation..." (Ansoff, 1988, p. 75).

"In today's competitive environment, leaders in higher education must think strategically and globally to survive" (Alstete, 1995, p. 5).

"Operational effectiveness and strategy are both essential to superior performance, which, after all, is the primary goal of any enterprise" (Porter, 1996, p. 1).

"Strategic thinking and effective leadership are essential to the pursuit of research competitiveness, as discussed by Irwin Feller and Harry Lambright in previous chapters" (Hauger, 2000).

Yet, "After reviewing the literature and consulting with knowledgeable colleagues, we have concluded that a convincing, generalizable empirical study on the efficacy of strategic planning in higher education has yet to be published" (Dooris, Kelley, & Trainer, 2004).

In order to effectively ensure their long-term success, RIUs must perform an increasing value of federally funded research. Intensifying competition for these funds is the primary factor preventing the achievement of this result. Prudent management demands that rigour be brought to bear to ensure that any competitive positioning be the consequence of deeply studied and ongoing consideration.

In competitive environments, strategic processes are most often engaged to inform resource allocation decisions. A review of the published strategy statements of the RIUs as well as the descriptions presented earlier suggests that RIUs do not use strategy sufficiently to maximize the competitive performance of their research operations. Indeed, given the current state-of-the-art of performance indicators related to research, RIUs are not able to be as informed in their resource allocations that support research as they are in their teaching and other operations, or as many similarly sized organizations competing for similar amounts money in other sectors of society (Zemsky, 2000). "Strategic planning at most universities today is primarily a matter of implementation and revision, not formulation" (Feller, 2000, p. 14). This thesis improves on the ability to formulate research strategy in RIUs by introducing various performance indicators that reveal the strategic research priorities of each RIU and of the federal government. As well, a quantitative indicator is introduced that measures the research performance, and by extension, the institutional strategic direction of each RIU. The research strategies of the RIUs are then correlated with the strategic outcomes to reveal which strategy is more likely to yield success. In the process, inefficiencies in each RIU's research operation are revealed.

Strategy presumes a theatre of operations. Economists, organizational theorists, strategists, and business managers all regard their theatres of operations in terms of markets. There is a growing recognition that colleges and universities are economic entities engaged in many markets, some of which include the research that is performed by colleges and universities (Dill, 1997; Feller, 2000; Geiger, 2004; Johnes, 1997; Massy, 1990; Teixeira et al., 2004; Tornatzky, 2005; Zemsky, 1997; Zemsky et al., 2005). Many of these markets overlap, and some can be more discretely defined. In this thesis, the academic research market (ARM) is defined to include the total of all federally financed research and development expenditures performed by colleges and universities in the United States, as reported by the colleges and universities that received those funds, regardless of which federal agency provided those funds, and as published annually by the NSF (2005c). A notable omission from this definition of the ARM is federally funded research in non-science and engineering fields, including Business and management;

Communications, journalism, and library science; Education; Humanities; Law; Social work; Visual and performing arts; and Other non-S&E fields. While it is assumed that the exclusion of these fields does not change the results of this research, it is worth noting that, in 2005, federal research funding to science and engineering fields exceeded $25.7 billion and was less than $1.0 billion to non-science and engineering fields (NSF, 2005b). The market is comprised of the federal government, which is the sole financier of research (the principal) and hundreds of universities that perform federally financed research (the agents). For reasons previously described, the ARM does not include research that was funded by sources other then the federal government, even though some of the same human and fixed capital spans multiple research service deliveries. The 39 RIUs are a subset of all colleges and universities that conduct federally financed research. They represent more than 45 % of the value of the market (NSF, 2000a), most of the largest institutions, and compete on the same basis and for the same pool of funds as every other university. They are believed to be a proxy for the entire ARM, with the proviso that there is no absolute assurance that non-RIUs will perform in the same way or produce the same results, when used in the model presented in Chapter Four, as the RIUs.

There is a long list of scholars and pop-culture writers who have forwarded definitions of strategy. One of the most widely cited scholars on the subject is Henry Mintzberg. In his 1972 paper entitled "Research on Strategy-Making," Mintzberg offers his definition as "*a pattern in a stream of significant decisions,* [italics in original] (And we define a decision as a specific commitment of resources…)" (p. 90). He goes on to explain that this definition provides for strategies "both as planned, a priori guidelines and as evolved, a posteriori results of decision-making behaviour" (p. 90).

This definition is relevant to this thesis on several dimensions, including the notion that strategy unfolds over time and that resource allocation decisions need not have been made according to any predetermined plan; rather, they could have been made one by one, balancing the factors that existing at that moment, the patterns observable only in hindsight. At any given time, a strategy is realized from a combination of intended, deliberate and emergent strategies (Mintzberg, 1985). In the context of RIUs, this means that there need not have been a proactive research plan for a research strategy to have actually been realized. The term *proactive* refers to a long- or medium-term strategic plan that identifies a market objective and delineates how the organization intends to achieve it. Such a plan would be expected to contain significant competitive analyses and identify how resources would be assembled to meet the desired outcome (Bryson, 1988). The reality of RIU research strategies is that their reactive and opportunistic nature is highlighted by foundational statements such as Creating conditions that are conducive to research and Hiring the best faculty possible. Nearly all of the research strategies of the RIUs contain similar statements.

Of even greater significance for this study is the notion that strategy is comprised of a series of resource allocations that have an operational consequence, a realized strategy (Mintzberg, 1994). If either the resource allocations or the operating results of those allocations can be tracked, then a university's strategy can be determined (Mintzberg & Rose, 2003). In the case of university research, it is assumed that investments in research capacity result in the production of research performance. Since investments are resource allocations, and since investments in research capacity results in research performance, tracking research performance can be used to determine research strategy. This reflects the methodological principles used by Mintzberg and Rose (2003) in their McGill study.

While there is currently no universal method used to measure success in the ARM (Dooris, Kelly, & Trainer, 2002; Feller, 2000; Hauger, 2000), two factors that most commonly underlie these measurements are academic output, such as faculty publications, and the monetary value of research performed. For the purposes of this analysis, the use of academic output to measure research performance presents several interrelated complications. One complication is that there is no reliable method of converting the full range of academic production into a precise value. The labour market for researchers is unreliable in that it is likely to produce different values for researchers who have similar academic production records. The asymmetry of the labour market for researchers may be due in part to the limitations of the quantitative data that are available through publication and citation records (Thompson Corporation, 2007). Some of these limitations include the incomplete value that publication records attribute to conference presentations, coauthorships, or the creation of intellectual property. Even limiting the publications data by narrowing the time periods or by narrowing the journal selection leaves many confounding measuring factors unresolved (Toutkoushian, Porter, Danielson, & Hollis, 2003).

Another complication is exemplified when a federally funded research project is completed and its results are published. The resulting prestige, which is realized in future financial benefits, is attached to both the performing researcher and to the institution. However, the historic costs and revenues are recognized entirely by the institution. The part of the future benefit that is attached to the researcher is mobile to the extent that it follows the researcher where-ever he or she goes. When a researcher leaves a university, the institutional goodwill that accrues from the prestige of the research is diminished, and the profit that might have been earned by the university from that production factor is lost. The extent of loss is unknown. Given the inconsistencies of the labour market for researchers, it is not known whether the value lost by the institution is equal to the value gained by a prestigious researcher. What is known is that prestige is at least partially exposed by citation counts. Prestige enables the researcher to demand better terms of employment and increased research support, and the institution can expect to accelerate its virtuous cycle. While neither publication records nor the monetary value of research performed adequately captures the full social and economic impact of the underlying research, at least research expenditures data enable a definitive accounting. In addition, federally funded research expenditures are reported in annual periods, which can be used to generate accurate return on investment measures. Because there are no specific time periods between when research is conducted and published, no precise accounting or return on investment results can be generated by using publications records. From the perspective of measuring institutional research performance and developing institutional strategy, publications records are less useful than are research expenditures.

In addition to the inability to establish definitive valuations for research through publication records, there are several other reasons that using federally funded research expenditures to measure success in the ARM are more appropriate for use in this study. One reason is a practical question of convenience. NSF data are disaggregated by discipline, by performing institution, and by every annual period required by this thesis. Citation counts present no such aggregation.

A second reason that this thesis considers research expenditures as the indicator used to measure success or failure in the ARM is that all RIUs, and most other universities, express research performance in terms of federally financed research expenditures. RIUs use these data for internal purposes to compare their research performance longitudinally and horizontally across divisions and disciplines. For example, Ohio State University provides a 10-year history of its total research expenditures and expresses gratification in the growth it has achieved (Ohio State University, 2006). In addition, most RIUs use research expenditure statistics to compare their performance with their peer groups or in a national ranking. As earlier noted, Pennsylvania State University, an advanced reporter, compares its research expenditures with the leading national competitors longitudinally in each NSF field of research in which it is strategically interested. As Pennsylvania State University's position advances on each national scale, it considers itself as progressing towards its strategic objective, which is to increase research performance. It is the strategic objective of every RIU to generate as much research revenue as possible. By inference, and in the very words of the RIUs, increasing research expenditures is an indicator of an RIU's advancement towards its strategic objectives. The universal use of research expenditures by the RIUs supports its application as a strategic indicator in this thesis.

The final reason to consider research expenditures as the most appropriate indicator of research performance in this thesis is because it is used as such by many important external reporters of academic research activity, including the NSF (2003c) and The Center (2006). Even the federal government's research award decisions are based, to a significant extent, on the research capacity of the home institution and the research performance history of the applicant researcher (NSF, 2007b; Office of Management and Budget, 2004; Teich, 2000). The change over time in the value of an RIU's research expenditures is an input indicator that is used to determine whether new research will be awarded. As such, current research expenditure data can be considered as an output indicator of the historic patterns in the values of an RIU's research performance (Johnes, 1997). That is, while the measurement of the output of research could include publication records, it must include current and historic federally financed research expenditure data if reliable quantitative valuations are to be established.

The definition of the ARM, which is comprised of all federally financed science and engineering research performed by colleges and universities, and the use of research expenditures as the basic unit of research performance, enables an approach to measuring whether an RIU is progressing or retreating in the ARM. As a reminder, advancement or decline in the ARM has strategic implications given the central role that federally financed research plays in institutional success. Indeed, advancement or decline in the ARM should be considered as a strong indicator of the direction of institutional reputation. Advancement in the ARM is a primary strategic objective of every RIU. This is the reason why answering the thesis question is so vitally important. If strategic advancement in the ARM strongly impacts institutional success, any strategy that improves the probability of success in this market must be pursued. A decision to pursue a different strategy should evoke accountability questions.

The most current methods of measuring progress in the ARM are by comparing total research expenditures and by using ordinals to establish rank within a peer group or in a national ranking, or both. Research activity is generally presented on tables that list an institution's peer group's comparable data, in descending order of research performance. Quite often these tables present ordinals as well. The tables provide insight into the quantitative distance between the next and last institutions' research performance and its ordinal placement. For example, the reader can know that a university ranks fifth in its peer group, but is quite close to sixth or is being threatened by the fourth-place performer. When viewed longitudinally, it is possible to know whether a university has improved its standing within its peer group, and by how much. What is not known is whether the peer group has advanced or declined against the total ARM.

In some instances universities disaggregate their total performance and report research expenditures in specific disciplines. When RIUs report their data in this manner, the disciplines almost always correspond with the NSF's research divisions, which it calls *fields* (NSF, 2005a). Field data is presented in tables that provide insight into whether the university has advanced in the featured field or fields and, as a consequence, whether research performance in those fields has contributed to, or detracted from, the overall performance of the institution. In other words, where the rate of growth in a particular field was less than the institution's total rate of growth, that field dampened the overall rate of growth in research performance. What is not known is whether the peer group advanced or declined against the total ARM, against the specified field within the total ARM, or whether the level of research expenditures in the university's specified field advanced or declined against the total ARM.

In cases where the peer group is defined by a national ranking, further insights are available. For example, it can be determined that a university's federally financed research expenditures ranked 10th in value nationally. Where public and private universities are presented separately, a further distinction can be made. RIUs that present data in this manner will often attach ordinals to facilitate the reader's understanding of its national standing and, as noted above, when viewed longitudinally, advancement or decline can be observed. What cannot be known is whether the group of universities presented on the table, even if they are the nation's top performers, improved or declined against the total ARM. Evidence that the top performers were declining against the entire ARM was presented by Geiger and Feller (1995), and policy statements made by the federal government confirm that the government's research strategy includes broadening the reach of institutions that receive its research funds (NSF, 2006c, p. 3).

To definitively respond to the unknowns noted above, a performance indicator that relates research performance to the entire ARM, or to entire fields within it, in an objective, quantitative, easily understood, easily derived, and universally applicable manner, is required. In addition, the central question asked by this thesis is whether the research strategies of RIUs produce outcomes that reflect those strategies. The answer to this question is contingent on being able to measure the outcomes. In this case, the outcome is measured in terms of institutional performance in the ARM. To this end, this study uses the indicator Change in share of the ARM (ΔMS) to measure strategic effectiveness in the ARM and, because of the broader institutional impact of research, ΔMS should be considered to be the primary indicator of the direction of institutional strategic success as well.

Market share is not a new concept, although it seems to have found its way into higher education literature relatively recently. In particular, reference to academic research, market share, as a measurement of performance, is used regularly by numerous universities in United Kingdom in regard to how their participation in the Research Assessment Exercise has been or could be used to increase their share of their research market (Leeds University, 1998; The University of York, 2007). Geiger and Feller (1995) used ΔMS to interpret how the disbursement of federal research funding across academic institutions changed during the 1980s. The NSF frequently references ΔMS in its descriptions of total academic research revenues and how the mix has changed, with statements such as "This … was enough to stabilize the … decline in industry's share of total academic R&D funding…" (Britt, 2005, p. 1). A recent and closely aligned use of ΔMS was made by the University of Florida's The Center in its 5th anniversary report. "The Center primarily measures market share. For example, the federal research expenditures reported for each institution represent that institution's share of federal research expenditures" (Lombardi, Capaldi, Reeves, & Gater, 2006. p. 4).

Despite the foregoing examples, a review of the research related performance indicators published by the RIUs reveals that ΔMS is not in common use. Perhaps the reason has to do with concern about adopting a basis of measurement that is new or different from past practice. However, every RIU already references federally funded research data to measure performance internally and to compare its performance with other institutions. The RIUs clearly understand that federal support for academic research is a pool of funds for which they compete. Using ΔMS to determine their progress would be an accurate measure of success or failure.

Apart from higher education, ΔMS is a very important basis of measurement in virtually every industry and economic sector (Capon, Farley, & Hoenig, 1990). The use of ΔMS came into wide use after several landmark publications, including those by

Henderson (1972) and Hedley (1977), and later publications, including Buzzell and Gale (1987). Of course, this does not automatically mean that the same principles can be applied in the case of the ARM (Birnbaum, 2000). However, every RIU already accepts and uses every component from which ΔMS is derived in their current reporting methodologies. Adding ΔMS to RIU research reporting would be but a small step to take, yet it would help standardize the reports, increase the reporting accuracy, better articulate performance and efficiency to government (Altbach, 1985), and align RIU research reporting more closely with the measurement methods used in most other sectors of the economy. In situations such as academic research, where the consequence of success is critically important to the organization and where the current state of ability to adequately report is lacking, even coarse measurements are better than none. This is not to say that ΔMS is a coarse measurement tool. Indeed, it is a precision instrument when used appropriately, and this thesis demonstrates some of this potential. Mechanically, ΔMS is determined by calculating an RIU's market share at the beginning of a period, at the end of the period, and determining the percentage change that occurred (see Formula 1).

Formula 1: Calculation of Change in Market Share (ΔMS)

> ΔMS = 100 x [(market share at end of period - market share at beginning of period)/ market share at beginning of period]

The operation of ΔMS can be demonstrated by way of the example that follows: In 1990, the University of Colorado spent $116.394 million of federally funded research in science and engineering and, in that same year, the total value of the ARM was $9.636 billion (NSF, 1992-2004a). This means that the University of Colorado had 0.0121 part of the market (\$116.493 million divided by \$9.636 billion), or when expressed as a percentage, it held a market share of 1.21 % in 1990. Using the same data set for the year 2000, it can be determined that the University of Colorado's market share was 1.72 %. By applying Formula 1, the University of Colorado's share of the ARM grew from 1.21 % to 1.72 %, or by 42.15 % in the 10 years ended 2000. Using this method, the ΔMSs of every RIU can be produced and compared. In a second example, between 1990 and 2000, Johns Hopkins University's market share declined from 6.23 % to 4.53 % of the ARM. Its ΔMS was -27.29 %. A major hypothesis of this thesis, and one that has already been extensively argued, is that the more an RIU's ΔMS has grown, the more strategic success it has had in the ARM, and by inference, the greater strategic success the institution will have enjoyed, the faster will its reputation have moved in a positive direction. In this example, the University of Colorado has been more successful than Johns Hopkins University.

As an alternative to ΔMS, other methods of determining success in the ARM should be considered. One such method is to compare the values of the research performance of each RIU in a given year. In this scenario, the RIU that performed the highest value of research, which is also the RIU that held the largest share of the market, would be deemed to be most successful. If this were the case, then in 2000 Johns Hopkins University would be classified as most successful because it had a market share that was greater than any other RIU. From a strategic competition perspective, the institution that performed the greatest value of federally funded research might be able to gain advantage over rivals in a variety of ways that include leveraging the benefits of economies of scale into enhancements for its principals or manipulating market conditions.

In the ARM, economies of scale can be observed through process performance indicators, such as the cost of research overhead as a percentage of sponsored research income (Taylor & Massy, 1996). Once an RIU has assembled a sufficient quantity and quality of buildings, laboratories, libraries, human capability, and other related infrastructure, its probability of winning research funding is substantially greater than institutions that lack these assets in sufficient quantity and quality. RIUs are among North America's largest performers of academic research. Even though each RIU has achieved a high market share ranking and relatively large market share, none has achieved an absolute market share that is large enough to influence market conditions (Geiger & Feller, 1995; NSF, 1992-2004c). This thesis assumes that all RIUs have achieved a level of market power that is similar enough as to negate a market advantage that one RIU might have over another or others (Buzzell & Gales, 1987; Henderson, 1974). The market power attributable to large size in the ARM includes economies of scale and the reliable delivery of research results from a fiduciary perspective, from a quality of researcher perspective, and from an infrastructure perspective. This assumption does not negate the reality that all RIUs have a different combination of human and capital costs, or different indirect costs, of supporting their research operations. It only suggests that these differences are not great enough to create a strategic advantage. In addition, since no single RIU has a large enough market position to have any significant influence on market conditions, no RIU has a market position that requires an extra-ordinary effort to defend. That is, no RIU has a market position that is large enough to require the development of tactics that would be useful to advance it towards its market objectives. This does not mean that the size of the market share held by an RIU is not an important factor. Rather, it means that, due to the relatively high degree of fragmentation of the market, the size of an RIU's market share in any given year is not a strategic factor. This is the reason that the absolute value of research performance, or that a static measurement of market share, is not included as part of the strategic outcome indicator in this study.

On the other hand, and in the absence of a significant anomaly, having the largest market share in any given year indicates past success. Given that the value of research performed by all RIUs prior to World War II was relatively small, the RIU that had the largest share of the market in any subsequent year must have also had the fastest rate of growth during that period. However, since relative growth rates are subsumed within the calculation that describes ΔMS, the decision to exclude the static market share of RIUs as a strategic factor is further supported.

Another method of identifying a successful strategy could be to examine the value of research performance of RIUs for every year, or for selected years, that occurred within a given period. Using these measurements, success could be determined by identifying the RIU that has performed the highest value of research for the greatest number of years or, alternately, the RIU that has the highest mean performance. However, these indicators are not likely to provide additional insights than those previously described or than ΔMS.

In summary, the outcome indicator that is used in this thesis to measure RIU performance in the ARM, and by extension, institutional strategic direction, is ΔMS.

Another important scholar in the field of strategy is Michael Porter, who offers a definition as "the creation of a unique and valuable position…" adding, "If there were only one ideal position, there would be no need for strategy" (Porter, 1996, p. 5). While

Mintzberg tends to believe that emotions, such as intuition or inspiration, can play a substantial role in strategy formation, Porter (1985) more clearly emphasizes analysis and proposes his 5-forces model for this purpose. One concept with which Porter and Mintzberg agree is that strategic processes and outcomes are both influenced by and measured against the external environment, which includes individual competitors, the total market, and the general context in which the organization exists.

To Porter (1985) there are three possible generic strategies that an organization can pursue: the *low cost* strategy, the differentiation strategy, or the focus low cost or focus differentiation strategy. The low cost position is held by the organization that provides its product or service to the market for a lower cost than all other competitors or substitutes. In the ARM, universities do not compete by reducing their selling price. One indicator of this is the research overhead recovery rates that are negotiated between universities and the federal government, where the universities' objectives are to maximize their rates. If universities aspired to the low cost position, they would want the lowest possible rate. A second indicator is reflected in the tendency for the most experienced researchers to win a disproportionately large number of federal research awards. Since the most experienced researchers are usually the highest earners, and since the cost of researchers is part of the direct cost of federally financed research, relatively higher priced research is more frequently funded. Since this type of signalling (Spence, 2001) is a factor in the purchase decision, it is evident that universities would not normally benefit from adopting a low cost strategy.

If university research strategy is not low cost, then it must be *differentiation* or *focus* differentiation. The differentiated position is achieved when an organization provides a unique combination of products or services, or provides products and services that are similar to those offered by competitors, but does so in a unique and valuable manner. One example of a differentiation strategy in higher education is Bible colleges, which compete with each other in the segment of the market that desires a particular type of education. A similar example can be made in the case of universities that compete for engineering students. Massachusetts Institute of Technology not only has a significant capacity and research performance record in Engineering Sciences (NSF, 2002b) but is also ranked as number one by *U.S. News & World Report* (2005) as having the Best Undergraduate Engineering Program among schools in its category. Semiotic theory applies in the case of Massachusetts Institute of Technology, where a large proportion of people have come to associate it with the premier positioning in engineering education in America. Massachusetts Institute of Technology has effectively differentiated itself among engineering oriented schools by establishing its top tier reputation.

The third strategy is a specialization approach, in that the organization differentiates itself in a very narrow product range or a very narrow segment of the population. An example of a focus strategy in higher education is tribal colleges, each of which serves a specific native group. However, RIUs are comprehensive in their educational and research programs. Their research has matured to the extent that they have substantial federal research expenditures in several departments that span a range of disciplines, the values of which are captured in the corresponding NSF fields (NSF, 1992-2004c). This status suggests that RIUs do not pursue a focus strategy.

If RIUs are pursuing a differentiation strategy (Porter, 1985), then an important question is, How are they differentiating themselves; How is the differentiating strategy manifesting itself? As Porter might ask, What are the differentiated market positions of RIUs and What have they done, or what has occurred at an RIU that has resulted in a market position that is different than other RIUs or than other universities? The answer to these questions lies partly in the differentiated reputations of individual institutions. This is because, in higher education, market position is reflected in institutional reputation (Altbach, 2004; Brewer et al., 2002; Garvin, 1980; *U.S. News & World Report*, 2005). As a consequence of the earlier described virtuous cycle, reputation grows out of the research performed in the departments of universities. RIUs perform a substantial amount of research in several departments and, as noted earlier, these amounts can be observed in the research reports published by the NSF. An RIU's differentiated position will be reflected in that combination of NSF fields in which high levels of federal research intensity have been maintained over a period that is sufficiently long as to enable a reputation to solidify. The combination of NSF fields that determines an RIU's differentiated position is dependant on the specific NSF fields in which the research is being performed, the degree of intensity of the research, the length of time during which the high level of research intensity has been sustained, and whether the level of intensity has been increasing or decreasing. The variance in the values of research performed across the array of NSF fields of an RIU represents its realized strategy (Mintzberg & Waters, 1985).

One method of determining the realized strategy of an RIU is by applying *portfolio theory*. A portfolio analysis can be used to expose the research priorities of each RIU and of the whole ARM. In this thesis, this is a critical application, since, if the strategies of the RIUs can be observed, then they can be correlated with ΔMS to determine which strategies were most closely associated with a successful result. This is the general method used to approach answering the thesis question which is whether the research strategies of the RIUs produce results that reflect those strategies.

A portfolio is defined as a group of interests held by a single enterprise (Ross et al., 1999). Using a financial investment analogy, a portfolio of stocks can be described as a collection of different stocks held by an investor, where each distinct security represents one component of the portfolio. At a higher level, a portfolio can comprise stocks that are grouped by industry, or a portfolio can include classes of assets, such as bonds, currency, and real estate, where the investment in stocks is only one component of the portfolio. Operating entities often classify their products or services into groupings or portfolio components as a convenient method of comparing performance.

The notion of *portfolio* is not new to higher education (Foster, 1983). Universities often refer to their portfolio of programs, their portfolio of assets and facilities (National Association of College and University Business Officers [NACUBO], 2006), and the portfolio of investments in their endowment. Portfolio divisions enable costs, revenues, usage, or any other measurements to be collected into predetermined categories and compared for both internal and external purposes. For example, a university's business school may have higher total and average salaries than its school of language studies, but it may also have average and total tuitions that more than offset the salary difference. While the wages in the business school may be a problem for the faculty in language studies, relatively low returns in the school of language studies may be a problem for the university. Such are the intricate balances that must be found in decisions in higher education and that are more thoroughly informed by using a more complete portfolio analysis. At the same time, and depending on the indicators used, that same business school may be underperforming in relation to its peers. In these cases resource allocation is informed, because, even when the contents of a portfolio component vary, or perhaps especially when the contents of a portfolio component vary, differences are identified and either justified or acted upon.

There have been many calls to increase the use of portfolio analysis to enhance the understanding and management capabilities for academic and industrial research (Carter, 1997; McGeary & Smith, 1996) and more specifically for academic research (Feller et al., 2002; Pasek & Asl, 2002). One problem encountered by most of these studies is that there is no standard measurement of research output. From an RIU administrative perspective, from an RIU strategy perspective, from the individual researcher's perspective, and from the perspective of the aforementioned virtuous cycle, the desired outcome of academic research is, simply put, more research. For RIUs, the return on investment for academic research is not the results of an external economic benefit analysis; it is ΔMS.

With specific reference to academic research, the NSF's fields serve as useful delineations for portfolio components. Indeed, the NSF refers to its fields as *portfolio components* commonly in its descriptive analyses (NSF, 2003b). NSF field definitions and database are used not only for this study, but are used by every RIU, and by most universities and other reporting bodies when describing research expenditures in the ARM. In this thesis, NSF fields are referred to as portfolio components, and vice versa, to describe the research content of individual RIUs. For example, an RIU that performs research in 12 NSF fields is considered to have a research portfolio comprised of 12 components. When describing the research expenditures of the federal government, each NSF field represents 100 % of the research that was performed in the ARM in that portfolio component. As a consequence, when describing the federal government's funding of academic research, NSF fields represent entire market segments of the ARM. For the purposes of this analysis, the ARM research market is comprised of 21 fields or market segments, which are more clearly defined in Chapter Four, Definition 7, and the names of which can be found in Appendix B. RIUs have between 11 and 20 components in their research portfolios; the arithmetic mean number of components is 16.10.

In resource dependant environments, such as exist in the ARM, RIUs, as the affected agents, must make choices between investing to enhance the research capacity of one research portfolio component to a greater extent, or at the expense of others. The reasons behind these allocations is strategy; the actual allocation is the activation of strategy. In other words, strategy is not the value of resources allocated to a particular research portfolio component; strategy is the value of the allocation in relation to allocations made to other research portfolio components, to historic levels of investment, or to other areas of the university. Strategy is about choices (Ansoff, 1988; Porter, 1996). Since research performance is directly related to investments in research capacity, it can be expected that a research portfolio component that has continually received the largest share of investment in research capacity will eventually achieve a rate of growth in research performance that outstrips other components of an RIU's research portfolio. At a certain point, this component is likely to become the largest component in an RIU's research portfolio. Such a result can be observed in most universities that conduct research in the medical sciences.

The portfolio theories that this thesis relies on (Henderson, 1973; Markowitz, 1990; Naylor & Tapon, 1982) are interpreted to support the following statements: In any organization with multiple portfolio components, those components that are the largest are more strategically important than those components that are the smallest. In addition, those components that are the fastest growing are more strategically important than those that are slower growing or may even be shrinking. Finally, an organization's largest and fastest growing portfolio components are its most strategically important. Markets can be similarly described in that the largest and fastest growing market segments present better opportunities for strategic success, all things being equal, than smaller slower growing market segments. Organizations want as many of their largest and fastest growing portfolio components to be in as many of the largest and fastest growing market segments as possible. RIUs that have research portfolio components that have achieved the latter status will maximize their return on investment which, in the ARM, is a greater value of research performed (as measured in real terms against the market as whole). In other words, return on investment in the ARM is measured by ΔMS.

All RIUs want to maximize the return on their investments in research capacity. All RIUs want to achieve the largest ΔMS possible. The question is whether there are investments in certain categories of research capacity that are more likely to produce a larger ΔMS than others? Making choices about which investments in research capacity to make represents the activation of strategy and, as such, tracking those investments, or in the case of this thesis, tracking the results of those investments reveals the underlying strategy. The important question is whether there is a strategy that produces the largest ΔMS? Can RIUs achieve the largest ΔMS by adopting a certain strategy? In the ARM, does strategy work? Is there a strategy that is most closely associated with the largest ΔMS? Do the research strategies of RIUs produce results that reflect their strategies? These are the fundamental questions on which this thesis is focused.

The NSF produces exactly the type of information that this application of portfolio theory can use to expose both the research strategies and the ΔMSs of the RIUs and of the federal government, which represents the entire ARM. The NSF has collected the federally funded research expenditures of every RIU, divided into each field, and published them annually throughout the study period. These data enable a calculation to be made that yields a quantitative measurement of the relative size, and the change in the relative size, of each portfolio component of every RIU and for the federal government. According to portfolio theory, the relative size and change in relative size of the components in an organization's portfolio reveal its strategy.

Based on the methodology described in Chapter Four, this study spans the 10 years ended 2000a. (An *a* appearing after a year has the meaning defined in Chapter Four, Definitions 5 and 6) In 2000a, federally funded research expenditures in Physics at Duke University was $9.899 million, out of a total $194.702 million of Duke University's federally funded research expenditures (NSF, 1992-2004c). Physics represented 5.08 % of Duke University's federally funded research expenditures in 2000a. In 2000a, Medical and Biological Sciences represented 52.37 % and 28.61 %, respectively, and Economics and Civil Engineering represented 0.53 % and 0.17 %, respectively, of Duke University's federally funded research expenditures. According to portfolio theory, Medical and Biological Sciences research were more strategically important to Duke University than were Economics or Civil Engineering research.

In 1990a, Mechanical Engineering represented 0.93 % and represented 1.19 % of Duke University's 2000a federally financed research expenditures. During the study period, Mechanical Engineering's share of Duke University's federally financed research expenditures grew by 27.96 %. During the same period, Electrical Engineering's and Political Science's share of Duke University's federally funded research grew by 737.94 % and 385.37 %, respectively, while Oceanography's and Economics' share of Duke University's federally funded research expenditures grew by -61.46 % and -58.62 %, respectively. According to portfolio theory, Electrical Engineering and Political Science were more strategically important to Duke University than were Oceanography and Economics.

As earlier described, an organization's largest and fastest growing portfolio components are its most strategically important. In the methodology described in Chapter Four, the relative size, and change in relative size, of each portfolio component are parts of a performance indicator called the Institutional Strategic Indicator (ISI). ISI is an indicator that represents the strategic importance of each of an RIU's federally funded research portfolio components. The two parts of ISI, those being the relative size and change in the relative size of each portfolio component, are weighted equally. The equally weighted relative size of a portfolio component is called the Equalized Value for Percent of Institutional Spending (EIS). The equally weighted change in relative size of a portfolio component is called the Equalized Value for Change of Share of Institutional Spending (ΔEIS) (see Formula 2). ISI is equal to the sum of EIS and ΔEIS.

Formula 2: Calculation of the Institutional Strategic Indicator (ISI)

$$ISI = EIS + \Delta EIS$$

The greater the value for ISI, the more strategically important it is to the RIU. An additional way of thinking about ISI is that the greater its value, the faster will the reputation of the RIU be moving in the particular portfolio segment. For example, at Duke University, IES and ΔEIS for Electrical Engineering were 0.0471 and 1.000, respectively, yielding an ISI of 1.0471. EIS and ΔEIS for Medical Sciences were 1.000 and -0.0095, yielding an ISI of 0.9905. At the other end of the spectrum, ISI for Oceanography and Economics were -0.0713 and -0.0693, respectively. According to portfolio theory, Electrical Engineering and Medical Sciences were Duke University's most strategically important research components, while Oceanography and Economics were Duke University's least strategically important. This analysis is fully described in Chapters Four and Five and was done for every portfolio component of every RIU, as well as for the entire ARM. As earlier noted, the portfolio components of the federal government represent individual market segments of the ARM. The sum of all market segments is equal to the total value of the ARM in any given year. In this thesis, RIUs take the ARM as a given. That is, no RIU has had any control or influence over the amount of research funding provided by the federal government or how these funds were allocated among the various market segments.

ISI represents the relative strategic importance of each component of individual RIU research portfolios. For example, Table 1 displays the spectrum of ISIs at the University of Wisconsin.

Table 1
The University of Wisconsin's Portfolio Components and the Corresponding ISIs

Portfolio Component	ISI
Civil	1.0325
Medical	0.9762
Biological	0.9006
Psychology	0.3641
Physics	0.2192
Computer	0.1579
Earth/Geology	0.1291
Atmospheric	0.1133
Economics	0.1026
Chemical	0.0832
Chemistry	0.0750
Agricultural	0.0711
Mechanical	0.0438
Ocean	-0.0077
Electrical	-0.0181
Sociology	-0.0243
Astronomy	-0.1001
Mathematics	-0.1110
Met & Mat	-0.1121
Political	-0.1640

The largest three or four components in Table 1 are the University of Wisconsin's most strategically important in that they are the largest and fastest growing. Most of the remaining components are of relatively low strategic importance. Each RIU will have a different combination of strategically important research portfolio components, and these differences contribute to their differentiated reputations.

The parallel analysis for the ARM data yields three more performance indicators. The equally weighted relative size of each segment of the ARM is represented by an indicator called the Equalized Values for Percent of ARM (EMS). The equally weighted change in relative size of a portfolio component is called the Equalized Values for Change in Share of ARM (ΔEMS). The federal government's research strategy, which is also those market segments that provide the best opportunity for the strategic advancement of RIUs, is represented by an indicator called the Market Strategic Indicator (MSI). Formula 3 shows that MSI is equal to EMS plus ΔEMS.

Formula 3: Calculation of the Market Strategic Indicator (MSI)

$$MSI = EMS + \Delta EMS$$

The greater the value of MSI, the greater the opportunities there are, all things being equal, for RIUs to achieve strategic success. While ISI is different for every RIU, MSI is the same for each RIU. Table 2 lists the values of MSI.

Table 2
The ARM Market Segments and Corresponding MSIs

Market Segment	MSI
Medical	1.517
Political	1.011
Astronomy	0.857
Biological	0.797
Sociology	0.676
Psychology	0.542
Civil	0.538
Chemical	-0.106
Computer	-0.123
Electrical	-0.159
Atmospheric	-0.202
Mechanical	-0.271
Agricultural	-0.384
Ocean	-0.391
Aero/Astro	-0.403
Earth/Geology	-0.432
Met & Mat	-0.437
Economics	-0.500
Chemistry	-0.702
Physics	-0.769
Mathematics	-0.887

According to portfolio theory, the larger MSIs provide greater strategic opportunities for RIUs than the smaller ones. For example, Biological's EMS was 22.31 % in 2000a, and its ΔEMS was 4.50 %. An EMS of 22.31 % means that Biological was 22.31 % of the $16.056 total ARM in 2000a, or $3.582 billion. Even though Biological's share of the total ARM grew by a relatively small 4.50 %, the shear value of the segment makes it a market segment worth pursuing. At 27.20 %, Political's ΔEMS was the highest of all market segments, a factor that catapulted it to the second most strategically important. If an RIU were to invest in research capacity in Political, they could take advantage of the high rate of growth in this market segment. That is, even though, at 0.39 % in 2000a, the EMS of Political is quite small, an RIU could positively impact its overall ΔMS if it could take advantage of the very high ΔEMS.

The next step in this application of portfolio theory is to find, for every RIU, which of its largest and fastest growing portfolio components were in the largest and fastest growing market segments. Which of its largest ISIs were also the largest MSIs. To achieve this, a graph or chart was created in which the horizontal axis is ISI and the vertical axis is MSI. An intersect is established at the arithmetic mean of ISI (0.1800) and of MSI (0.0082). This creates a four quadrant chart which is called the Strategic Portfolio Array. Coordinates on each RIU's Strategic Portfolio Array (or Array) are determined by using the values of ISI and MSI. For example, at Case Western Reserve University (Case Western), ISI for Medical was 1.0947 and MSI (which is constant for every RIU) for Medical was 1.5165, creating a coordinate or incident at 1.0947 on the horizontal axis and 1.5065 on the vertical axis (1.0947, 1.5165). Medical, Sociology, and Biological were Case Western's most strategically important portfolio components. Figure 2 displays Case Western's Strategic Portfolio Array.

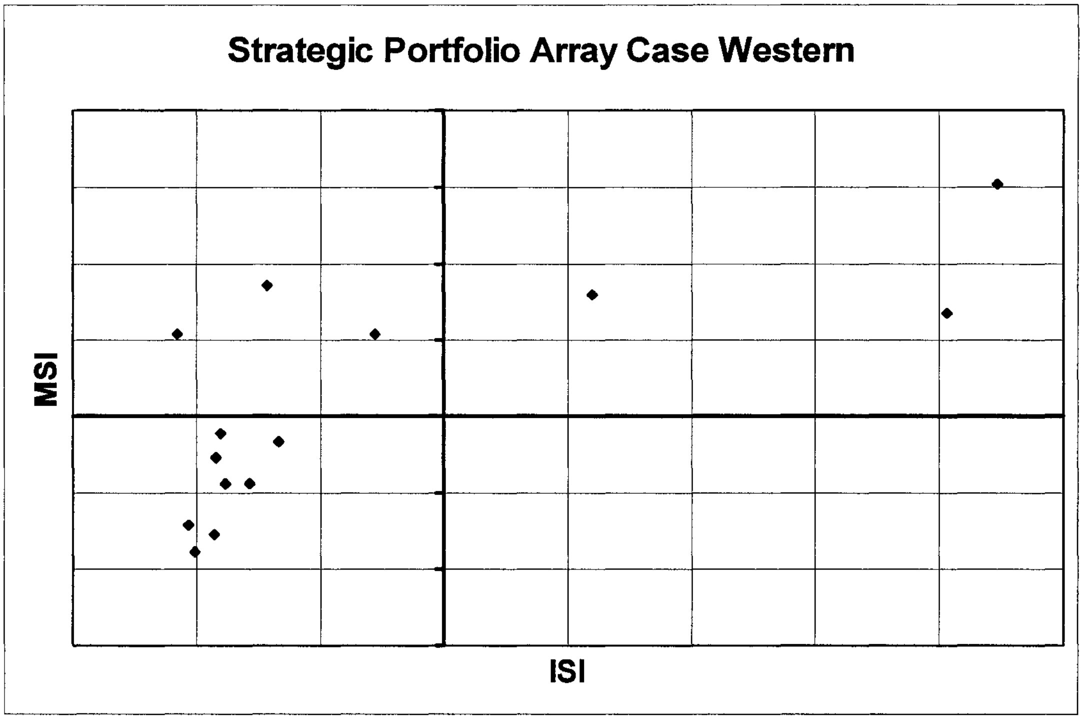


Figure 2. Case Western Reserve University's Strategic Portfolio Array

The upper-right or northeast (NE) quadrant of the Array in Figure 2 represents portfolio components that are an RIU's largest and fastest growing and that are in the largest and fastest growing market segments. One hypothesis espoused in this thesis suggests that an RIU's differentiated reputation will be moving in the direction of these components. Case Western quotes *U.S. News & World Reports*, *The Chronicle of Higher Education*, and the National Institute of Health to demonstrate the increasing national ranking of its medical school (Case Western Reserve University, 2006). While this is not conclusive evidence of increasing reputation, it certainly stands as recognition that Case Western medical school's national stature is increasing and lends at least some support to the aforementioned hypothesis. The type of questions that this thesis does *not* attempt to answer is, What length of time or what degree of research intensity is required to establish a long term reputation in a certain field? However, the theory and methods that underlie this study could contribute to such an investigation.

This thesis also postulates that an RIU that has an incident in the NE quadrant will maximize its return on investment in research capacity in the portfolio component represented by that incident. All RIUs have at least one incident in the NE quadrant. In fact, the range in the number of incidents in the NE quadrant among all 39 RIUs, as well as the arithmetic mean and standard deviation of this range, are one to five, 3.36, and 1.01, respectively. There is a temptation to think that the greater the number of incidents that an RIU has in the NE quadrant, the more likely will it have maximized its ΔMS. However, the number of incidents an RIU has in any quadrant is relative to the total number of components in its portfolio. In addition, the overall productivity of an RIU's research program is also a question of efficiency, a factor revealed in the number of incidents that occur in the southeast (SE) and northwest (NW) quadrants. All of these factors are discussed in detail in Chapters Four and Five; they are raised here to demonstrate the powerful insights available by using these tools.

The Strategic Portfolio Array exposes the realized strategy (Mintzberg & Waters, 1985) of an RIU. It can be stated that Case Western had three incidents in its NW quadrant, three incidents in the NE quadrant, no incidents in the SE quadrant, and eight incidents in its SW quadrant, comprising a total portfolio of 14 components. This was the research strategy that Case Western realized as of 2000a. It may have worked towards this strategy in a proactive manner, in a partially proactive manner, or the strategy may have unfolded into this configuration as a result of decisions made based upon the best information available at that time. However it occurred, based on the application of portfolio theory herein presented, this is the strategy that Case Western used.

When involved in a strategic discussion, one critical question that must be asked is whether the strategy yielded a successful outcome. In the language of this thesis, did it result in a positive ΔMS and, if so, how positive? The methodology used in Chapter Four reveals that Case Western's ΔMS was 13.33 %. In other words, over the decade ending in 2000a, Case Western increased its share of the ARM by 13.33 %. Given that the minimum and maximum values, the arithmetic mean, and the standard deviation of the values for all 39 ΔMSs was -34.67 and 36.78, -2.28, and 18.82, respectively, Case Western seems to have performed quite well, but not exceptionally well. Case Western was in the top performance group, as defined in Chapter Four, Table 3.

An Array was produced for every RIU, and their realized strategies were examined by counting the number of incidents that occurred in each quadrant of their Array. Using the methodology described in Chapter Four, it was determined that there is a research strategy that correlates strongly with the highest ΔMS. This is the strategy that every RIU will want to at least consider when developing strategy for their research programs. Furthermore, if such a strategy is not considered, accountability questions should be anticipated.

Summary

Internal and external accountability is adversely affected by the reality that the research operations of RIUs are less measured and less well informed than other major RIU operations. Any stakeholder who is interested in understanding the degree of RIU educational operational efficiency or productivity can never be certain as to the extent of cross-subsidization with research operations. Since the research function of RIUs is substantially less well informed than RIU teaching, institutional accountability is diminished. Any contribution that improves the understanding of the efficiency or productivity of the RIU research function also contributes to overall institutional accountability.

There are currently surprisingly few performance indicators that enable an RIU to understand the productivity and relative performance of its research operations across its portfolio of research interests, longitudinally, on an intercollegiate basis, or against the total ARM. The use of the word *surprisingly* refers to the notion that the magnitude of the research performed by RIUs and its critical importance to them should have, as has been the case in most other heavily resource dependent environments, stimulated intense measurement. In addition, the internal and external principals of RIUs have forced them to develop a substantial array of performance indicators, but research has, by and large, sidestepped equal scrutiny. As a consequence, no concrete statements can be made about the productivity or efficiency of the research operations at any RIU or about the system overall. Any enhancement to the ability to measure these aspects of research can make a significant contribution to ensuring that the limited resources that are available to the ARM are being most effectively deployed.

For direct financial reasons and for strategic reasons, research performance is critical to the long-term success of every RIU. The direct financial imperative is that research has been one of the RIUs' largest and fastest growing revenue streams and, at least as of 2002, must be considered as their most strategically important. From a long term strategic perspective, an RIU's reputation drives revenue from all sources. The earlier described virtuous cycle puts federally funded research performance at the heart of institutional reputational direction. Any method that improves an RIU's ability to increase its federally funded research performance is an absolute contribution to its institutional success.

RIUs face intense competition when attempting to increase their federally funded research performance. Strategy is used to guide RIU resource allocations as part of their effort to perform an increasing amount of federally funded research. The nature of the strategic development processes relating to the research operations of RIUs, as reflected in their published documentation, indicates a very shallow view of their competitive situation. External competitive scans, which should be used to identify organizational opportunities and threats, are absent. Improving an RIU's ability to undertake an external scan will contribute greatly to its ability to develop a fully elaborated research strategy.

This thesis asks whether the research strategies of RIUs produce outcomes that reflect those strategies. This research does not attempt to answer the specific question of whether an RIU that has a strong and growing research program in engineering is developing an improving reputation in engineering. This is a more basic question, the answer to which lies in an RIU's overall research performance relative to other RIUs and relative to the ARM. In order to answer the latter question, performance indicators, some of which are new to the measurement of research operations in higher education, are used.

Defining the market is a critical component of any efficacy of strategy study. The ARM is defined to include only federally funded research in the 21 NSF science and engineering fields listed in Appendix B. The only enterprises in this market are the federal government and the colleges and universities that receive its research funds. It is assumed that this is a proxy for all federally funded research to colleges and universities, although no absolute assurance is made that non-RIU university research behaved in a manner consistent with that of the RIUs. The ARM is a convenient definition, in that the relevant information is available and, since it is a closed system, the probability that the study is contaminated by blurred market boundaries is lessened.

ΔMS is a critical performance indicator in this thesis. ΔMS measures the actual change in the share of the ARM that an RIU experienced during the period beginning in 1990a and ending in 2000a. As compared with existing performance indicators used to measure the strategic results of RIU research operations, ΔMS is more accurate, inflation adjusted, easier to understand and calculate, completely objective, and is more reflective of the type of measurements being made in other industries and sectors. A major contribution that this thesis hopes to make is to stimulate the use of ΔMS as the standard measure of advancement or decline in a university's research enterprise and of the success or failure of institutional research strategy in higher education. In addition, ΔMS could be the primary indicator of institutional reputational direction. Whether the market is defined as the ARM or as the Total Federal Research Market (see Chapter Four, Definition 2) is less important than encouraging universities to measure their performance in a standardized manner. If third-party reporters, such as The Center and the NSF, adopted this measurement, many universities might be persuaded to follow suit. In terms of accountability to both internal and external principals, no measurement can be more starkly honest. If state legislatures really want to know whether their flagship university is competing successfully on a national level (Knott & Payne, 2004), ΔMS is the truest measure of all. In other words, ΔMS, as a real measure of institutional reputational direction, can be used by the states to help judge the success of their flagship institution. In terms of the basic starting point of an environmental scan, winners and losers are obviously exposed. The winners become targets, their foci and methods may be worth emulating.

One of the corollary calculations that was made available by this methodology is that ΔMS for every field of every RIU can be determined. If the University of North Carolina knew that it had an increasing share of the national market in Chemistry, it might be encouraged to act more aggressively in an effort to solidify its progress. In cases where ΔMS in one portfolio component is greater than institutional ΔMS, that component is a positive influence on institutional reputation. Of course, the opposite is also true.

The proportion, and the change in the proportion over time, that each component of an RIU's research portfolio represents of its total provides powerful insights, many of which are discussed in Chapter Five. In this thesis, these two measurements are represented by EIS and ΔEIS. These measurements are useful both separately and when taken together well beyond their direct application in this study. For example, and even though this thesis does not pursue this line of inquiry, it could now become possible for an RIU to compare its investment in research capacity with its EIS and ΔEIS to determine whether a certain level and change in level in investment affects EIS and ΔEIS proportionately in one portfolio component as compared with others. The same principle could be applied to determine the average lag time between investments in research capacity and the resulting performance. This latter information could inform portfolio management decisions and tenure decisions. When comparing the size, and change in size, of research portfolio components with those of competitors, new types of questions can arise, particularly when competitors' performance is superior.

Equally important is the relative size, and the change in relative size, of each market segment, because it provides a more clear understanding of potential growth opportunities for RIUs. In this thesis, EMS and ΔEMS represent these factors and, when combined by using the methodology in Chapter Four, new understandings about the competitive environment in which research occurs are revealed. In regard to accountability, incidents that occur in the SE or NW quadrants of an RIU's Strategic Portfolio Array can be either inefficient, higher risk, or both. This information is valuable for both the internal and external principals of RIU research. When an RIU juxtaposes its Array against all others, or selected others, it might see market opportunities or threats that were not previously apparent. A portfolio approach to managing research enables an RIU to compare its performance, component by component, with the ARM. As is the case in financial management, when a portfolio component becomes overweighted relative to the market, accountability questions arise. Strategic positioning is developed by decisions about which portfolio components an institution wants to overweight and underweight. Since one of the conclusions of this thesis is that a modified specialization strategy produces the best ΔMS, RIUs will want to know how they compare with the market and adjust their investment decisions accordingly.

The Strategic Portfolio Array of each RIU represents its realized strategy (Mintzberg & Waters, 1985). An important discovery of this study is that realized strategy corresponds quite strongly with ΔMS. The central question of this thesis is whether the research strategies of RIU's produce outcomes that reflect those strategies.

The reality is that the correlational methodology used to determine the results of this study preclude causality claims that would otherwise produce such a conclusion. Moving towards determining a causal relationship between strategy and market performance (ΔMS) is an ideal next stage in this research thrust. If a conclusive causal relationship was ever established, RIUs would be even more compelled to adopt such a strategy. Nevertheless, the .622 correlation between the winning RIU research strategy and ΔMS is very significant and should be ignored only at the risk of falling behind in the ARM, as well as in that which is the real currency of success in higher education: institutional reputation (Raines & Leathers, 2003). The conclusion reached in this thesis must be at least considered when research strategy is being developed.

Chapter Three: Literature Review

The Academic Research Market

The quantity of literature pertaining to academic research seems to have grown along with the value of research performed at universities and as research's impact on higher education in general, and research intensive universities in particular, has increased. The literature can be broken down into several categories, some of which are more relevant to this study, but all related nonetheless. One of those categories explores the costs and benefits of academic research. Financing the apparently insatiable appetite of the academic research enterprise is a great concern. Several formal and less formal economic descriptions (Brewer et al., 2002; Clotfelter & Rothschild, 1993; Garvin, 1980; Raines & Leathers, 2003) trace the impact of research on institutional prestige and reputation and vice versa, and the impact of both of these factors on the ability to generate financial support for research. There are no econometric studies describing any of these relationships, nor are there any analyses that attempt to quantify the impact of any of these relationships on the institution or on each other. There are quantitative studies demonstrating that there is a high correlation between institutional reputation, as measured by *U.S. News & World Report*, and research output, whether measured by publication production or federally funded research expenditures (Volkwein & Sweitzer, 2006).

Other commentaries provide insight into the sources of funds that support research, including the extent to which these sources have changed (e.g.: the rise of industrial funded research), probable reasons as to why funding sources have changed, and speculation about how research funding sources are likely to change in the future (Lombardi, 2005; Santos, 2007; Schmidtlein & Taylor, 1996). Tornatzky, Waugaman, and Gray (2002) describe the cultural attributes that can lead to increased industry funded research.

Another set of literature explores various aspects of the benefits that society derives from academic research. The well known human capital theory falls into this category, as well as a range of topics that includes, for example, local economic spin-offs from university research (Jaffe, 1989), and commercialization of university research (Mowery, Nelson, Sampat, & Ziedonis, 2001). Indeed, there is a peer adjudicated journal published by a professional association devoted specifically to the latter topic (Association of University Technology Managers, 2007). Duderstadt (2005) and Wolfe (2005) broach a variety of issues relating to the costs and social benefits of academic research. Geiger (2006) discusses how relationships between governments, industry, and universities are evolving to enhance the economic contribution of universities.

Despite a growing volume of literature, it is notable that most higher education literature does not deal primarily with academic research. In most cases, it represents only a minor part of the higher education literature. One probable reason is that only about 20 % of America's postsecondary institutions conduct federally financed research, and perhaps only half of that number produce a material amount. In other words, academic research is not the main topic of higher education. However, for research intensive universities, of which RIUs are a subset, research is critical, and for the national research enterprise, RIUs are integral. In any event, there have been few studies published that quantify the social or economic benefits that have been created by higher education, although there have been estimates (Mansfield, 1991). Trying to parse out research from such a complex exploration would be even more difficult.

The longstanding debate about the degree to which research is impinging on undergraduate education (Massy, 1996; Massy & Zemsky, 1994; Middaugh, 2005) contrasts its importance to the career advancement of faculty (Clark, 1997) and to institutional reputation (Geiger, 2004; Garvin, 1980; Lang, 2005), all of which helps put research in perspective within the university setting as well as to various communities that are external to, but interested in universities (Bok, 1982).

A second category of the academic research literature pertains to how it is measured. This category of literature is relevant to this thesis because of the use of federally funded research expenditures as a proxy for research performance as an output indicator and as an indicator of institutional reputation. Johnes (1997) states

> that research grants are in general awarded to meritorious groups of researchers on the basis of the quality and quantity of their previous work (and that the weights assigned to quantity and quality in this measure are precisely those assigned by the 'market' for research). The measure may therefore be regarded as a valid proxy for output. (p. 728)

In this thesis, federally funded research expenditures are also used as a basis for several new performance indicators that are introduced and for other existing indicators and data that are used in new ways.

Measuring research almost always involves a performance indicator. Burke and Minassians (2002) and many others have presented thorough discussions about how performance indicators are used, about how they offer a partial or simplistic view of the university or fail to reveal the required information, and about how they have caused unintended behaviours. In order to avoid the issues raised by Burke and others, this thesis defines the performance indicators it uses as precisely as possible and attempts to align these definitions, and the use of the indicators, closely to the theories that underlie them.

Publications are one of the most important research outputs, and citation indexes are one of the most important methods used to measure them. With specific regard to academic research, several authors have tried to explain the use of citation indexes to describe research quality, such as Johnes (1990), and how to use these measurements to judge individual, departmental, or institutional prestige (Toutkoushian et al., 2003). The premise for using citations as a measure of quality is an expectation that researchers will normally attempt to publish their work in the most prestigious journal possible. The higher the prestige of the journal in which an article appears, the higher is the presumed quality. The second part of the quality formula is that the more times an article is cited, the higher the quality that peers must believe it to be. A highly cited article in a prestigious journal is thought to have been written by a high quality researcher (Braxton & Boyer, 1986). Citation indexes are important because they form part of several significant rankings (Shanghai Jaio Tong University Ranking, 2006).

The other important measure of research performance is research expenditures. In reference to commercial league table rankings, Dill and Soo (2005) state that, "The quality of the faculty and research is another prominent [shared] measure, which is assessed primarily by staff qualifications and the ability to attract research grants" (p. 499). For the reasons described in Chapter Two, federally funded research expenditures is the indicator used to measure research performance in this thesis. Notably, the Carnegie Foundation for the Advancement of Teaching only uses federally funded research data, as published by the NSF, in its ranking methodology (Carnegie Foundation for the Advancement of Teaching, 2007).

In regard to measuring institutional reputation, as reflected in either publication or expenditure outputs, Volkwein and Sweitzer (2006) note the current trend towards measuring faculty productivity on a per capita basis. The practice prevents confusing a high level of institutional research produced by highly productive faculty with that produced primarily because of an institution's large size. It is important to note that the methodology used in Chapter Four uses the relative values and the changes in the relative values of federally funded research expenditures as components of the indicators used to measure the realized strategies of the RIUs. This methodology circumvents the potential confusion referred to above. ΔMS, the indicator used to measure strategic performance in the ARM, also avoids the above mentioned confusion.

As noted in Chapter Two, every RIU uses NSF published federally financed research expenditures data to describe their institutional research performance. No RIU uses publication or citation data in an equally disaggregated manner to reflect institutional research output (Research Performance Reports, 2003-2008).

That universities generally, and academic research in particular, operate in an environment usually portrayed as a highly competitive market is increasingly a forgone conclusion (Dill, 1997; Feller, 2000; Geiger, 2004; Johnes, 1997; Massy, 1990; Teixeira et al., 2004; Tornatzky, 2005; Zemsky, 1997; Zemsky et al., 2005). It is both interesting and significant to think of higher education as a mature industry, and Levine (1997) makes a compelling case as to why it should be recognized as such. The point was made in Chapter Two that RIUs operate in many markets and, given the ARMs relatively high growth rate and the professionalization of its management (Clark, 1997), it may still be in a formative stage. Whatever stage of development that the ARM is at, appropriate market oriented disciplines should be used by RIUs to improve their competitive capabilities. Indeed, Dill's (1999) article in *Higher Education* is an application of business theory and practice in a higher education setting which presumes that universities operate in market conditions and that universities need to adopt the described business practice in order to be more successful (read: in order to more effectively compete with other universities). Dill's concepts are relevant since, in this thesis, business theories and practices have also been applied in a higher education setting. It is apparent that the marketization (Slaughter & Leslie, 1997) of higher education has penetrated the academy deeply, and the degree of sophistication in some realms of university market facing activity is comparable with even the most advanced markets (The First Marblehead Corporation, 2006).

In competitive markets, strategy is employed. Yet, "After reviewing the literature and consulting with knowledgeable colleagues, we have concluded that a convincing, generalizable empirical study on the efficacy of strategic planning in higher education has yet to be published" (Dooris et al., 2004). As discussed in Chapter Two, a lack of strategic processes, due in part to the relative deficiency of available quantitative data, is particularly prevalent in RIU research. Of course, a major reason for this condition is that there is no universally accepted method of measuring strategic success in the ARM (Feller, 2000; Hauger, 2000). If there is no generally accepted method of measuring success in the ARM, then return on investment in research capacity cannot be measured, since no comparisons are possible. If return on investment cannot be measured, there is no quantitative basis upon which to inform resource allocation decisions. This is, after all, the underlying point that Feller, Hauger, and Dooris et al. are making. Furthermore, shallow strategies indicate a weakened management capability in this critical component of RIU operations. Success in the ARM and return on investment are both measured in this thesis by ΔMS.

Another reason for an inability to undertake complete strategic processes in the ARM is that the market itself is not well understood. Beyond the use of the word *competitive*, relatively few authors have attempted to describe the nature of the ARM from an economic, strategic, structural, comparative, or competitive perspective, or have provided much theoretical or practical advice about how best to compete. The extent of this literature begins with Leslie and Johnson's (1974) economic analysis of the higher education market, in which they attempted to dissuade governments from treating the university market as perfectly competitive. However, Leslie and Johnson did not take a position as to what sort of market might actually exist and, as well, their focus was primarily on the student market, only mentioning research in passing.

In Dill's (1997) view, the ARM is not a "quasi market" (p. 3). He suggests this to mean that the ARM is sufficiently unregulated so as to enable overtly competitive behaviours to be more prominently displayed than would be evidenced in more controlled conditions. Dill further describes an environment in which individual researchers and their institutions compete in a market that is sophisticated, well developed, transparent, and informed. Geiger seems to corroborate Dill's description, when he states that the high degree of plurality of the federal system of research funding enables any researcher in any institution the ability to submit proposals for support through a national paninstitutional bidding process (2004). The thought is completed by Massy's remark that federal research proposals "are filtered though a powerful market mechanism, peer review…" (Massy, 1996. p. 43). Dill goes on to describe how the structure of the ARM protects the social welfare by, for example, establishing a market that fosters economic efficiency through controlled prices, continually increasing rigor, discipline, and quality in the conception, preparation, execution, and management of research, and by helping ensure that the range and methods of research are in the public interest (Dill, 1997).

Despite the ideal of equal access to federal funding in the ARM, the reputations of individual researchers and of the supporting institutions are factors in funding success rates. The point is made by Teich (2000), and this reality is confirmed by the application requirements of most funding agencies (NSF, 2004). Reputation is an attribute that indicates that a differentiated market position is a factor in the transaction decision. The higher is the reputation of a researcher, or an institution, or both, all things being equal, the greater is the probability that he or she, or the institution, will win a given federally financed research award. The differentiated market positioning phenomenon is exceptionally important to any description of the ARM from an economic or strategic perspective. In addition, any lack of understanding of this phenomenon, or how it is most effectively applied, diminishes the ability to develop strategy in the ARM. Given the importance of research to RIUs, to research intensive universities, to the higher education system, and to overall economic development, it is surprising that no substantive economic or strategic descriptions of the ARM have been published.

Geiger and Feller (1995) indicate that, in the 1980s, no single university had a share of the research market that was greater than 2.5 % and, during that decade, the market share of the 20 largest performers declined, as the number of academic institutions participating in the market for the first time increased. With regard to the existence of a colluding group, Taylor and Massy (1996) refer to the "federal peer review processes" (p. 19). which, in hindsight, resemble a failed attempt by a group of the most research intensive universities to raise barriers to entry for smaller institutions. Indications are that the ARM is highly fragmented, a trait that tends to intensify competition. Competition is further intensified by chronic overcapacity in the ARM, a condition substantiated by Massy's remark that research capacity is sticky (Massy, 1996). That is, once research capacity is put in place, it remains in place for the long term, even if not fully utilized. Overcapacity in the research market is reflected in the emphasis that most RIUs put on attracting research from all sources, a position which is evidenced by the placement of a high value on faculty that help satisfy this need (Slaughter, 2001; Slaughter & Campbell, 1999).

Economies of scale in the ARM were observed by Cohn et al. (1989), findings that were later confirmed by Patterson (2000). Important for the purposes of this thesis is the notion that it is possible to exhaust economies of scale in university research. According to Johnes (1997), there may even be diseconomies of scale beyond a certain point. As described in Chapter Two, if the absolute size of an RIU's research program ceases to be a strategic advantage, then it should not comprise part of the measurement of strategic outcome. The assumption made in Chapter Two is that all RIUs have achieved a level of research activity that is sufficiently large so that economies of scale do not provide a strategically exploitable advantage in the ARM.

There is a great deal that remains unexplored regarding the ARM. This thesis aims to add to the base of knowledge in this area.

Strategy and RIUs

Within an organization as large and complex as a major research university, strategy can be developing and be in the process of implementation at every level, and in every corner, of the institution simultaneously. Strategy includes the choices a researcher makes about pursuing one line of inquiry instead of another, given his or her limited time and resources. At the highest level, boards of governors, presidents, and senior management groups engage in strategic activities that include approving the budgets, either directly or tacitly, that allocate resources in the organization (Appelbaum & Patton, 2002; Clark, 1983). External factors, such as government policies, also influence resource allocation decisions in the academy. The site of the strategy contemplated in this thesis also occurs at various levels in the institution. Since strategic implementation in RIUs is composed of mutually informing components of a generally vertical approval process, the origination of which often depends on the success of individual researchers, resource allocation decisions move higher up the chain as the value of the resources required aggregates (Prowle & Morgan, 2005). Given the incremental nature of university strategy implementation (Dill, 1999), most resource allocation decisions remain relatively small and this helps maintain the highly decentralized organizational structures of research universities (Clark, 1997; Dill, 1999).

Since organizational structure is a strategic choice, the question of whether a highly decentralized environment is the best environment in which to conduct research that is primarily basic in nature must be asked. A comparison with privately operated research laboratories, such as the National Aeronautics and Space Administration (2007), Sandia National Laboratories (2007), Bell Labs (2007), or the pharmaceutical laboratories (Pharma, 2007), where the presumption is that the organizational structure is substantially more centralized, might help shed light on this issue (Castagnos & Echevin, 1985). However, this question is beyond the scope of this thesis and, as such, RIU organizational structures are taken as given in this thesis.

From a resource allocation perspective, the budget is a major source of power in universities (Prowle & Morgan, 2005; Massy, 1996). The moment of approval is the documentary confirmation of strategic implementation, and the processes preceding and following these approvals comprise a point of leverage for any proactive strategy. In the face of the potential political, financial, and even legal consequences of budget decisions, enhancing or restricting resources that flow into a department will ultimately impact output (Appelbaum & Patton, 2002). The amount and timing of the changes in output will depend on the extent and duration of the changes in the resource allocation patterns.

Strategy is irrelevant without execution. While this thesis is about informing strategic development at the institutional level, its implementation is equally important. In this regard, this thesis is about informing the principals of the research operations of the RIUs, which include those people who are the budget holders and those who either directly or indirectly influence the budget holders. Given the highly decentralized structure of RIUs, the principals of research can be found throughout the institution, as well as outside of the institution. Internal principals of research include frontline administrators, such as department chairs, and up the organizational ladder from there. External principals of research include the financiers of research and policy-makers. Political considerations can also influence research resource allocations, especially when local industries and state governments collude to pressure universities to invest in specific directions (Geiger & Sá, 2005).

It is always useful to point out that the purpose of strategy is to enhance performance, however it is measured. Porter's 5-forces model (1985) provides a good framework for the objectives that a successful strategy should fulfill. There are as many types of strategies as there are people. Over time, certain strategies have emerged in sufficiently similar form so that they have been dubbed with names. It is interesting that, although strategic performance in this thesis is measured by ΔMS, the attainment of market share can be considered as both a strategic result and as a strategy. In some studies, a strategy of attaining increased market share is correlated quite strongly with higher profits (Capon et al., 1990). Rumelt's (1974, 1982) well known diversification strategy was also associated closely with higher profits, as was Robins and Wiersema's (1995) study of portfolio relatedness and firm performance in a resource dependent environment. Economies of scale and scope (Cohn et al., 1989; Patterson, 2000) are one of the relatedness factors that may have encouraged a diversified portfolio of research to unfold in RIUs. Other common or shared capabilities that generate an environment in which RIUs are encouraged to diversify their portfolios may include a common understanding of research methods among faculty, a shared notion of what constitutes quality, rigor, and academic production, as well as shared support services. Clark's (1997) stark contrast between the academic life of a clinical medical researcher and an English professor suggests the presence of these factors. The concept of shared competencies will not be explored in this thesis; economies of scale are taken as a given.

The reality is that the relationship between strategy and performance remains unclear, as a large number of studies have produced varied results (Boyd, 1991). Identifying what constitutes strategic behaviour and the method used to measure strategic outcomes are points of criticism of many studies, as is the chronic problem of adequately defining the market in which the relationship between strategy and performance is being examined. In light of these controversies, the onus on this thesis is to demonstrate that there was a relationship between the research strategies of the RIUs and ΔMS with an extra level of certainty. In the case of this study, the ARM is a closed system that includes only the federal government and those universities that received federal research funds. Since the ARM represents more than 72 % of all externally funded research performed by universities (NSF, 2002a), and since the ARM, as defined, is a discrete market with little *leakage* does help raise the level of credibility of this study by reducing the market definition criticism.

Given that the objective of institutions of higher education, including RIUs, is to enhance their reputations and, should a definitive relationship between strategy and ΔMS be adequately demonstrated, competition in the ARM likely manifests as a differentiation strategy (Porter, 1985). While identifying a strategic type is also beyond the scope of this thesis, describing the physical form of any related strategies can add qualitative credibility to the statistical evidence and these descriptions are included.

It is useful to raise Baldridge, Curtis, Ecker, and Riley (1986), to distinguish the less focused strategic orientation of research intensive universities from private sector organizations of similar or larger size. Vague missions enable a great breadth of institutional foci. In turn, this dilutes the potential to rally enterprise resources toward a single, easily identifiable purpose (Clarke, 1997). As a result, strategic execution cannot be expected to be as efficiently executed in RIUs as it is in private sector enterprises because employees may be following widely varied interpretations of the same strategy. If this thesis definitively establishes the relationship between RIU research strategy and research performance, its significance is magnified in light of the diluted environment in which it is unfolding. That is to say, if the correlation between RIU research strategy and strategic performance is relatively weak, it does not necessarily negate that a relationship still exists because the environment in which this relationship is occurring must be considered. If the correlation between RIU research strategy and strategic performance is relatively strong, then the relationship should be thought of as even greater than such a correlation might otherwise indicate.

Equally important is how the strategic success of a research intensive university should be measured, especially when it is not completely clear what exactly the strategy is. In the private sector, profit, return on investment, market share, enterprise value, enterprise capacity, and like measurements constitute the primary range of strategic outcome measurements. Of course, all of these measurements are in the context of historic performance, competitor performance, market segment performance, and the overall economic environment. The ongoing problems with the meaning and credibility of many performance indicators (Burke & Minassians, 2002) is testament to the difficulty of even understanding what to measure in higher education; yet, measurements are pervasive. In this thesis, the theories and calculations that identify the strategies of the RIUs and ΔMS, the indicator of strategic success, are carefully described.

In spite of Baldridge et al.'s (1986) commentary on the complexity of university organizational structure, the strategic objective and cultural imperative for the research operation of every RIU is clear enough: conduct as much research as possible (Mission Statements, 2004-2007). Furthermore, the incentive system for faculty is closely aligned with this objective (Alfred, 2006). As such, in a sea of goal uncertainty and diverse interests, the institution and academic core are strongly motivated to generate high volumes of research activity, the outputs of which can be measured in the form of research expenditures. Should a relationship between research strategy and research output be established, this critical alignment may be an important factor. However, the purpose of this thesis is to establish whether such a relationship exists, not why. As such, the issue of whether institutional mission, strategy, and incentive alignment contribute to such a relationship is beyond the scope of this study.

A major assumption of this thesis is that investments in research capacity result in research performance. The relationship between investment and performance is a concept that is common in for-profit enterprises that expect to generate revenue and profit from investments in capacity, whether these investments are in fixed, human, or intellectual capital (Barney, 1991; Chen, 1996; Wernerfelt, 1984). Corporate strategy can be recognized by observing "the firm's asset investments, which in aggregate are the fundamental determinants of its strategic position" (Collis, 1991, p. 51). The identification of the strategies of the RIUs in this thesis is very consistent with this practice. In other words, if *research capacity* (which represents an RIU's asset investments) and *research performance* are interchangeable terms in this thesis, then observing an RIU's research performance reveals its strategy. This is the methodology described in Chapter Two and applied in Chapter Four.

The literature pertaining specifically to strategy in the research operations of universities is comprised of case studies of universities that were confronted with specific institutional challenges and for which research was at least part of the solution. For example, in *Creating Entrepreneurial Universities: Organizational Pathways of Transformation* (1998), Clark details how four universities revived their stature under adverse conditions. Bok's (2003) *Universities in the Marketplace: The Commercialization of Higher Education,* is important for its recognition of the volatility of funding for higher education and the reactions of individual institutions to these challenges. *Innovation U.: New University Roles in a Knowledge Economy* (Tornatzky, 2002) describes the strategies and actions of exemplar institutions in the area of the commercialization of research and thus, the position of research to maximize this result. Feller's (2000) commentary is one of the rare instances, where he introduces 10 strategies that universities can use to support growth in their research revenues. Yet, while Feller's tactics and strategies are as valid as any, he does not provide the theoretical foundation from which these strategies might naturally emerge.

Portfolio Theory

The capital asset pricing model describes a method that a portfolio manager can use to select among all possible choices of investments in terms of which investments should be made, which should not be made, and for those made, how much should be invested. These decisions are made on the risk differential between systematic risk, the risk premium associated with making a particular investment, and the risk threshold or return expectation of the portfolio operator. Deviations from the market weight of any portfolio component have an associated risk premium. The risk premium should translate into a rate of return. In this thesis, rate of return is measure by ΔMS and deviations from the market weight are considered to be the difference between an RIU's ISI in a market segment and the MSI in the same segment. The importance of Naylor and Tapon's (1982) article is the application of the capital asset pricing model outside of financial markets and as "a strategic planning tool for diversified, decentralized companies ..." (p. 1167). RIU research operations have many similarities with diversified, decentralized businesses, and the literature describing academic research in a market context supports this contention.

Markowitz's (1990, 1999) fundamental theory of portfolio management is that diversification drives down nonsystematic risk. Investing in a single security poses an existential threat. Therefore, diversifying away from a single security is a strategic choice. Furthermore, choosing between portfolio components is strategic because it is a risk adjustment activity. If measured correctly, higher risk should yield a higher return. Of course, a great deal of Markowitz's theories deal with how to measure risk and estimate return for the purpose of limiting uncertainty. In this regard, a portfolio should be managed to create the correct balance between risk and return. If risk is to be minimized, portfolio managers must look for investments in which the mean of potential outcomes, plus or minus the standard deviation of the potential outcomes, is a narrower band than the mean of the potential outcomes of the existing portfolio, plus or minus the standard deviation of the potential outcomes of the existing portfolio. Nonsystematic risk relates closely to historic performance in respect of the relative size, change in size, and rate of change in size of individual portfolio components.

Markowitz's theory is highly relevant to this thesis from many perspectives, including the notion that portfolio management is a strategic activity. In its essence, this thesis is a portfolio analysis that asserts that managing research as a portfolio of interests is a strategic activity that has strategic consequences.

A major assumption of this thesis is that investments in research capacity result in a corresponding amount of research performance. According to Markowitz, an investment decision is, at its core, a risk decision. As one effect of the aforementioned assumption, the terms *risk* and *investment* are interchangeable in this thesis. Investment decisions should therefore be made on the basis of the relative size, the change in relative size, and the rate of change in relative size of the target assets. In the vernacular of this thesis, large fast growing market segments present better opportunities for strategic advancement than do small slow growing market segments. This is because historic properties are used to determine the potential future values of the asset; namely, the risk return decision. Large high growth assets, with low volatility, will have the highest mean of future potential values and the smallest standard deviation of future potential values. The mean plus or minus the standard deviation, the value of the mean, and the value of the standard deviation, are mathematical principles that appear throughout this thesis; the establishment of performance groups and their use being one example, the statistical analysis being another.

Many of the principles forwarded by Markowitz are used to inform the interpretations and proposed actions in respect of the Strategic Portfolio Array. Issues of market potential and risk are informed by Markowitz as they relate to an RIU's existing portfolio, to relative market segment size and change in size, and relative to other RIU's portfolios. The Markowitz objective, and the objective of every RIU, is to outperform the market without taking on disproportionate risk. For RIUs, this translates to working to achieve a high ΔMS with a minimized investment in research capacity through correct portfolio investment choices. In other words, to operate a research portfolio that is the most efficient.

The contribution of Henderson (1972) and Hedley (1977) to the portfolio theories upon which this thesis relies is both an affirmation of the capital asset pricing model and Markowitz, and recognition of the legitimacy of these theories as strategic tools for nonfinancial portfolio management. In this regard, they are adapted to the language of nonfinancial organizations by, for example, referencing market share as a primary means of judging strategic success, by noting that the strategic advancement of a portfolio component is closely related to a market's size and rate of growth, and by providing a tool to help an organization understand whether its existing portfolio is properly balanced. The tool Henderson and Hedley present is called the Boston Consulting Group Growth-Share Matrix, which provides a visual portrayal of an enterprise's portfolio, so that it can determine whether the number, the sizes, and rates of growth of the components within its portfolio are in balance from an internal and from an external perspective. The Strategic Portfolio Array is, to some extent, modeled after the Growth-Share Matrix.

Summary

As at the time of writing, there were no quantitative efficacy of strategy studies published in the field of research in higher education. There were no publications that presented the strategies of university research operations or of the ARM, or of the federal government's research funding strategy, in a quantitative manner. There has been no study published that exposes the efficiency of the research program of any university in total, or identifies which part of such a program is inefficient, or provides a method to quantify what the extent of the inefficiency might be. Questions as to what strategic ideas might work are rare, and none are grounded in sound strategic theory. When it comes to the strategic management of university research there are few, if any, quantitative tools that have been developed and that are available to use to support these activities. To varying degrees, it is the intention of this thesis to inform many of the issues raised in this summary.

Chapter Four: Methodology

The primary purpose of this chapter is to present an arithmetic model that most authentically interprets the portfolio theory and market share concepts described in Chapters Two and Three. It is intended that the following methodology, and the results that flow therefrom, are able to be replicated in every respect. Embedded in the methodology are treatments used to ensure that the data conform to anomalistic limitations that are specific to this application. The statistical analysis follows a standard social science process. Another important purpose of this chapter is to demonstrate, with a high degree of reliability, that if the underlying theories and assumptions are correct, then the results of this methodology are also correct. Thus, even if portions of the interpretations and conclusions offered in the following chapters are questioned, the efficacy of the methodology can remain intact.

Executing this methodology follows four basic steps: selecting and accessing the data, checking for and correcting for anomalies or missing data, applying portfolio theory to manipulate the data, and undertaking a statistical analysis to produce the results. The details of the four steps follow a formal definition of the components that are used in the model. Chapter Five discusses the meaning of these results.

The study period begins in 1990a and ends in 2000a. For the specific meaning of the occurrence of an *a* at the end of a year, please refer to this chapter, Definitions 5 and 6, and the Exceptions Method within Definition 6. For convenience, it is reasonable to refer to the study period as a 10-year period, or colloquially as the decade ended in 2000. Patterns in the values of research performance over time were the determinant for selecting a 10-year period in this study. A 1- or 2-year period would create an increased risk of an incorrect result. The primary reason is that the value of research performed by an RIU in a single NSF field can fluctuate erratically from one year to the next. In many cases, an RIU will not experience a constant rate of change over time in the value of research it performed in any single NSF field but in nearly 10 % of the 8,164 RIU-NSF field-years, these fluctuations exceeded ± 2 standard deviations (σs) from that RIUs' average annual rate of change in that NSF field. In other words, short-term variability might adversely impact the reliability of the results produced by this methodology if the study period was too short.

It is also the case that annual fluctuations may not reflect the longer term trend in the changes in the value of research performed in any given NSF field, whether that change is positive, negative, or constant. This study assumes that there is a direct relationship between investments in research capacity and research performance. The question raised by the annual fluctuations in research capacity versus longer term trends in performance relates to the time lag between the inputs and outputs of research. In this case, there is a further assumption that research strategy unfolds over extended periods. *Research strategy* in the case of this study refers to an institution level thrust to build significant capacity in a certain field of study. Such a strategy would involve assembling a critical mass of researchers and the accompanying support structures. These strategies can manifest in the form of research institutes or research centres and are operations that cannot usually be established and become fully productive in a 1- or 2-year period.

Patterns of research performance would indicate that longer term trends are more reflective of unfolding strategies in RIUs. As such, a 5-year period, or 7- or 8-year periods were considered, but a 10-year period seemed most reasonable. Since other studies of research have used a 10-year period (Feller & Geiger, 1995), this choice is not without precedent. In addition, periods of 15 and 20 years were also considered. However, these periods were deemed too long, since trends in a single RIU-NSF field could emerge and diminish within a 15-year period. The methodology used in this thesis would not capture a sufficient proportion of strategic successes and failures if the period was extended much beyond 10 years.

The period chosen does not include the most current NSF data available, which were for the fiscal year 2005. In order to establish values for 2000a, NSF data up to and including fiscal 2002 are required. NSF data are corrected retroactively when reporting institutions update their records. As more time passes, more of the updates will have been made. As such, it was determined that using the past 3 years would enable virtually all retroactive corrections to have been made. In addition, 2000 is a convenient and easily understood year upon which to base a study of this nature.

This study relies on the efficacy of NSF data in respect of their accuracy and consistency from the perspective that they underlie every calculation in this methodology. In this regard, the reader should take great comfort in the knowledge that NSF data are universally used by universities and colleges, governments, industry, and external reporting agencies for a wide range of uses that include longitudinal analyses as well as for resource allocation decisions at the institutional and system levels. NSF federally financed research expenditure data are highly credible because colleges and universities report honestly and promptly to the annual survey so as not to prejudice their future federal funding. The NSF consistently reports that nearly 98 % of all doctorate-granting institutions provide the required information by the NSF's prescribed due date.

The NSF annual surveys report data that are collected and published annually. As earlier noted, the data are broken down by colleges and universities, including RIUs, and then by science and engineering fields that are defined by the NSF. In other words, it is possible to know that the University of Southern California spent $1.127 million on Chemical in 1999. The NSF also publishes total federally financed research broken down by science and engineering field. As such, it is possible to know that colleges and universities spent $479.583 million in research in Chemistry in 1992.

It is critically important to note that the NSF's survey methods have not changed in any way that would materially impact the results of this study (NSF, 1992-2002). This ensures that the research performed in each field, nationally, and for each RIU, comprises expenditures on topics that continue unchanged over time. New topics often fall into *nec* (not elsewhere classified) fields, a reporting policy that helps maintain the purity of the data in the longer standing fields. The longitudinal use of NSF field data is further supported by its universal use.

Also as earlier noted, NSF defined non-science and engineering research expenditures are not included in the ARM, as defined below. One reason for this is the practical reality that humanities research expenditures data are not published in sufficient detail or for the entire period of the study. Substantial assumptions would be required to integrate the available information into the ARM. The second major reason is that research expenditures in the humanities are relatively small when compared with expenditures in science and engineering. The mechanism in this methodology can cause a disproportionately large impact when small values of expenditures change by relatively large amounts. The exaggerated influence caused by these situations can adversely affect the study results which, in turn, can lead to incorrect conclusions. However, if humanities research was viewed separately, one could speculate that the model used in this thesis would generate information of equal utility. This speculation is supported by a simplified application of this model that was performed on the University of Oxford, Cambridge University, and the University of Glasgow, using Research Assessment Exercise data (RAE, 1992, 1996). This exercise produced a result that, while far from conclusive, appeared reasonable.

Definitions

1. Academic Research Market (ARM): The ARM is defined as the total of all federally financed research and development expenditures in colleges and universities, as reported by the colleges and universities that received those funds, regardless of which federal agency provided those funds. Even though universities receive research funds from other sources, for the purposes of this study these sources have been excluded. For reasons described above, federally financed research expenditures in non-science and engineering fields has also been excluded from this definition. Non-science and engineering fields include "Education, Law, Humanities, Visual & Performing Arts, Business and Management, Communications, Journalism, and Library Science, Social Work, and Other Non-S&E fields" (NSF, 2006d, p. 6). In addition, amounts from NSF fields entitled "Engineering, Other, nec, Physical Sciences, Other, nec, Environmental Sciences, Other, nec, Life Sciences, Other, nec, Social Sciences, Other, nec, Other Sciences, nec, and Engineering, Bioengineering/biomedical" (NSF, 1994-2001) were

excluded. The rationale for excluding nec data is described in the section entitled ARM Data that follows.

2. Total Federal Research Market: The Total Federal Research Market is identical to the ARM, with the addition of all of the nec fields and as well data in the Engineering, Biotechnology/biomedical field.
3. Total Reported: This term applies only to the RIUs. The Total Reported is the sum of the data reported by an RIU in any of the 21 fields listed in Appendix B. For example, Indiana University reports research performance data for 12 of the 21 fields, while the University of Colorado reports in 19 of the 21 fields. In the case of Indiana University, Total Reported is the sum of data occurring in the 12 fields in which it reported research activity.
4. Total Actual: This term applies only to the RIUs. The Total Actual is identical to the Total Reported, with the addition of the data reported in all of the nec fields and the Engineering, Biotechnology/biomedical field.
5. 1990a: 1990a is the arithmetic mean of data from the years 1989, 1990, and 1991 inclusive. The purpose for using an average of years is to mitigate the risk that 1990 was an anomaly. For greater certainty, when the term *1990* is hereafter used, it refers to that actual year. In the circumstances described in the Exceptions Method within Definition 6 below, 1990a is the arithmetic mean of data from the 5 years 1988 to 1992 inclusive.
6. 2000a: 2000a is the arithmetic mean of data from the years 1999, 2000, and 2001 inclusive. As in the case of 1990a, the purpose for using an average of years is to mitigate the risk that 2000 was an anomaly. For greater certainty, when the term

2000 is hereafter used, it refers to that actual year. In the following circumstances, 2000a is the arithmetic mean of the 5 years 1998 through 2002 inclusive. To further reduce the possibility that the expenditures in any field in the component years of 1990a or 2000a were exceptional, the Exceptions Method was used. The threshold used to capture these exceptions had to balance the dampening effect inherent in the defined terms of 1990a and 2000a against the reality that research expenditures in some disciplines fluctuated widely from year to year. As a consequence, it was determined that only very low probability events should trigger an additional adjustment.

The Exceptions Method:

a. The procedure was undertaken for each field in the ARM and each RIU.

b. The percentage change from one year to the next year was determined for all years, beginning with the percentage difference from 1988 to 1989 and ending with the percentage difference from 2000 to 2001.

c. The arithmetic mean of the percentage changes was determined. There were 13 percentage changes.

d. An amount equal to 2σs of the percentage changes was determined.

e. A range equal to the mean determined in point 6 c ± 2σs, as determined in point 6d, was established.

f. Each percentage change was compared with the range, and all amounts that out lay the range were identified.

g. If any of the identified amounts were from the years 1989, 1990, or 1991, then an adjustment was triggered.

h. The adjustment affected 1990a only in the specific field in which the exception occurred. The adjustment was that, instead of using the arithmetic mean of data from the years 1989, 1990, and 1991 to establish 1990a, the arithmetic mean of the 5 years of 1988 to 1992 inclusive was used to establish the value for 1990a.

i. Likewise, if any of the identified outliers were from 1999, 2000, or 2001, then an adjustment was triggered such that 2000a became the arithmetic mean of data from the 5 years of 1998 to 2002 inclusive.

7. Field: A field is a category of research as defined by the NSF. For example, Physics is a field of research that is defined to include "Physics as well as Acoustics, Atomic/Molecular, Chemical, Condensed Matter, Elementary Particles, Nuclear Structure, Optics, Plasma, and Theoretical/Mathematical Physics"(NSF, 1997). There are 21 fields in this study, as listed in Appendix B. A field may also be referred to as a research category or a portfolio component in the case of an RIU, or as a *market segment* or a *market* in the case of the ARM.

8. Currency: Since this study compares percentage changes in the relative sizes of fields and market shares, the effect of currency inflation does not impact the results and, as a consequence, the decision was made to present all currency amounts in nominal United States dollars. For greater assurance, the model was run simultaneously for the ARM using constant 1996 dollars and, while the percentage measurements were smaller than when using nominal dollars, the results were identical.

9. RIU: An RIU is a university that was a member of the Association of American Universities from 1988 to 2002 inclusive (Association of American Universities,

2005), that was classified by the NSF as one of the top 100 recipients of federal research funding from 1988 to 2002 inclusive, and that was categorized by the Carnegie Foundation as a Research University I in its 1987 and 1994 surveys and as a Doctoral/Research University-Extensive in its 2000 survey (Carnegie Foundation for the Advancement of Teaching, 1987, 1994, 2000). The final filter used to define an RIU relates to the consistency of the data that each RIU reported in the annual NSF surveys. All institutions that met the first three conditions had to further qualify by passing a reporting consistency test called the Ratio Variance test. The Ratio Variance test was used to determine whether an RIU's reporting history was sufficiently consistent so that its reported data could be reliably used in the study. The percentage that the Total Reported (see Definition 3) was of the Total Actual (see Definition 4) for 1990a and for 2000a was determined. If the percentage difference between these values was greater than ± 12.5 %, that institution was disqualified from the study. The decision to use the 12.5 % cutoff point was based on the existence of a gap in the ratios actually observed, from slightly more than 10 % to the next institution at nearly 20 %. For example, in 1990a Pennsylvania State University's Total Reported was $75.659 million and its Total Actual was $132.505 million. Its Total Reported was 57.10 % of its Total Actual in 1990a. In 2000a, its Total Reported was 86.20 % of its Total Actual. The percentage difference between these reporting ratios is 50.96 %. Since 50.96 is greater than 12.5, Pennsylvania State University was disqualified from the study.

This RIU definition ensures that only the most research intensive universities were included in the study, while also protecting the quality of the data to the greatest extent possible.

10. x-axis: On a two-dimensional plain, the x-axis represents the values on the horizontal dimension.

11. y-axis: On a two-dimensional plain, the y-axis represents the values on the vertical dimension.

12. EMS: The Equalized Value for Percent of ARM (EMS) is an indicator, as seen in Appendix E, that corresponds to the equalized values for the proportion that each field represented of the ARM in 2000a. EMS comprises one of two equal parts of the Market Strategic Indicator (see Definition 14), the second equal part being ΔEMS (see next definition). The first step in generating EMS for a field is to determine the percentage that each field represented of the ARM in 2000a. For example, in 2000a Mathematics was 1.41 % of the $16.057 billion ARM. This datum can be found in the column entitled "2000a Percent of ARM" in the Mathematics row. The first step used to ensure that EMS was an equally weighted component of MSI was to determine that largest value of "2000a Percent of ARM." This value was then used as the denominator for all other values in for "2000a Percent of ARM" to determine EMS. For example, at 35.32 %, Medical was the field that was the largest proportion of the ARM in 2000a. "2000a Percent of ARM" for Medical was used as the denominator. Astronomy was 1.59 % of the ARM in 2000a. ("2000a Percent of ARM" for Astronomy was 1.59). When divided by 35.32, the value of EMS for Astronomy equaled 0.0449. EMS manifests the earlier

described portfolio theory, which stipulates that the greater the proportion that a market segment represents of a market's total value, the greater will be its strategic importance to the competitors operating in that market. EMS can be used to rank 2000a federally financed R&D expenditures by field as a proportion of the ARM. Fields that have a greater value for EMS represent fields that are a larger proportion of the ARM. Fields that are a larger proportion of the ARM provide better opportunities for the strategic advancement of RIUs than do fields that are a smaller proportion of the ARM.

13. ΔEMS: The Equalized Value for Change in ARM (ΔEMS) represents the equalized values for the change that occurred in the proportion that each field represented of the ARM between 1990a and 2000a. The first step in determining ΔEMS is to find the percentage change in "2000a Percent of ARM" from "1990a Percent of ARM." For example, Civil was 1.32 % of the ARM in 1990a and 1.50 % in 2000a, which means that its share grew by 13.49 % during the period. (1.50 is 13.49 % larger than 1.32.) Agricultural's share was 4.17 % in 1990a and 3.62 % in 2000a, representing a decline in share of expenditures of 13.24 %. This result is presented as "-13.24" in Appendix E, column "Percent Change in Share of ARM" in the Agricultural row. In contrast to EMS, which can only have positive values, ΔEMS can be either positive or negative. In order to ensure that ΔEMS was equally weighted to EMS, the largest value of ΔEMS was equated to one. In the ARM, Political Science had the largest ΔEMS at 27.20 %, and this value was used as the denominator for all values of "Percent Change in Share of ARM." Completing the earlier Agricultural example, the decline of 13.24 % in share, divided by 27.20, produced a ΔEMS for Agriculture

of -0.4868. This is represented as "-0.4868" and can be found in Appendix E, column "Equalized Value for Change in ARM (ΔEMS)" in the Agricultural row. The concept of ΔEMS reflects the earlier described portfolio theory attribute, in which a market's fastest growing segments provide greater strategic opportunities for competitors than do slower growing or contracting market segments. The greater the value of ΔEMS, the faster a market segment has grown as a proportion of the ARM. The greater the value of ΔEMS, the greater the opportunity for strategic advancement there is for the RIUs. For example, ΔEMS for Sociology and Astronomy was 0.8125 and 0.6518, respectively, while it was -0.8145 and -0.9269, respectively, for Chemistry and Physics. The market provided better opportunities for strategic advancement in Sociology and Astronomy than it did in the fields of Chemistry and Physics.

14. MSI: The Market Strategic Indicator (MSI) is the sum of EMS and ΔEMS. This is a repeat of Formula 3, as was earlier displayed in Chapter Two. Market segments that are both the largest and the fastest growing should be considered as those segments that provide the greatest opportunities for competitors. MSI is an indicator that represents the relative size and change in relative size of each of the 21 market segments that comprise the ARM. The greater the value of MSI, the larger and faster growing is that market segment and the greater is the strategic opportunity provided to the RIUs. For example, the market segments of Medical and Biology provide better opportunities for RIUs to generate strategic advancement than do the fields of Mathematics or Economics.

15. Mean MSI: The arithmetic mean MSI ($\overline{\text{MSI}}$) is the total MSI for the ARM (0.1721) divided by the number of market segments (21), which is equal to 0.0082. $\overline{\text{MSI}}$ is used as the intercept on the y-axis on the later described Strategic Portfolio Array.
16. EIS: The Equalized Value for Percent of Institutional Spending (EIS) indicates the equalized values for the proportion that each field represented of an RIU's federally financed research expenditures in 2000a. The first step in generating EIS for a field is to determine the percentage that each field represented of the institution's research expenditures in 2000a. For example, Chemistry was 3.65 % of the $298.563 million spent by the University of Pennsylvania in 2000a. This datum can be seen in the column entitled "2000a Percent of Institutional Spending" in Appendix G in the Chemistry row. Since EIS comprises one of two equal parts of the Institutional Strategic Indicator (see Definition 18), all values of "2000a Percent of Institutional Spending" were adjusted by the factor that equated the largest value to one. At the University of Pennsylvania, Medical had the largest share in 2000a at 51.02 %, and this value was used as the denominator for all values of "2000a Percent of Institutional Spending." For example, Chemistry was 3.65 % of the University of Pennsylvania's expenditures in 2000a. When divided by 51.02, the value of EIS for Chemistry equals 0.0716. This result can be observed in Appendix G, column "Equalized Value for Percent of Institutional Spending (EIS) in the Chemistry row. EIS parallels the portfolio theory attribute in which the largest components of a multiunit enterprise's total portfolio are more strategically important to it than are its smaller components. In this methodology, the larger the

value of EIS, the more strategically important those fields are to the RIU. At the University of Pennsylvania, Biology is more important than Electrical.

17. ΔEIS: The Equalized Value for Change in Share of Spending (ΔEIS) represents the equalized values for the change that occurred in the proportion that each field represented of an RIU's federally financed research expenditures between 1990a and 2000a. ΔEIS is determined by finding the percentage change from "2000a Percent of Institutional Spending" to "1990a Percent of Institutional Spending." For example, at the University of Pennsylvania, Sociology was 0.79 % of spending in 1990a and 0.97 % in 2000a, which means that its share of institutional expenditures grew by 23.04 % during the period. (0.97 is 23.04 % larger than 0.79). Physics' share was 5.39 % in 1990a and 3.77 % in 2000a, representing a decline in share of expenditures of 30.03 percent. This value is represented as "-30.03" and can be found in Appendix G, column "Percent Change in Share of Institutional Spending" in the Physics row. In order to equally weight ΔEIS with EIS, the largest value of "Percent Change in Share of Institutional Spending" was equated to one. At the University of Pennsylvania, Political Science was the largest "Percent Change in Share of Institutional Spending" at 77.89. This value was used as the denominator for all values of "Percent Change in Share of Institutional Spending." Completing the earlier Physics example, the decline of 30.03 % in share, divided by 77.89 produced a ΔEIS for Physics of -0.3855. This is represented as "-0.3855," and can be found in Appendix G, column "Equalized Value for Change in Share of Spending" (ΔEIS) in the Physics row. Portfolio theory says that, in any multiunit enterprise, faster growing portfolio components are more strategically important

than slower growing ones. The concept is that, in limited resource environments, portfolio components that grow relatively rapidly are absorbing resources faster than other portfolio components. RIU research operations exist in a limited resource environment. The decisions that enable resource allocations represent strategic activation. Those components that are receiving a disproportionate share of resources are strategically more important than other components in an RIU's portfolio. The greater the value of ΔEIS, the faster growing is the proportion that field represents of an RIU's total portfolio and the more strategically important it is to that RIU. At the University of Pennsylvania, Biology is more strategically important than is Civil.

18. ISI: The Institutional Strategic Indicator (ISI) is the sum of EIS and ΔEIS, and is a repeat of Formula 2, as was displayed in Chapter 2. Portfolio components that are both the largest and the fastest growing should be considered as the most strategically important to an organization. ISI is an indicator that represents the relative size, and change in relative size, of every component in an RIU's portfolio. The greater the value of ISI in any RIU, the more strategically important is that field to it. In the case of the University of Pennsylvania, Medical and Sociology are more strategically important to it than are Chemical or Electrical.

19. Mean ISI: The arithmetic mean ISI ($\overline{\text{ISI}}$) is equal to the sum of the ISIs from all RIUs (113.067) divided by the total number of fields reported by all RIUs (628), which is equal to 0.1800. $\overline{\text{ISI}}$ is used as the intercept on the x-axis on the later described Strategic Portfolio Array.

20. ΔMS: The Change in Share of the ARM (ΔMS) is the percentage difference in the share of the ARM held by an RIU in 2000a as compared with 1990a. The ARM share held by an RIU in 1990a is determined by dividing its Total Reported for 1990a by the ARM in 1990a. Dividing the University of Pennsylvania's Total Reported in 1990a of $128.994 million by the ARM in 1990a of $8,634.825 million produces a market share of 1.49 %. This datum can be found in Appendix G, column "1990a Percent of ARM," in the Total Reported row. Determining the University of Pennsylvania's 2000a share of the ARM entails dividing its Total Reported in 2000a of $298.563 million by the ARM in 2000a of $16,056.698 million producing a market share of 1.86 %. This makes it possible to state that the University of Pennsylvania's share of the ARM grew by 24.47 % during the period. (1.86 is 24.47 % larger than 1.49.) Formula 4 presents the calculation of ΔMS.

Formula 4: Calculation of ΔMS for Each RIU

For each RIU, $\Delta MS = 100 \times \{[(\text{Total Reported}_{2000a}/\text{ARM}_{2000a})- (\text{Total Reported}_{1990a}/\text{ARM}_{1990a})]/(\text{Total Reported}_{1990a}/\text{ARM}_{1990a})\}$

Where ARM_{1990a} is the ARM in 1990a, $\text{Total Reported}_{1990a}$ is Total Reported in 1990a, ARM_{2000a} is the ARM in 2000a, and $\text{Total Reported}_{2000a}$ is Total Reported in 2000a.

ΔMS is the critical measurement of strategic success in this study since it measures the actual performance of an RIU in relation to all other RIUs and in relation to the ARM. An RIU that has increased its market share to a greater degree than its competitors has achieved a better strategic outcome.

21. Other Market Performance Taxonomy: Market performance is described by quoting the actual ΔMS realized by an RIU, or by referring to its performance as either market outperform, market perform, or market underperform. A *market outperformer* is an RIU that realized a ΔMS that was greater than $0.5\sigma_{\Delta MS}$ from the mean ΔMS ($\overline{\Delta MS}$). Any RIU that has achieved a ΔMS of greater than 7.13 is a market outperformer. Eleven RIUs satisfy this condition. A *market underperformer* is an RIU where $\Delta MS < \overline{\Delta MS} - 0.5\sigma_{\Delta MS}$, or a ΔMS of -11.69 or less. There are 14 RIUs that meet this condition. The remaining 14 RIUs' ΔMSs fall within $\pm 0.5\sigma_{\Delta MS}$, and these are referred to as *market performers*. As shown in Table 3, $0.5\sigma_{\Delta MS}$ was chosen as the delineator because it created the most evenly spread array of ΔMSs. A range of $\sigma_{\Delta MS}$s were considered in this decision.

Table 3
Establishment of Performance Groups

	Underperform	Market perform	Outperform
Range ($\sigma_{\Delta MS}$)	$< -0.5\sigma_{\Delta MS}$	$-0.5\sigma_{\Delta MS}$ to $0.5\sigma_{\Delta MS}$	$> 0.5\sigma_{\Delta MS}$
Range (ΔMS)	$< \overline{\Delta MS} - 11.69$	- 11.69 to 7.13	$> \overline{\Delta MS} + 7.13$
# RIUs	14	14	11

Selecting and Accessing Data

Federally funded research is that source of research funding that has been the sustaining source of funds upon which America's public research capacity and capability has been built and within which America's RIUs compete (Rosensweig, 1992). The NSF presents federally funded research data in two forms. The first is a survey series generally entitled "Federal obligations for research to universities and colleges" (NSF, 1992-2004b; NSF, 1988-2002). This form was not used because some research funding obligations span several periods and, in some instances, the obligations may not have been satisfied. Both of these factors tend to add unnecessary complications. The form selected was a survey series generally entitled "Federally financed R&D expenditures at universities and colleges" (NSF, 1992-2004b; NSF, 1988-2002). The NSF provides this survey data for all recipients of federal research funds, broken down by science and engineering field, for annual periods beginning in 1972. These data were used because they reflect a current cash accounting methodology wherein each survey participant reports the research it performed in each annual period, regardless of when the funding was received. Thus, a clean cut-off is achieved. Importantly, from 1988 through 2002 inclusive, the NSF's survey methodology, including field definitions, data reporting instructions, corrections for errors and omissions, and data presentation, did not change in any way that would materially impact the results of this study. However, users of NSF data should access the most currently available surveys because minor adjustments are made when reporting institutions provide updated information in subsequent reporting periods.

The two main categories of data that were collected for this study were for the national market (ARM data) and for each RIU (Accessing and processing RIU data).

ARM Data

For the ARM, the required data were retrieved from various NSF websites (NSF, 1992-2004b; NSF, 1988-2002). A chart was set up on a Microsoft Excel spreadsheet to receive the data from the NSF websites. The chart's columns were the NSF fields and its rows were the years 1988 through 2002 inclusive (see Appendix D). For convenience, the order in which the fields were reproduced on the spread sheet matched the NSF surveys and remained consistent across the ARM chart and those of the RIUs. A row at the bottom of the ARM chart, labelled ARM, represents the sum of federally financed R&D reported in the 21 included fields in each year. In this study, ARM is the value of the academic research market in each year.

Prior to using the data in the model, they were examined for anomalies to ensure that the results were not skewed by the inadvertent inclusion of unusual events, a check that included the Exceptions Method (see Definition 6). It is important to note that the steps used to prepare the ARM data were also applied to the data of each RIU. The three most obvious irregularities in the Total Federal Research Market data were that (a) the reporting of research activity in the field of BioEng begins only in 1999, (b) reporting in the field of Metal & Mat begins only in 1990, and (c) the nature of the research activities that occurred in all fields in which the acronym nec appears (NSF, 1992-2004b) required an accurate description or they would have to be disqualified from use in the study.

Extrapolation was used in cases where there were missing years of data and where this technique provided a result that was reasonable in the circumstances. The Extrapolation Rules used to establish whether extrapolation provided results that were reasonable were as follows:

1. At least 3 consecutive years of data were required to extrapolate the next consecutive year at either end of the known series, but not both.
2. At least 4 consecutive years of data were required to extrapolate the 2 consecutive years at either end of the known series, but not both.

3. At least 6 consecutive years were required to extrapolate the next 3 consecutive years at either end of the known series, but not both.
4. The maximum number of known years was always used.
5. The maximum number of years that could be extrapolated was 3.
6. No datum was used to extrapolate more than once.

The method used to extrapolate missing data was to determine the slope of a line using the first and last values in the known series. When divided by the number of years in the known series, the average annual change in expenditures results. This amount was added or subtracted, as appropriate, to the last known series value to provide the extrapolated value of expenditures for the next year. The final step was repeated when multiple years were being extrapolated.

The Extrapolation Rules enabled establishing values of research expenditures for Metal & Mat in 1989 of $130.453 million and in 1988 of $121.744 million. The method described required the disqualification of BioEng as a usable field in this study.

The exclusion of all nec fields was an important decision because, in some disciplines, they represented a significant proportion of an RIU's total research performance. For example, in the Total Research Market data, nec represented between 21.2 and 35.5 % of expenditures in the Engineering Sciences in the years 1987 to 2001. The problem of using nec data arose when trying to define what research was encompassed within this category. The NSF's definition of nec fields makes it is possible for a single RIU to classify the same research project differently from year to year, or for the same type of research to be classified differently between RIUs. The extent of inconsistent reporting cannot be known and, as a consequence, the data within the nec fields are unreliable. The NSF's definitions of non-nec fields are specific enough as to reduce the possibility of inconsistent reporting of this nature. In addition, nec research may have been comprised of one-time events, of projects that were incomplete or that, as was the case in Metal and Mat and BioEng, grew to a size that was sufficiently large for the NSF to establish a separate field. All of these examples are presented to support the notion that the research that occurred in nec fields was unknowable and transient. Research of this nature cannot be understood as a strategic thrust or, if these activities were strategic, they were unsuccessful and not relevant to this study. As such, all nec fields were disqualified from the study.

After making the aforementioned adjustments, which included the disqualification of all nec fields and BioEng, the 21 remaining fields comprised the ARM data used in this study (see Appendix B). The same 21 fields were used for the RIUs.

Using the method described in the Exceptions Method within Definition 6, the next step was to check for anomalies in the data presented in each field. In the ARM, Aero/Astro, Electrical, Astronomy, and Medical for 2000a were the only fields that required adjustments of this nature.

Processing the ARM Data

The ARM data were now ready for use in the model. The following descriptions should be read in conjunction with Appendix E.

1. The first column to the right of the field names is the defined term 1990a. At the bottom of this column is the ARM, which displays the sum of the 21 field values; the ARM in 1990a was $8,634.825 million. It is important to note that the ARM for 1990a is not necessarily equal to the arithmetic mean of data from 1989, 1990, and

1991, since some field values may be the arithmetic mean of 5 years (see Definition 6). Coincidentally, the ARM for 1990a is the arithmetic mean of the ARM for the years 1989, 1990, and 1991, but this is not true for the ARM for 2000a.

2. The next column, entitled "1990a Percent of ARM," is the percent that each field represented of the ARM in 1990a. For example, expenditures in Electrical in 1990a were $418.109 million. This was 4.84 % of the 1990a ARM of $8,634.825 million. This calculation was made for each field. By definition the total for this column is 100 %.

3. The following two columns, respectively, are "2000a" and "2000a Percent of ARM" and were created using the same procedure described in point 1 and 2 above. As a matter of confirmation, the ARM for 2000a was $16,056.698 million, and the "2000a Percent of ARM" summed to 100.

4. The next column is entitled "Percentage Change in Share of ARM," a name that accurately reflects its meaning. This column represents the percentage change that occurred from the "1990a Percent of ARM" to the "2000a Percent of ARM." For example, Ocean was 3.03 % of the ARM in 1990a and was 2.65 % of the ARM in 2000a, a decline of 12.68 % (2.65 is 12.68 % less than 3.03). In the column entitled "Percent Change in Share of ARM," this appears as -12.68. There is no need to determine the ARM for this column, although, as a separate statistic and at the risk of confusing the meaning of this column, it is interesting to note that the nominal value of the ARM grew by 85.95 % during the study period.

It is important to recognize that the 2000a Percent of ARM and the Percent Change in Share of ARM represent the relative size, and change in relative size, of each market segment of the ARM. These indicators manifest portfolio theory in that the larger that each of these indicators is, the greater the opportunity there is for RIUs to achieve their strategic objectives. As earlier described, EMS and ΔEMS are the equally weighted converted values of these indicators which, in turn, are subsumed in MSI.

5. The following two columns are "EMS" and "ΔEMS" (see Definitions 12 and 13). There is no need to determine the ARM for these columns.
6. The final column is MSI (see Definition 14). MSI for each field is the sum of EMS and ΔEMS, and is a factor representing the strategic market opportunities that each field holds for the RIUs. The greater the value of MSI, the more market potential there is.

Accessing and Processing RIU Data

The Institutional Strategic Indicator (ISI) was determined for the RIUs using, with noted exceptions and additions, the same operations that were used to determine MSI. Using the example of the University of Pennsylvania, the following steps were used to determine the ISIs for every RIU.

A chart was set up on a Microsoft Excel spreadsheet to receive data accessed from the NSF's Caspar website (NSF, 1988-2002), and the procedure described in Appendix C was used. The chart's x-axis was the years 1988 to 2002, inclusive, and the y-axis was the 21 fields. At the bottom of the y-axis were two rows labelled Total Reported (see Definition 3) and Total Actual (see Definition 4). Total Actual data were required only for the years 1989, 1990, 1991, 1999, 2000, and 2001. All fields were subjected to the

Extrapolation Rules and the Exceptions Rule, the results of which are displayed in Appendix F. The University of Pennsylvania reported research activity in 16 fields.

Once the above described operations were complete, the data were ready to use in the model as displayed in Appendix G.

1. The first column to the right of the field names is the defined term 1990a. At the bottom of this column is the Total Reported and the Total Actual for 1990a.
2. The next column, entitled "1990a Percent of Institutional Spending," is the percent that each field represents of Total Reported in 1990a. For example, at the University of Pennsylvania, expenditures in Psychology of $1.465 million in 1990a were 1.14 % of the 1990a Total Reported of $134.003 million.
3. The next column is called "1990a Percent of ARM." The important figure in this column is the Total Reported, which is the share of the ARM held by the RIU in 1990a. Specifically, this figure is determined by dividing the Total Reported in 1990a, $134.003 million, by the ARM for 1990a, $8,643.825 million, which is equal to 1.49 %.
4. The next column is the defined term "2000a." At the bottom of this column is the Total Reported and Total Actual for 2000a which, once known, can be used in conjunction with the 1990a data to run the Ratio Variance test (see Definition 9). Since the University of Pennsylvania's reported variance was -1.38 %, it qualifies as an RIU.
5. The next two columns are "2000a Percent of Institutional Spending" and "2000a Percent of ARM," which are derived using the same method as was used in steps 2 and 3 above, with the exception that 2000a data were used instead of 1990a data.

Importantly, the Total Reported for 2000a Percent of ARM was 1.86 %. In other words, the University of Pennsylvania's share of the ARM in 2000a was 1.86 %.

6. The next column, entitled "Percent Change in Share of ARM," is determined by finding the percentage difference between "1990a Percent of ARM" and "2000a Percent of ARM." The important figure in this column is the Total Reported since this is ΔMS for this institution (see Definition 20). Specifically, the Total Reported for the Percent Change in Share of ARM was 1.49 % in 1990a and was 1.86 % in 2000a resulting in an increase in market share over the study period of 24.47 % (i.e.: 1.86 is 24.47 % larger than 1.49). ΔMS for the University of Pennsylvania is 24.47. From a practical perspective, it is important for an RIU to understand how it is performing in real terms, against the ARM, and against other competitors in each field in its research portfolio. While not specifically used in this study, the share of the ARM for 1990a, 2000a, and the Percent Change in Share of ARM have been determined for each field, for every RIU, and are presented in Appendix G.

7. The next column is the "Percent Change in Share of Institutional Spending." Continuing the earlier example of Psychology at the University of Pennsylvania, 1990a Percent of Institutional Spending was 0.87 % and was 0.85 % in 2000a. This means that Psychology's share of spending declined by 2.64 % during the study period (i.e.: 0.85 is 2.64 % less than 0.87). The "Percent Change in Share of Institutional Spending" is determined for all fields.

It is important to recognize that the 2000a Percent of Institutional Spending and the Percent Change in Share of Institutional Spending represent the relative size, and change in relative size, of an RIU's portfolio components. When equally weighted, their values are represented as EIS and ΔEIS, which are both subsumed in ISI. In this application, portfolio theory is interpreted such that the larger the value of ISI, the more strategically important it is to an RIU.

8. The following two columns are "EIS" and "ΔEIS" (see Definitions 16 and 17). There is no need to determine the Total Reported or Total Actual for these columns.
9. The final column is ISI. ISI for each field is the sum of EIS and ΔEIS, and is the indicator representing the strategic priority that each field is to an RIU. The greater the value of ISI, the more strategically important it is to the RIU.
10. A Strategic Portfolio Array (Array) is created for each RIU, as displayed in Appendix H. The four quadrants are formed by an x-axis intercept at the $\overline{\text{ISI}}$ (which is 0.1800, see Definition 19) and a y-axis intercept at $\overline{\text{MSI}}$ (which is 0.0082, see Definition 15). The quadrants are hereafter referred to as the northwest (NW), northeast (NE), southwest (SW), and southeast (SE).
11. Each field is plotted on an Array such that the value of x is ISI and the value of y is MSI for coordinate points at (ISI, MSI). For example, ISI for Chemical at the University of Pennsylvania was -0.2972, and MSI for Chemical was -0.106 creating a coordinate point or incident for Chemical at (-0.2972, -0.106). This incident occurs in the SW quadrant. All fields where research activity was reported are plotted on a separate Array for each RIU.
12. The number of incidents in each quadrant was counted and recorded in Appendix I.

Calculating the Results

ΔMS, the number of fields in which research activity was reported, and the number of incidents that occurred in each quadrant is now known for each RIU. Appendix I displays the compilation of these data.

1. The first two columns of Appendix I are the RIUs, sorted in descending order according to their ΔMS and their ΔMS. For example, the University of Pennsylvania, which is 5th from the top, had a ΔMS of 24.47.
2. The next column is the number of fields in which research activity was reported for each RIU. For example, the University of Pennsylvania reported activity in 16 fields. As seen at the base of this column, there were a total of 628 fields reported by the 39 RIUs. The mean number of fields per RIU was 16.10. In other words, during the study period, the average RIU reported federally financed research in slightly more than 16 fields.
3. The next four columns record the number of incidents that occurred in the quadrants of each RIU's Strategic Portfolio Array. Continuing the example of the University of Pennsylvania, there were no incidents in its NW quadrant, four in its NE, 10 in its SW, and 2 incidents in its SE quadrant. This information is displayed as follows in Table 4 as it appears in Appendix I.

Table 4
The University of Pennsylvania's ΔMS and its Strategy Portfolio Array configuration

RIU	ΔMS	# fields	# NW	# NE	# SW	# SE
University of Pennsylvania	24.47	16	0	4	10	2

At the bottom of each of the four columns in Appendix I is the total number of incidents in the quadrant, the mean number of incidents that occurred in each quadrant, and their correlation to ΔMS. For the entire population of RIUs, the mean number of incidents in the NW quadrant was 2.56, there were 3.36 in the NE, 7.26 in the SW, and 2.92 in the SE quadrant. On average, the SW quadrant had more than twice the number of incidents of any other quadrant. The SW quadrant contains 45.06 % of the average number of fields (7.26 divided by 16.10).

4. Correlations to ΔMS or, when specified, R^2, are critical in this study, as they provide insight into the relationship between the number of incidents that occurred in various quadrants of the RIU's Arrays and their market performance as expressed by ΔMS. Although interpretations of these data are presented elsewhere (see Chapter Five), it can be said that, at -0.316, there does appear to be a moderate inverse correlation between the # SE and the value of ΔMS. That is, as ΔMS declines, the average number of incidents in the SE quadrant will tend to increase. At 0.286, a slightly weaker but direct correlation exists between the # SW and ΔMS.

5. The following series of columns in Appendix I are the quadrants, and combination of quadrants, that yielded the highest correlation of all those examined. These are called *analytic variables*. All sets of analytic variables employ the principle that every institution's mix of portfolio components is relative only to the portfolio of which it is a part. In other words, every set of EISs and ΔEISs is specific to the portfolio of the RIU from which it was derived. Methodologically, this requires that the number of incidents in the quadrants of any RIU be viewed in relation to the

number of fields in which that RIU reported research activity. This view produces a ratio whereby the number of incidents in a quadrant, or combination of quadrants, is always divided by the number of fields in which research was reported by the corresponding RIU. Whether it chose to be engaged in 16 fields or it just unfolded that way, the University of Pennsylvania's strategy was to compete in 16 market segments. In addition, it realized a strategy that included 10 incidents in its SW quadrant. The University of Pennsylvania's strategy was to operate 10 out its 16 research portfolio components in its SW quadrant. Ten of 16, or 10 divided by 16, or 0.63 of its portfolio was in its SW quadrant. The Ratio Method more truly represents the realized strategies of the RIUs and, as a consequence, provides a more accurate correlation to ΔMS. The correlation between the # SW and ΔMS is .286 whereas the correlation between the SW quadrant and ΔMS using the Ratio Method is a much stronger .398. This result can be seen at the bottom of the analytic variable entitled "SW."

6. In Appendix I, all sets of analytic variables use the Ratio Method.
7. In order to find those analytic variables that were most closely correlated to ΔMS, every possible combination of quadrants was examined that could be produced using only addition and subtraction. There were 30 such combinations. Multiplication and division were not used to determine analytic variables because RIUs cannot multiply or divide their portfolio of research operations whereas they can add and subtract and add or subtract them. In addition, three additional sets of analytic variables entitled Largest - Smallest, Largest - 2nd Largest, and Largest - 2nd Smallest were developed, for a total of 33 sets of analytic variables. Appendix I

presents only those sets of analytic variables that exhibited a correlation to ΔMS that was greater than .425. While this value seems like a somewhat arbitrary cut-off point, the next lower correlation values represent sets of variables that would not significantly add to the understanding of strategy presented in Chapter Six.

8. The analytic variables in Appendix I represent those quadrants, or combination of quadrants, that exhibited the strongest correlative relationship to ΔMS. As earlier mentioned, each combination uses the Ratio Method. For example, the first set of analytic variables is labelled NW + SE. This variable set is derived by adding the values of NW and the SE for each RIU. For example, Northwestern University's NW was 0.20 and its SE was 0.07 establishing a value for NW + SE of 0.27. An alternative method of deriving this value is by using Formula 5.

Formula 5: Using the Ratio Method to Calculate the NW + SE Quadrants

For each RIU, NW + SE = (# NW + # SE)/# fields

The correlation between the NW + SE variable and ΔMS is -.453. This relationship indicates that the greater the proportion of incidents that an RIU has in its NW and SE quadrants, the more likely it will be a market underperformer. Notably, there can never be a perfect correlation since there can never be a perfect strategy that was perfectly planned and perfectly executed. In the case of universities, Baldridge et al.'s (1986) argument, that varied and often conflicting goals serve to emphasize this point.

Statistical Analysis

The statistical analysis was undertaken only for those analytic variables listed on Appendix I and for selected composite strategies (see part 15 below).

1. The correlations in this analysis were determined using the Microsoft Excel correlation function and Statistical Package for the Social Sciences (SPSS). All other statistical analyses were undertaken using SPSS.
2. The entire population of subjects in this study RIUs comprises the 39 RIUs. There is no absolute representation made that the results of this methodology reflects any non-RIU university's research performance. However, there is a distinct possibility that this methodology is a significant step toward the creation of a generalizable model. In any event, there is no inference related calculations required. It is also methodologically notable that no adjusted R^2 statistic is referenced, since there is no risk that other members of the population of RIUs would impact the existing relationship. As noted above, the only RIUs are those included in this study.
3. The variables are ΔMS and each set of analytic variables. This is a univariate analysis.
4. This is a retrospective study. This is not an experimental study; there is no control group. This is a study that uncovers relationships that existed during the defined study constraints.
5. The question asked by this thesis is whether the research strategies of RIUs produce outcomes that reflect those strategies. Implicit in this question is that the RIUs' strategies are the independent variable, and ΔMS is the dependent variable. One corollary question is whether there is a strategy that is more likely to produce a

market outperformance. If there is, RIUs will want to pursue it. Strategy is the independent variable because RIUs can choose their strategy and ΔMS is the dependent variable because its value depends on the strategy that each RIU has realized. Stated differently, RIUs can only choose a possible ΔMS by adopting the appropriate strategy.

6. ΔMS and the RIU strategies, as represented on their Strategic Portfolio Arrays, are continuous variables. ΔMS has a range of -34.67 to 36.78, and a zero value for ΔMS equates to a market performance that is exactly the same as the mean ARM performance. RIU strategies are comprised of ISI and MSI, each of which have positive, negative, and zero values. A zero strategy, (i.e.: where all incidents on an RIU's Strategic Portfolio Array are at the source) represents a university that does not perform any federally financed research.

7. It was determined that ΔMS was normally distributed. The following steps were used to reach this conclusion:

   a. A histogram enabled a visual inspection of the distribution.

   b. The skewness statistic (0.396) was less than twice the skewness error (0.378), and the kurtosis statistic (-0.558) was less than twice the kurtosis error (0.741).

   c. There were no outliers.

8. Since ΔMS is normally distributed, $\overline{\Delta MS}$ is used for statistical analysis purposes. $\overline{\Delta MS} = -2.277$.

9. There were 39 RIUs. The minimum value for ΔMS was -34.67, and the maximum value was 36.78, establishing a range of 71.45.

10. The $\sigma_{\Delta MS}$ was 18.818. $\overline{\Delta MS} \pm \sigma_{\Delta MS}$ encompasses a range of ΔMS from -21.095 to 16.541. Twenty-five of the 39 RIUs, or 64.10 %, fit within this range. $\overline{\Delta MS} \pm 2\sigma_{\Delta MS}$ encompasses a range of ΔMS from -39.913 to 35.359. Only Northwestern University, with a ΔMS of 36.78 or $2.057\sigma_{\Delta MS}$, falls outside of this range. $\sigma_{\Delta MS}$ in this population is relatively large, indicating that it is broadly distributed. There is a lot of variability in the strategic research outcomes of the RIUs.
11. ΔMS is the dependant variable in this study.
12. All sets of analytic variables that had a correlation to ΔMS of greater than .425 were further analyzed using SPSS. These variables are listed in Table 5.
13. A histogram was produced and a visual inspection was made of the distribution of each variable set. Skewness and kurtosis tests were run to establish the nature of the distribution of each variable set. There were 39 RIUs in each variable set. This information is listed in Table 5. All analytic variables are independent variables.

Table 5
The Means, Ranges, Standard Deviations, and Other Statistical Attributes of the Analytic Variables

Analytic variable	Mean	Minimum value	Maximum value	Range	Standard deviation	Outliers	Distribution
NW + SE	0.34	0.08	0.61	0.53	0.1341	None	Normal
NE + SW	0.66	0.39	0.92	0.53	0.1341	None	Normal
NW - SW	-0.29	-0.63	0.00	0.63	0.1371	None	Normal
NW - NE - SW	-0.51	-0.91	-0.19	0.72	0.1748	None	Normal
SW - NW - SE	0.11	-0.55	0.50	1.05	0.2452	None	Normal
(SW + NE) - NW - SE	0.33	-0.22	0.83	1.06	0.2683	None	Normal
Largest - Smallest	0.40	0.13	0.63	0.50	0.1168	None	Normal
Largest - 2nd Largest	0.23	0.06	0.40	0.34	0.1212	None	Normal
Largest - 2nd Smallest	0.22	0.00	0.40	0.40	0.1103	None	Normal

14. The next step was to establish the strength of the relationship between each analytic variable and ΔMS. This involved further use of SPSS to determine the correlation, the R^2 value, the regression coefficient, the *SE* of the coefficient, the regression

constant, and the *SE* of the constant for each analytic variable. These statistics are displayed in Table 6.

Table 6
The Correlations to ΔMS, R^2, and Other Statistics of the Analytic Variables

Analytic variable	Correlation to ΔMS	R2	Regression coefficient	Coefficient SE	Regression constant	Constant SE
NW + SE	-.453	.205	-63.52	± 20.57	19.12	± 7.45
NE + SW	.453	.205	63.52	± 20.57	-44.39	± 13.91
NW - SW	-.468	.219	-64.24	± 19.94	-20.88	± 6.37
NW - NE - SW	-.427	.182	-45.97	± 16.00	-25.62	± 8.58
SW - NW - SE	.453	.205	34.75	± 11.25	-6.02	± 2.98
(SW + NE) - NW - SE	.453	.205	31.76	± 10.28	-12.63	± 4.32
Largest - Smallest	.433	.188	69.78	± 23.88	-29.77	± 9.80
Largest - 2nd Largest	.507	.257	78.67	± 22.00	-18.57	± 5.26
Largest - 2nd Smallest	.443	.196	75.59	± 25.15	-24.28	± 7.82

15. The next step was to determine whether any stronger correlations exist by combining strategies. As discussed in Chapter Five, there are basically two types of analytic variables. The first type is combinations of quadrants and includes NW +

SE, NE + SW, NW - SW, NW - NE - SW, SW - NW - SE, and (SW + NE) - NW - SE, which are aptly called *combination variables*. The second type of analytic variable is called a *derivative variable* and describes the spread between the proportionate number of incidents in various quadrants of an RIU's Strategic Portfolio Array. They are called derivative variables because their value is derived by calculating the proportionate values in the quadrants, regardless of which quadrants they are. Note that all variables represent the strategies that could be, or that have been, realized by the RIUs. For practical application, it is possible to engage a strategy that employs both a combination variable and a derivative variable, or derivative variables, simultaneously. Variables comprised of combination variables and derivative variables are called *composite variables*. An RIU can maximize the proportionate number of incidents it has in its NE and SW quadrants and, at the same time, it can maximize the spread between the quadrant with the greatest proportionate number of incidents and the quadrant with the second greatest proportionate number of incidents. In other words, an RIU can use the NE + SW strategy and the Largest - 2nd Largest strategy at the same time. However, an RIU cannot maximize the proportionate number of incidents in its NW + SW quadrants and NW - NE - SW quadrants at the same time. Lastly, an RIU can engage a strategy that simultaneously includes the Largest - Smallest, Largest - 2nd Largest, and Largest - 2nd Smallest together with only one of the combination strategies, or together with only one of any of the single quadrant variables.

16. Using a correlation matrix generated by SPSS, all analytic variables were correlated with each other in order to gain some insight as to which strategies, when engaged

simultaneously, might produce an even stronger correlation to ΔMS than when any is engaged alone. As a general rule of thumb, whenever the correlation between two analytic variables is less than the correlation between either of the component variables and ΔMS, there is a greater chance that the simultaneous strategy will produce a stronger correlation. For greater certainty, each derivative variable, and combination of derivative variables, was combined with a combination variable and, using multiple regression analysis, correlated with ΔMS. The highest correlative results are presented in Table 7 with the R^2 statistic immediately below each correlative value.

Table 7
The Correlations to ΔMS and the R^2 Resulting from the Multiple Regression Analysis of the Analytic Variables

Derivative strategy combined with		NW+SE	NE+SW	NW-SW	NW-NE-SW	SW-NW-SE	(SW+NE) - NW-SE
Largest - Smallest	Correlation	.502	-.502	.505	.483	.507	.502
	R^2	.252	.252	.256	.233	.257	.252
Largest - 2nd Largest	Correlation	.595	-.595	.579	.614	.565	.595
	R^2	.354	.354	.335	.377	.319	.354

Derivative strategy combined with		NW+SE	NE+SW	NW-SW	NW-NE-SW	SW-NW-SE	(SW+NE) - NW-SE
Largest - 2nd Smallest	Correlation	.508	-.508	0.499	.512	.491	.508
	R^2	.259	.259	.249	.262	.241	.259
Largest - Smallest and Largest - 2nd Largest	Correlation	.595	-.595	.580	.618	.570	.595
	R^2	.354	.354	.336	.382	.325	.354
Largest - Smallest and Largest - 2nd Smallest	Correlation	.517	-.517	.512	.515	.511	.517
	R^2	.267	.267	.262	.265	.261	.267
Largest - 2nd Smallest and Largest - 2nd Largest	Correlation	.600	-.600	.587	.620	.568	.600
	R^2	.360	.360	.344	.385	.322	.360
All three derivative strategies	Correlation	.601	-.601	.591	.622	.578	.601
	R^2	.362	.362	.349	.387	.334	.362

17. In this study the populations of each data set were normally distributed, and there were no outliers. An arbitrary boundary had to be established to identify those RIUs that were the most abnormally situated in comparison with the entire population. Using SPSS, a scatter plot was produced for each analytic variable (which is presented on the x-axis) and ΔMS (which is presented on the y-axis) upon which the linear regression line and 90 % prediction boundary lines were drawn. Composite variables were not examined in this manner. In each case, those RIUs that were represented by points that occurred entirely outside of the 90 % prediction boundary were identified. This process negated the need to determine the standard residuals, since the visual inspection identified those RIUs that outlay the selected confidence boundaries. Figure 3 shows the scatter plot that was created for the NW - SW strategy. The only incident that was entirely above the upper boundary was Northwestern University, and the only incident that was entirely below the lower boundary was Johns Hopkins University.

Examining outliers can be instructive when attempting to determine a causal relationship between variables by exposing some of the factors for the anomaly. Alternatively, examining anomalies may help eliminate some potential causal factors in a given relationship. Figure 3 was produced to demonstrate that this type of analysis could be undertaken with the available data. In future research, this analysis could produce important insights. However, the focus of this thesis is whether there is a relationship between the research strategies of RIUs and ΔMS and is not about the causal factors underlying such a relationship. As a result, an analysis in respect of outliers has not been done.

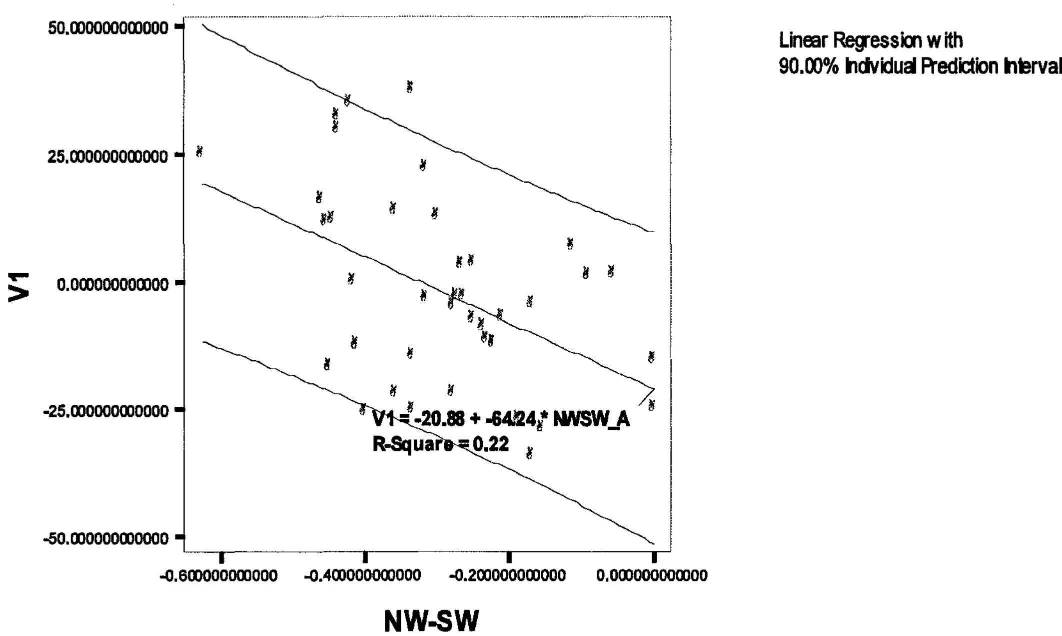


Figure 3. Identification of RIUs that outlay the 90 % prediction boundaries on a regression graph of the NW - SW analytic variable.

18. The RIU or RIUs that outlay the 90 % predictability boundaries were identified and removed from the population, and the adjusted variable set was correlated with ΔMS. The adjusted correlations are displayed in Table 8, in comparison with the unadjusted correlations.

Table 8
Correlation of analytic variables to ΔMS before and after removing outlying RIUs from the population

Analytic Variable	Unadjusted correlation to ΔMS	RIUs removed from population	Adjusted correlation to ΔMS
NW + SE	-.453	Northwestern University	-.452
NE + SW	.453	Northwestern University	.452
NW – SW	-.468	Northwestern University, Johns Hopkins University	-.524
NW - NE - SW	-.427	Northwestern University, University of Colorado	-.435
SW - NW - SE	.453	Northwestern University	.446
(SW + NE) - NW - SE	.453	Northwestern University	.452
Largest - Smallest	.433	Northwestern University, University of Missouri, New York University	.497
Largest – 2nd Largest	.507	University of Missouri, University of Wisconsin, Cornell University	.637
Largest – 2nd Smallest	.443	Northwestern University, University of Missouri	.464

Summary

This chapter presented a methodology that conforms to the scientific method in that it will produce identical results if followed diligently. While this methodology, and the underlying data may be reductionist to ethnographers, it preserves credibility in many other communities that are both within universities and external to them, and that are both the principals and agents of academic research.

One chain of assumptions in this thesis begins when an RIU makes a resource allocation decision to invest in the research capacity of one of its research portfolio components instead of another. Allocating resources is the activation of strategy. Whether these decisions were made more or less centrally in the organization, or were based on a proactive plan or evolved a posteriori, does not negate that RIUs engage strategy in their research operations. Strategic choices are necessitated by the reality of the resource dependence of the higher education environment. The patterns of investment in research capacity that emerge represent an institution's realized strategy (Mintzberg & Waters, 1985) and are reflected in the variability of research performance across an RIU's research portfolio. In this thesis, research performance is represented by federally funded research expenditures. Research expenditures are assumed to be directly related to the levels of investment and the changes in the levels of investment in research capacity in the components of an RIU's research portfolio. Using a method that is reminiscent of the Boston Consulting Group's Growth-Share Matrix (Hedley, 1977; Henderson, 1972), this methodology is an authentic translation of Markowitz's (1990) and Naylor and Tapon's (1982) portfolio theory concepts. While additional types of data would undoubtedly enrich this study, the NSF published the most complete set of data that were readily available for a study of this nature. This continues to be the case in higher education (Toutkoushian et al., 2003).

The purpose of investments in research capacity is to generate research performance. RIUs are compelled to generate as much research revenue as possible and their success or failure in this effort can be measured by ΔMS. Success in the ARM has broad strategic implications for organizational achievement. The realized research strategies of the RIUs were projected onto the Strategic Portfolio Arrays, the configurations of which were correlated with ΔMS to determine the strength and nature of the relationship between the research strategies of the RIUs and the relative value of their research performance. This process was necessary to answer the central question posed by this thesis which is whether the research strategies of the RIUs produce outcomes that reflect those strategies.

Finally, the methodology exposes those strategies that were most closely associated with market success. If an RIU invested in the right combination of portfolio components, there is a reasonable probability that it achieved a higher ΔMS, and by extension, an improving strategic outcome, which in this case, includes institutional reputation. Chapter Five interprets these results.

Chapter Five: Interpretation and Analysis

Introduction

This chapter is the most important of this thesis. Whereas Chapter Two, Context and Rationale chapter presented why the information produced by the model is needed, and the theoretical and practical underpinning of how it was derived, and the Methodology chapter described exactly how to develop the indicators, produce the model, and conduct the statistical analysis, this chapter describes the Strategic Portfolio Array and the component performance indicators for the purpose of crystallizing their meaning and discussing possible applications. Ultimately, it is hoped that the model and its components will be regarded as a step forward in enhancing the ability to measure university research performance as well as informing its strategic management. The order of this chapter begins with a discussion of some important qualifications and suggestions for further development in the Boundaries section. This is followed by a review of the components of the model, their importance, and some ideas as to how they might be used. The Strategic Portfolio Array is a powerful tool, and various interpretations are offered. The significance of the statistical analysis is presented followed by a summary of the strategies that are most likely to yield a successful market outcome. By the end of this chapter, all of the components of the model and their interrelationships should be understood sufficiently well to determine whether they could, in whole or in part, have a practical application and what future development work might be required to achieve this status. This understanding will provide increased comfort that the conclusions are credible and justified.

Some of the concepts presented in this chapter originated from sources that include Aaker (2001), Henderson (1972), and Kotler and Turner (1998).

Boundaries of the Study

1. The ARM is taken as a given. There is no attempt to determine the strategy of the federal government. However, the federal government may have research funding strategies that could impact on the growth rates of the overall market or individual market segments that would otherwise not be predictable. Indeed, such fluctuations are less predictable as the market tends toward the monopsony condition.
2. A major assumption of this thesis is that investments in research capacity result in the generation of research revenues. This may not always be the case. For greater clarity, federally funded research expenditures are enabled by the generation of research revenues won from the federal government.
    a. Given that the aforementioned relationship does exist, the time horizons between the investment and resulting performance may be very long, or unevenly timed across NSF fields. For example, investments in research capacity in Ocean may take far longer to generate research revenues than do investments in Mechanical. This thesis uses research expenditures as a proxy for output measures that reveal the realized strategy of the RIUs. The assumption is that the time lag between generating research revenue and the investment in capacity that generated it is, on average, the same for all NSF fields.

If the strategy described in the thesis unfolds over the very long term, different time lags between investment and performance are less important. The shorter the time horizon, the more this factor will impact on the results of this study. The difficulty is, while the time horizon spanning the 10 years of this study anticipates a long-term view of strategy, the fact is, 10 years may be too long for some disciplines but not long enough for other disciplines.

In order to diminish the potential impact of this circumstance, a study that determines the average time span between investments in research capacity and the research performed in NSF fields could be undertaken. If that study found that there were differences, appropriate weighting could be applied to the research performance data to counter the impact. Such a weighting method could include time value of money calculations. Such an adjustment would strengthen the use of research expenditures as a proxy for the measurement of the output of research in this context. As a matter of interest, such a study would also be able to establish the average level of investment in capacity required to produce a given level of research performance on a discipline by discipline basis. Such a result could produce risk-return benchmarks.

b. Another boundary of this study comprises two potentially interrelated issues that must be considered before using this model, in its present form, for practical applications. One part of the problem is that relatively small dollar changes in research expenditures can result in large percentage changes if the base is also relatively small. This can generate large values for ΔEIS. In turn, this condition might produce a result in strategic ranking of seemingly undue importance. For example, Political's Percent of ARM was 0.31 % in 1990a and was 0.39 % in 2000a. At 27.20 %, its proportionate share of the ARM increased by a greater amount than any other market segment. Yet, at only $89.708 million, it does seem unlikely that Political should be the second most important market segment, especially considering the number one and three market segments had values of $5,671.560 million and $3,582.181 million, respectively. This phenomenon could diminish the validity of research expenditures as a proxy for measuring research outputs that are included in the measurement of strategy.

Solving this problem may require the development of an algorithm that underweights fields that have a value for 2000a Percent of ARM that is below a threshold value. It may also be that this model can only be used when 2000a Percent of ARM values are greater than a certain threshold. Perhaps the model will only produce correct results within a specified range of 2000a Percent of ARM values. It may also be that the current version of the model has produced the correct results.

The second related issue is that different fields have different expected levels of dollars of research performed per capita, or per dollar of investment in capacity. For example, the average political scientist may spend an average of $25,000 per year on research, while chemists may spend an average of $100,000 per year per capita. The consequence of not adjusting for these differences is that relatively small value fields take on undue strategic importance. A study that determines the average value of research performed per capita, by discipline, would provide the weight factors that could be used to make the appropriate adjustments.

3. The use of research expenditures as an output measure of research was discussed in Chapters Two and Three. In addition to research expenditures, factors that include publication records, patenting activity, or merit awards can reflect investments in research capacity. Indeed, there may be some instances where these data are more reflective of strategy than are research expenditures. The use of research expenditures as the only proxy of research performance may be limiting to the credibility of this study in some instances.

4. A primary theoretical assumption of this thesis is that the relative size of a portfolio component is weighted equally with the relative change in size of a portfolio component in the composite ISI indicator. Even though there is no evidence to suggest that these factors should not be equally weighted in this application (Henderson, 1973), this assumption may be incorrect. Alternatively, this assumption may be incorrect outside of certain ranges of data. Of particular concern is when low value EISs are combined with large ΔEISs. The same assumption was made in respect of EMS and ΔEMS, and the same risk applies as to whether the assumption is correct.

5. The statistical analysis is intended to explain the relationship between two sets of variables, one describing the realized strategies of the RIUs and the other being their change in market share (ΔMS). The relationship that the statistical analysis describes, while fairly strong, is not perfect. Since the relationship is not perfectly

correlated, its nature is subject to interpretation. It is also important to note that this is not experimental research. No control group was observed, nor is it possible to construct a control group in this type of experiment. No causal relationship is implied by the relationships described by the statistical analysis. However, given the strength of the correlations, probabilities among variables is pertinent. Finally, the purpose of this thesis is to answer the thesis question which seeks to determine whether there is a relationship between strategy and performance. The question does not ask what the strategy might be, although an extensive commentary is offered.

6. This study is fundamentally reliant on the integrity of the NSF published data. Precautions were taken to help ensure that changes in NSF methodologies would not materially impact the findings herein presented. No attempt was made to audit the data that the RIUs provided to the NSF. There is an expectation that RIUs feel a strong obligation to accurately report their research expenditures to the NSF out of fear of the repercussions of behaving otherwise. In addition, the extensive use of this secondary data provides comfort that the risks associated with this concern are low. In addition, no qualitative confirmations were made.

7. While the research activities that comprise any single NSF field are not homogeneous, this study uses the net effect of these activities as the determinant of the size and changes that occurred in the NSF fields. Resource allocations should be viewed at the department level or even smaller units, if appropriate, as long as the sum of the decisions matches the institution's strategy. All data-fed strategic input must be confirmed with the activities that are actually transpiring. Another divisor is that some federal research funds are awarded in the form of grants, while others are

awarded through contracts. Different conditions apply in each type of award, although peer review tends to oversee both types.

8. The triangulated view that institutional reputation is reflected in the value of research performance does not answer the question about how much time lapses between research performance and its impact on reputation. In some cases, these time periods can be long and, in other cases, much shorter. The time periods may also be impacted by rate of change, the starting reputation of the specific institution, and the level of publicity that accompanies these changes. This study cannot account for these differences since there has been no previous empirical work on this topic.

Performance Indicators

Academic Research Market (ARM) and Total Federal Research Market

All RIUs and most other universities are currently using the Total Federal Research Market when they refer to the federally financed research being performed on their campuses. This definition of the academic research market satisfies most of the needs for which research measurements are currently made and, as such, would be an ideal standard for comparing research performance, including market share statistics, in higher education. The NSF refers to this as "Federally financed R&D expenditures at colleges and universities" (NSF, 2001). Whatever the name, the primary reasons that the Total Federal Research Market was not used in this study were (a) to be certain that all components of the defined market could be longitudinally tracked and strategically identified and (b) to ensure that the institutions that were included in the study were consistent in their reporting throughout the study period. In the case of the ARM, this is possible because the nec fields were removed. If the Total Federal Research Market was used in this study, the market shares would be diluted, but the RIU ΔMS rankings would have been the same. To be certain, the model was run using the national market data with and without the nec fields and the same MSI rankings were produced. The problem arose when the inconsistent reporting of the non-RIU universities was included in the calculation of the ISIs. As earlier described, investing in the research capacity of topics that are included in nec fields is not an identifiable strategy. The inconsistency of including the nec fields in the national market, but not the RIUs, created avoidable risk to the credibility of this study. Having said this, it is practical to determine the ΔMSs of all universities that perform federally funded research using the Total Federal Research Market as the basis of comparison.

Change in Market Share (ΔMS).

Change in market share is one of the most important indicators of enterprise performance currently in use. In the case of higher education, whether the market is defined as the Total Federal Research Market or the more restricted but completely identifiable ARM, ΔMS measures the real performance of an institution, as compared with the market and the competitors that operate within it. Increasing ΔMS is strongly correlated with increasing market power (Capon, et al., 1990; Henderson, 1972; Buzzell & Gale, 1987). In the ARM, market power can be leveraged into increased research performance and ultimately into an enhanced institutional reputation. Even though measuring research performance on league tables provides important and useful information, the problems associated with it are significant. ΔMS substantially augments the understanding of institutional performance in the ARM because it is more objective, universally applicable, easily understood, and simple to derive. ΔMS is more accurate then ordinal rankings and better than currency values because users of these measures cannot know if the performance is good, in real terms or relative to the market. In addition, ΔMS is an indicator that is closely related to institutional strategic direction. If ΔMS is going up, research revenues are climbing relative to other competitors, and this indicates an increasing institutional reputation. ΔMS is at the heart of the previously described virtuous cycle. ΔMS will help those more removed from the higher education sector to understand university performance and, as such, should form part of a complete reporting. ΔMS is the measure used to determine strategic performance in this study.

2000a Percent of ARM and Equalized Value for Percent of ARM (EMS).

EMS is the indicator used to construct the model, but Percent of ARM is the indicator that would normally be used for measurement and assessment purposes. As previously noted, it may ultimately prove more useful to use Total Federal Research Market instead of the ARM as the reference market, but whichever market definition is used, larger market segments present greater opportunities for growth than smaller ones. Recognizing the size of a market segment relative to the total market is important for organizations when planning their investment strategies. If an RIU is considering a substantial investment in a market segment where size limits the potential return, such an investment must be considered as higher risk. If positive externalities cannot be rationalized, such an investment should be either scaled down or made over time to allow for a progressive monitoring approach to the investment.

Large market segments can present growth opportunities, particularly in instances where the market is highly fragmented. Fortunately for RIUs, this condition exists to varying degrees in all market segments of the ARM. For example, Johns Hopkins University had the largest share of the Medical segment, but held just 3.70 % of it in 2000a. The largest share of any market segment held by any RIU in 2000a was the University of Arizona, which held 14.63 % of Astronomy. A Herfindahl analysis will help answer some of these questions. As resource allocation decisions are refined, the sizes of the market segments should be further defined by the matrix of subdisciplines and funding agencies. This process will enable a proper risk-weighting assessment to be done.

Percent Change in Share of ARM and Equalized Value for Change in ARM (ΔEMS).

Percent Change in Share of ARM is the indicator that will be of practical use and shows how the Percent of ARM has changed over time. A market segment that has grown faster than the ARM will have a positively valued Percent Change in Share of ARM, and vice versa. Positive values present greater growth opportunities for RIUs than do negative values. The fastest growing market segments in the ARM were Political Science and Astronomy, which had a Percent Change in Share of ARM of 27.20 and 22.10, respectively, during the study. In nominal terms, these two segments increased by 136.55 % and 127.06 %, respectively, while the ARM increased by 85.95 %. A fast growing market segment means that the federal government is investing at an elevated rate and, while this thesis does not attempt to predict the strategies of the federal government, systematic market risk decreases as the duration of market rates of change extend over time. That is, as the length of time that a market segment exhibits a positive Percent Change in Share of ARM, the systematic risk associated with making investments in this segment declines.

Fast growing markets increase market opportunities and act as a lure for all existing and potential market participants. Market entrants will be making applications for research funding in areas that are new to the institution. These efforts are likely to be mirrored, or even led by, changes in educational program offerings or any other number of leading indicators that expose this type of institutional activity. The number of new entrants can be confirmed by reviewing NSF data. New entrants increase the intensity of competition.

During the study period, Physics' Percent Change in Share of ARM declined by 25.22 %. This situation is a warning against making large investments in capacity on a speculative basis. That is, if a contract has been won in which the full required investment is returned, an investment in Physics could be rationalized. The less the proportion of return on such an investment is assured, the greater is the risk that a return will never be earned. Of even greater concern are those institutions that already have a large capacity, which can include buildings, equipment, and of course most importantly, people. If not supported by expanding educational programs, this capacity is either going to become excess capacity or allowed to depreciate and reduce the system capacity when it eventually comes off line. RIUs that have excess capacity will find themselves carrying a heavy load and should work very hard to diversify their revenue streams away from the federal government and into industry or state funded programs. RIUs should be cautious about investing large amounts of their own funds in building research capacity in Physics as the potential for growth is limited. Having said this, every situation is different, and very small competitors will be able to grow their Physics research performance.

Market Strategic Indicator (MSI).

This indicator is the starting point when conducting a market analysis geared to identifying which market segments are most likely to present opportunities. Larger MSIs indicate segments that are larger and faster growing. However, MSI does not identify which of the two component factors were more important: relative size, represented by Percent of ARM or change in relative size, represented by Percent Change in Share of ARM. For example, Astronomy and Biology had similar MSIs, being third and fourth most important, but were quite different in terms of their composition. Astronomy comprised just 1.59 % of the ARM in 2000a, but enjoyed growth in its share of research expenditures of 22.10 %. While this is not dramatically attractive from an absolute market size perspective, it is very attractive from the perspective of finding growth opportunities. On the other hand, Biology was a huge market with a 2000a Percent of ARM of 22.31: yet, its share of the ARM grew much more slowly, gaining just 4.50 percentage points over the study period. Which market segment presents greater opportunities for RIUs? This depends on current strengths, institutional objectives, and the resources that can be brought to bear to realize the desired result. One initial question could be, Does the institution want to pursue a diversification strategy, deepen its existing research interests, or some of both?

MSI can be equally instructive when the decisions are marginal. For example, with a 2000a Percent of ARM of 4.47 %, Electrical is a large market segment. During the study period, its Percent Change in Share of ARM declined by 7.77 %. This is large, mature market, with an MSI that is around the middle of the pack. Knowing that Electrical is not a homogeneous collection of research activities, the approach in this situation should gravitate to some or all of the following strategies even though actions in specific areas may vary. Those with large legacy operations should be wary of continuing to invest in this field. In fact, if research performance can be maintained while disinvesting, the institution may be forced to consider difficult options which can include pressuring faculty to increase their research productivity, in much the same manner as they are pressured at certain universities that compete for funding in the United Kingdom under the Research Assessment Exercise regime. At a minimum, any action that reduces gross margins less than costs should be considered; actions that could include reducing footprint, reducing the replacement rate of equipment, reducing technical and support staff, ceasing bidding on research that requires investments in new equipment or staff, and engaging in cooperative research, alliances, and other consortia. The use of existing capacity to generate industry sponsored research is another ideal and less painful strategy. In general, an RIU with a substantial investment in Electrical should not be investing its own funds to further develop its research capacity in this market segment.

MSI is an extremely important indicator of the existing status of each market segment in the ARM and of their probable future direction. However, it is a *starting* point from which questions relating to strategic planning should be asked, not the ending point. MSI and its component parts must be continually monitored to ensure that assumptions made about their status are unfolding as expected.

Total Reported and Total Actual.

Total Actual is important because it is one of the most commonly used indicators describing research in higher education and is more often referred to as *federal research, federal research expenditures*, or similar names. Among its many applications, Total Actual could be used to determine national market share.

When attempting to determine whether an RIU is using its research funds for strategic advantage, it is far better to be able to identify all of the components of a university's research than to have to make assumptions about how it is spending nec categorized expenditures. As described in Chapter Four, Definitions 3 and 4, the difference between Total Reported and Total Actual represents a gap that requires an assumption that becomes more tenuous by inconsistent reporting between institutions. In the Methodology chapter, RIU reporting consistency is assured within the specified criteria.

2000a Percent of Institutional Spending and Equalized Value for Percent of Institutional Spending (EIS).

EIS is an indicator that informs both the internal and external parts of a strategy development process. From an internal perspective, while powerful voices might sway institutional direction, they do not necessarily represent the strategic reality. EIS can be used to confirm the areas that are important to an institution's actual research priorities. The greater the proportion that a component comprises of a total portfolio, the greater will be the relative value of the research being performed, and the greater the parent RIU's investment in research capacity is likely to be. Larger areas of investment are priorities for the institution. Large research areas need to be protected and enhanced, and to be the focus of dialogue that strengthens these positions.

The same judgments can be made about competitors. For example, Physics was 31.39 % of all research expenditures at California Institute of Technology in 2000a. This institution is likely to have a substantial staff, investment in fixed assets, and educational activity in the disciplines that comprise this NSF field. In the absence of other data, or as a simple snapshot of a university's research strategy, the percent that a discipline represents of its total research expenditures is a useful indicator.

It is always worth knowing who are the significant competitors when planning an expansionary initiative. This is because these competitors are, on one hand, not likely to step aside and let others encroach on their success and, on the other hand, targets by virtue of the notion that large departments employ larger numbers of the types of faculty that an expansionary effort requires.

EIS is an important indicator of what research is important to an institution. Remaining vigilant about the actions of competitors is vital to ensure that a strategy is more or less likely to be successful or might require interim adjustments. EIS is an indicator that can be used to view competitive actions as well as to indicate which educational programs are likely to be important in a university. Confirming these priorities against programmatic or departmental reputations will serve to triangulate possible conclusions about competitor intentions.

Percent Change in Share of Institutional Spending and Equalized Value for Change in Share of Spending (ΔEIS).

Percent Change in Share of Institutional Spending is the indicator that will be more usually used, as opposed to ΔEIS, the factor used to construct the model. The change in the proportion that a component represents of an enterprise's total portfolio reflects the relative changes in resource allocation patterns. In RIUs, where strategic implementation tends to be more evolved, knowing where levels of investment have been accelerating or decelerating provides hard data about the organization's strategic direction.

A competitive view of Percent Change in Share of Institutional Spending can expose vulnerabilities. Since every RIU, and every other university, has limited resources, elevated levels of investment in one area must mean the investment levels are declining in other areas. In any university, those areas that are being starved of resources are more subject to attack than those that are the recipient of increasing investment. In addition, the longer that an investment trend has been in place, the greater momentum there will be and the more likely that the trend will continue. Whether positive or negative, momentum is hard to change. Relevant questions that need answering include, how long the change has been going on, how abrupt the change has been, whether the rate of change has been increasing or decreasing, and what was the absolute value of change. A dramatically decelerating rate of research performance can mean the loss or expiration of a major contract or an exodus of top performers. For example, in 4 years, research expenditures at Carnegie Mellon University in Biology dropped from $5.9 million in 1993, to $5.45, to $3.84, and then to $3.27 million in 1996. In most cases, such situations present opportunities for others. Percent Change in Share of Institutional Spending can signal an RIU's intentions about improving the reputation of certain programs or departments.

Institutional Strategic Indicator (ISI).

ISI is an indicator that ranks the strategic importance of an RIU's portfolio components. It reflects the equally weighted balance between the relative size, and change in relative size, of an RIU's portfolio components. An overarching indicator, ISI does not reveal which of its two component parts contributes more to its ranking. This could be important depending on the information required. For example, to understand exactly how big a component is, or how fast it has been changing, reference to EIS or ΔEIS is required. ISI is useful to understand which of an RIU's research fields are strategic priorities and which fields are not. As a matter of definition, large fast growing components are areas where a university has a significant investment in research capacity and is continuing to make large investments. In general, this means that a university may be searching for new researchers to hire and will be trying to recruit students to the educational programs that can be taught by corresponding faculty. Depending on the extent of the expansion, the need for additional footprint may impinge on other existing facilities and may also require a philanthropic effort. An intensification of competition across a range of capacity creating and revenue production activities is inevitable. Retention efforts are one key defensive strategy. However, an RIU that is committing substantial resources and effort to some fields may also be creating exploitable vulnerabilities in the areas from where resources might have been diverted to feed the new initiative. These strategies, both defensive and more aggressive, are proactive and informed by ISI. In all cases, these strategies operate at the department or even at the program level. Of course, retention strategies should be culturally embedded. It is interesting to note that so many RIU research strategies focus on attracting new people to their institution while very few explicitly detail their retention programs.

Relatively low value ISIs indicate small, low growth or shrinking portfolio components, which are represented by incidents that are located on the west side of an RIU's Strategic Portfolio Array. In some cases, a low value ISI represents a portfolio component of significant size, but that declined rapidly in relative value. Such a situation can indicate increased vulnerability because, just as positive momentum is generally a powerful force, negative momentum is difficult to reverse. At the risk of sounding Machiavellian, attacking weakness can often lead to relatively easy victories.

In addition to using ISI and its components to inform externally oriented strategic development, it is important to keep in mind that aggressive competitors may be using some of the same tools to inform their tactical maneuvering. ISI is useful to identify internal strengths and potential vulnerabilities. When used in a mapping exercise on a Strategic Portfolio Array, powerful new insights are revealed, some of which are discussed in the Strategic Portfolio Array section of this chapter.

From a strategic planning perspective, ISI is at once an indicator from which questions begin and, when aligned with MSI, an indicator from which strategy can be viewed. ISI provides insight into whether an RIU can be expected to vigorously defend its position in certain market segments, as well as where it hopes to build programmatic reputation. ISI is at the source of an RIU's virtuous cycle since it exposes its strategically important fields, fields where a large value and fast growth of federally financed research expenditures is occurring. Large fast growing areas of federally financed research expenditures are at the heart of institutional reputation.

Strategic Portfolio Array

In order to more completely present the results of this study, the Strategic Portfolio Array and its component parts should be more thoroughly understood. The Array is comprised of four quadrants. Incidents in the NE quadrant are those that have the highest values of ISI and MSI. Incidents in the SE quadrant are the highest values of an RIU's ISI, but low MSIs. The NW quadrant has incidents that have high MSIs but low

ISIs, and the SW quadrant contains incidents that are low values of both ISI and MSI. The Array portrays the realized strategy (Mintzberg, 1994) of each RIU. As a reminder, a realized strategy is the strategy that an entity has actually used; it need not have been a preplanned or purposeful strategy but might have evolved a posteriori. As earlier noted and at least anecdotally, most university research strategies tend to be more evolved (Feller, 2000).

In the context of RIUs, it should not be enough to describe strategy as an institutional ambition and a plan to increase overall research performance by allocating resources to research generally. In this thesis, strategy should be taken to mean engaging in a specific process to generate increased research performance by making more informed and increasingly proactive decisions about which NSF fields will receive more or fewer resources. Strategic implementation can be as bold as establishing a new research institute, or as subtle as providing a chosen department more assistance to prepare funding applications or reducing the teaching responsibilities of a key researcher.

Strategy is a pattern in a stream of research allocation decisions (Mintzberg, 1972). In order for a research field to become large and fast growing, the parent RIU must have been allocating a level of resources that are disproportionately large over an extended period. Disproportionately large investments will result in a rate of growth in research performance that is faster than the institution's average. Over time, high growth rates will produce a field of research that has a large value. A field that is both large and fast growing will appear on the eastern side of an RIU's Array. Otherwise, the field will appear on the western side. Of all RIUs, there were 245 of 628 fields or 39 % of the fields on the east side. Since the MSI intersect is at $\overline{\text{ISI}}$ on the x-axis, the 245 eastern fields must be further from the y-axis, on average, than are the 383 western fields. A visual scan of the Arrays bears this out.

The same holds true of the ARM in that market segments that have continually received a disproportionately large rate of investment have become larger and faster growing. One way that a Strategic Portfolio Array exposes the strategy of an RIU is by comparing, on a field by field basis, the differences between the proportion that a market segment represents of the ARM with the proportion that each component represents of an RIU's total portfolio. This mechanism involves comparing the relative distance that a market segment is from the Array source with the relative distance that an RIU's portfolio component of the same market segment is from the source. The source is coordinate point (0.00, 0.00). Differing relative distances represent strategy. The difference in relative distances represents an underlying decision to invest in a portfolio component at a rate that is different than the market signals indicate would be appropriate. In cases where an RIU's research emphasis in a given field is relatively greater than the corresponding market's, that RIU can be seen to be overweighting its investment level. Overweighting is a strategic attempt to gain market share.

In any given market segment, where MSI and ISI are proportionately equidistant from the source, the RIU's strategic performance is at the market weight. A line that bisects the SW and NE quadrants is drawn through the source. Incidents that are due east of the bisecting line are overweighted, and vice versa. The horizontal distance between an incident and the bisecting line is a determinant of the extent of over or underweighting.

Another way that an RIU's realized strategy is manifested on its Strategic Portfolio Array is by comparing it with other RIU's Arrays. The two basic comparisons to be made are the total number of fields in which an RIU reports research and the number of incidents that occurred in each quadrant as a proportion of the total number of fields. The total number of fields in which the RIUs are engaged are extremely weakly related to ΔMS. In fact, the correlation between these two factors is only .0087.

However, the configuration of an RIU's Strategic Portfolio Array is fairly strongly related to strategic performance. Indeed, the configuration of incidents on the RIUs' Arrays is a main story of this thesis. That is, all RIUs will want to emulate an Array configuration that is most likely to result in a market outperformance. From an accountability perspective, if an RIU's configuration differs from the ideal, questions could be asked about what, if anything, should be done to correct the misalignment. The "if anything" part of the question is important because an RIU may be satisfied to accept a lesser performance in order to achieve a different objective. For example, the reputation of a department might be such that student demand for its educational programs has consistently and substantially exceeded delivery capacity. This seems like a valid trade-off to maximizing research income, so long as the RIU recognizes the potential long-term risks associated with not pursuing the ideal research strategy. As described in the Portfolio Theory section of Chapter Three, risk is a term that is interchangeable with cost. As Kay says in Mintzberg, Ahlstrand, and Lampel (2005), "Strategy costs money" (p. 25).

Another question is, Do the risks of isomorphism increase if all RIUs are working towards similarly configured Strategic Portfolio Arrays? Assuming diversity is a positive attribute in higher education (Lang, 2000; Birnbaum, 1983), the objective of working towards an ideal configuration may be harmful to the system, even while it is increasing the likelihood that RIUs will achieve better market performance. There are three factors that tend to mitigate this risk. The first is that the research activities that are occurring within each NSF field are not homogeneous. In fact, each NSF field is comprised of an extensive range of current and potential topics. Peer review and intense competition, which is forcing research to become evermore narrowly focused, will help prevent isomorphism from a research perspective. MSI, as an indicator of market size and direction, will govern the number of departments, and their size, that RIUs will operate in each market segment. As MSI rises, more entrants can be expected and vice versa. This mechanism will also help regulate the degree to which isomorphism occurs at the undergraduate level. That is, the fewer research opportunities there are, the fewer researchers there will be, and the fewer the number of students will be able to be taught. This does not, however, negate the notion that isomorphism can be caused by student demand or other factors.

The second factor recognizes that the NSF fields that underlie each incident are not the same for each RIU. For example, the NSF fields that underlie the incident in California Institute of Technology's NE quadrant are Astronomy and Civil, while they are Medical, Sociology, and Biology at University of California at Los Angeles. Having said this, it is also the case that 33 RIUs have Medical in their NE quadrants and 38 RIUs have Biology in their NE quadrants. It is interesting to note that one of Irwin Feller's eight strategies for achieving success in the research market is to "Build a Medical School" (Feller, 1999, p. 10). The intention of the Strategic Portfolio Array is not to dictate, or even to remotely suggest, on which disciplines an RIU should focus its research. It is intended to act as a guide to allocate research resources so that the ideal configuration will eventually be realized. This thesis is not proposing programmatic or research topical isomorphism. It is proposing portfolio alignment isomorphism.

The third argument as to why working towards the ideal strategic configuration does not promote isomorphism is that the RIU population represents just over 45 % of the ARM and about 35 % of all research performed in America's universities. Working towards the ideal configuration will increase efficiency for the RIUs, which frees up resources for all market participants. This provides more research opportunities to be funded and, given the rigour of the ARM forces, more chances for diverse research to arise. In addition, adopting the ideal strategic configuration may help the RIUs regain some of the market share they collectively lost over the study period.

The Strategic Portfolio Array is a powerful tool that can identify inefficiencies in a self examination and in an external scan. Such an examination can help identify competitive strengths and weaknesses and generate accountability questions in the process. In addition, the Array can guide resource allocations as RIUs decide whether they are going to deemphasize or strengthen their research capabilities in one NSF field or another.

Another method in which the Strategic Portfolio Array can identify the strategies of the RIUs is to integrate the information garnered in the previous two strategic identification methods as part of an examination of individual NSF fields. This process entails choosing a portfolio component of interest and attempting to determine the strengths and weaknesses of other RIUs operating in the same market segment as part of an exercise to identify specific opportunities or threats.

Using Michigan State University as a hypothetical example, the framework of such an analysis could take the following form. By observing Michigan State University's Strategic Portfolio Array, Psychology occurs in the NW quadrant at coordinate (0.0917, 0.5421). It is Michigan State University's only incident in this quadrant and, since as later described, incidents in this quadrant are inefficient, it will want to move it out of the NW quadrant. It has two choices. It can stop conducting federally financed research in Psychology, which would remove this field from its Array completely, or it could add resources, which would move the incident eventually into its NE quadrant. In terms of developing a plan, Michigan State University can determine the value of ISI it should have for Psychology, compare it to its current ISI for Psychology, and then establish the resource commitments it feels will be necessary to achieve this status.

The first step in this process is to calculate the correct weighting that Psychology should have within its portfolio of research. This is done by determining the relative distances that MSI and ISI for Michigan State University are from the source on Michigan State University's Strategic Portfolio Array. The calculation for determining the market weighted incident coordinate point for Psychology on Michigan State University's Strategic Portfolio Array is as follows:

1. $\overline{MSI} = 0.0082$ and $\sigma_{MSI} = 0.6655$.

2. The actual MSI of Psychology is 0.5421, which equals $0.8146\sigma_{MSI}$. The y-axis coordinate point of Michigan State University's NE to SW bisecting line is 0.5421.

3. The mean ISI for Michigan State University is 0.3915, and the standard deviation of its ISI is 0.3606.

4. Michigan State University's mean ISI plus the market adjusted standard deviation of its ISI yields the x-axis coordinate of Michigan State University's NE to SW quadrant bisecting line. This point is equal to 0.3915 + (0.3606 x 0.8146) = 0.6852.

5. On Michigan State University's Array, its NE to SW bisecting line is drawn through coordinate (0.6852, 0.5421) and the source.

6. Any of Michigan State University's incidents that are to the east of its bisecting line are overweighted, any incidents to the west are underweighted, and those incidents that are close to the bisecting line are market weighted.

At Michigan State University, Psychology is substantially underweighted, given that it is at x-axis coordinate 0.0917. In this example, Michigan State University should augment its research activity in Psychology so that the incident moves closer to its market weight. Now it has two new streams of choices: how to execute and where to get the resources to support the execution. Resources can be generated from external sources, internal sources, or both. One source of internal resources can be realized by reducing investments in research fields in which the institution is heavily overweighted, with the proviso that some overweighting could be part of an effort to gain market share in a particular market segment. As later described, incidents in the SE quadrant represent fields in which an RIU may have an unsustainably large market share. Working to increase market share in these fields is contrary to a risk-averse strategic approach. In the case of Michigan State University, its activity in Physics is heavily overweighted. If it is looking for internal resources, it should consider diverting investments from Physics to Psychology. In any event, Michigan State University will now be able to set quantitative objectives for progress in its Psychology research and, as a consequence, can estimate the amount of investment it will likely have to make to achieve these objectives.

Assuming that Michigan State University has Psychology faculty that produce a normal amount of research, the question of how it should operationalize its strategy involves a series of self-informing questions, the first one being where to find the best researchers. From a national interest perspective, perhaps the best solution is to find high quality researchers currently in other countries and convince them to move to Lansing. However, this strategy may not work to fill all, or even any, of the positions that will be needed. If the positions are to be filled by a domestic search, the next question is, What group of RIUs (or other universities) is most susceptible to attack?

An initial thought is to go after the big players. After all, they have a larger number of quality researchers so the possible pool of candidates is bigger. However, these institutions are also investing heavily in Psychology, and part of the reason that people are working there is to try take advantage of these growth opportunities whereas the Change in Share of Institutional Spending in Psychology at Michigan State University was a paltry 2.36 % during the study period. Attracting someone from a high growth situation is, to some extent, asking them to engage in a rebuilding process, a career risk the very best might not be prepared to take.

The middle Psychology performers may be a good group to look at, since there are likely some star performers at locations that are in decline. An example of this could be Rutgers University, where the value of 2000a research expenditures in Psychology was about $3.25 million, but its Percent Change in Share of Institutional Spending declined by nearly 30 %. Purdue University may be a more difficult target, with expenditures in Psychology of just $1.85 million but a Percent Change in Share of Institutional Spending of 12.5 %. When comparing these two institutions, Rutgers University appears to have other priorities.

Those RIUs where Psychology is a low priority deserve a hard look for possible candidates. In these cases, the Percent Change in Share of Institutional Spending is in decline and the 2000a Percent of Institutional Spending is also low. Possible candidates may reside in institutions where these conditions apply but where the actual values are relatively large. Two such examples are the University of Minnesota, where its actual 2000a research expenditures, 2000a Percent of Institutional Spending, and Percent Change in Share of Institutional Spending were $5.171 million, 2.33 %, and -32.37 % and for the University of California at Los Angeles, $6.477 million, 2.31 %, and -34.40 %, respectively.

It is important to note that this methodology only helps to focus the attack. Institutions in an aggressive recruiting mode must maintain an opportunistic demeanor. As a warning to all institutions, competitors may also be behaving in this manner.

The Array bisecting line can also be used to judge an RIU's overall research profile against the market. A line is drawn through the NE and SW quadrants at a 45-degree angle from the x-axis. If the RIU's bisecting line is rotated counterclockwise from the 45-degree line, the RIU's research program is more subject to market fluctuations. If the RIU's bisecting line is rotated clockwise from the 45-degree line, its research activities are less subject to market fluctuations and more under its own control. A description of the how incidents in each quadrant behave will help explain this phenomenon.

The NE quadrant may be the most straightforward to describe in that it is populated with an RIU's largest and fastest growing fields which are in the largest and fastest growing market segments. While an RIU will want as many fields as possible in the NE quadrant, moving fields into this quadrant will require a substantial and sustained investment. Fields in this quadrant are strategically vital to an RIU and any significant shock could have repercussions for the RIU beyond the directly corresponding loss of research revenue. For example, the loss of, or expiration of, a large contract might force an institution to downsize the home department, an action that could also impact the corresponding educational programs. The reassignment of supporting infrastructure and termination of personnel at all levels might also be required to resize the institution in the face of large losses. This raises the issue of intensity in that a shock to a field represented by an incident that is a greater distance from the source than others is likely to have a greater impact on the RIU.

In addition, the juxtaposition of an incident to a line that is 45 degrees from the x-axis can provide other types of insights. For example, an incident that occurs above the 45-degree line represents increased susceptibility to market fluctuations. This is because a shock to such a market segment will move the incident closer to the source than a shock to the corresponding RIU's portfolio component. Since market shocks are beyond the control of any RIU, research activity represented by incidents that are above the 45-degree line may also be less controllable by the RIU. Below the 45-degree line incidents may represent, depending on the actual size of the market segment, unsustainably large market shares. In these cases, actions by the RIU are likely to have a greater impact on the distance of the incident from the source. This means that the RIU is in somewhat greater control of its own destiny. This concept makes intuitive sense since incidents to the east of the 45-degree line and the bisecting line are market overweighted. Research fields are overweighted because the parent RIU has made a continual effort to expand within this market segment. It could decide to change its level of commitment at any time and, as such, can be seen to be in greater control than if it were more subject to changes in market conditions. This is another layer of analysis that can flow from the Strategic Portfolio Array and explains the implications of the juxtaposition of the bisecting line to the 45-degree line.

Out of a total of 628, 131, or 20.86 % of the incidents of all RIUs' Arrays were in the NE quadrant. The mean number of incidents per RIU in the NE was 3.36 out of an average of 16.10 active fields. There were 16 RIUs with 3 incidents in the NE quadrant, 12 RIUs with 4 incidents, 4 with 5, 4 with 2, and 2 RIUs with 1 incident in its NE quadrant. Using the ratio method (see Chapter Four, Calculating the Results, step 5), the correlation between the NE column and ΔMS is weak, being only .119. As such, the number of incidents in the NE quadrant does not appear to be an indicator of market performance. Despite this, the number of incidents that an RIU has in its NE quadrant should, at least intuitively, provide some insight into its market performance. Alternative views of this relationship show that 90 % of the market outperformers have either 3 or 4 incidents in their NE quadrants. In contrast, only 64 % of underperformers have 3 or 4 incidents in their NE quadrants. Still another way of way of interpreting this relationship is to consider that the mean number of incidents in the NE quadrant for the 11 market outperformers is 3.73 (see Chapter Four, Table 3). The σ for this population is 0.647. The mean less the σ is 3.081. The same calculations in the case of market performers and market underperformers is 2.243 and 1.963, respectively. For ΔMS, the means less the σ for the market outperformers, market performers, and market underperformers are 12.15, -6.95, and -23.62, respectively. These two sets of data are nearly perfectly correlated (.970). The same data using the ratio method produces a correlation of .930. In other words, when viewed according to the defined market performance groups, the number of incidents in the NE that indicates an outperformance is at least 3. An RIU with less than 3 incidents in its NE quadrant will almost certainly not be an outperformer. Lastly, the degree of intensity might also be a factor in these relationships.

For every RIU, incidents in the NE quadrant are strategically vital to the institution's reputation.

The NW quadrant is interesting for several reasons, including the notion that time could be a more significant analytic factor than it would be in other fields. This quadrant represents situations in which fields are low priority to RIUs but operate in important market segments. The time factor is important to know because RIUs that have incidents in this quadrant may be at the early stages of attempting to develop high priority fields that would eventually reside in the NE quadrant. An alternate circumstance, in which an incident has been in the NW quadrant for an extended period, could mean either a missed opportunity or that an RIU is satisfied to be a very minor niche player in an important market segment. Perhaps an RIU simply wants to maintain a presence in the market or remains active for historical reasons. A vector analysis, whereby the direction of movement of an incident over time as well as its inertia, would provide the kind of dynamic view of an RIU's Array that would help answer some of these questions and would further inform strategy formation.

Incidents in the NW quadrant should be considered unstable and are likely to drift towards the NE quadrant, given the influence that powerful market forces can exert. The operational rationale for this inherent instability involves exploring the scenarios that could lead to this condition. As a starting point, incidents in the NW quadrant have low ISIs. The value of research being performed in the given field is either low and stable, or moderately sized but shrinking rapidly. It is worth a reminder that these scenarios exist in RIUs which tend to be places where the cultural expectation is generally one that encourages the aggressive pursuit of externally funded research (Clark, 1997). A specific example of an incident in the NW quadrant is Columbia University which performed $411,000 of research in Civil in 1990a and $261,000 in 2000a, out of a Total Reported value of research of more than $280.0 million. It also performed a total of $872,000 in industrial sponsored research in this department in 2000 (NSF, 2000). From a research perspective, many of the 15 full-time faculty members in this department must be considered somewhat mediocre (Columbia University, 2007), in comparison with high performing Civil Engineering departments in other RIUs. At some level there must be pressure on this department to become more productive. It is these pressures that constitute the source of the instability. From an overall ARM perspective, it seems like this department either has to grow or will continue to shrink into irrelevance. Growth will require a vigorous effort by the faculty to win awards and preparedness by the institution to make significant new investments in facilities, equipment, and perhaps the recruitment of new research faculty. However, if the effort and the investments are made, the market already exists to exploit. Growing into an existing market is substantially easier and less risky than growing into a market that does not yet exist or that must be created. Incidents in this quadrant represent the best opportunities for growth.

Of the 628 incidents in this study, 100 or 15.92 % were in the NW quadrant. The average RIU had 2.56 incidents in its NW quadrant, the lowest of the four quadrants. Using the ratio method, the correlation between the NW quadrant and ΔMS is only slightly stronger than that of the NE quadrant at -.170. The inverse relationship suggests that as the number of incidents in an RIU's NW quadrant increases, its ΔMS declines. However, the weak correlation does not establish a solid connection between these factors. If viewed in performance groups, the relationship becomes much stronger. When the means plus 1 σ of the market underperformers, market performers, and market outperformers of the NW quadrant are correlated with the performance group means plus 1 σ of ΔMS, the relationship is a much stronger -.437, or -.629 using the ratio method. As such, if the number of incidents in the NW quadrant is either 4 or 5, the chances of being a market outperformer are reduced.

The SE quadrant represents fields that are very important to an RIU but operate in low potential markets. These market segments are low potential in that the associated MSI is less than $\overline{\text{MSI}}$. No matter what an RIU does, it can never move an incident from the SE to the NE quadrant. The amount of federal research funding available in these segments is either small and has been growing very slowly, or moderately sized but has been shrinking rapidly. The latter scenario describes market segments that may once have been in the NE quadrant. Regardless of the level of investment to enhance its research capacity in its SE fields, growth in these fields will eventually plateau. Of course, this is a best case scenario for RIUs since fields that have declined in relative importance have left a legacy of overcapacity.

On the surface, these scenarios paint a high risk picture in that an RIU may be overreliant on a field in which it holds an unsustainably large market share. The reality is that some subsegments may be growing rapidly, while others are declining precipitously. An RIU that is investing in an emerging subsegment may be enjoying overall growth. On the other hand, relatively large markets, even if they are declining, still present significant growth potential and this attracts new entrants. The lure is even stronger when legacy facilities and equipment are not as appropriate to the potential emerging research as new capital stock would be, negating the competitive advantage of large institutions. A longitudinal Herfindahl analysis would help provide insight into whether a market segment was concentrating or fragmenting, and if it was fragmenting, who was winning and losing.

A field that fits this description is Physics. Physics 2000a Percent of ARM was 5.59 %, down 25.22 % from 1990a. Yet, at $898.279 million in 2000a, it is still a large value market. Table 9 shows the 10 RIUs that had Physics in their SE quadrant; these RIUs had a high ISI for Physics. Of these, 6 RIUs had a large 2000a Percent of Institutional Spending (from 13.98 to 23.45 %). Of these 6, five RIUs had declining Percent Change in Share of Institutional Spending, 3 of which were serious (20.34 to 46.53 %). On the other hand, the University of North Carolina had the smallest 2000a Percent of Institutional Spending for Physics and, at 155.02 %, had by far the largest Percent Change in Share of Institutional Spending. These numbers tend to fit the hypothesis that there is room for small competitors to grow, but legacy players can be hurt by the large exposure. This suggests that the story of the SE quadrant might colloquially be expressed as, the bigger they are, the harder they fall.

Table 9
RIUs with Physics in their SE quadrants, with the corresponding 2000a Percent of Institutional and Spending and Percent Change in Share of Institutional Spending

RIU	2000a Percent of Institutional Spending	Percent Change in Share of Institutional Spending
Massachusetts Institute of Technology	23.45	-21.43
Michigan State University	23.21	-9.37
University of California at Berkeley	17.60	-21.92
University of Maryland	17.38	-46.53
Princeton University	16.81	0.66
Cornell University	13.98	-2.01
University of Wisconsin	6.97	-0.74
Purdue University	6.70	-3.86
Rutgers University	6.61	-32.10
University of North Carolina	2.46	155.02

These data and explanations also point to the inherent instability of this quadrant where fields that are the farthest from the source are likely to drift to the SW. Even though fields that are close to the source are likely to be more stable, they should also tend to drift to the SW quadrant, albeit more slowly. A vector analysis will help expose the direction of an RIU's research effort. If an RIU has a relatively large share of a market segment and a high 2000a Percent of Institutional Spending in that segment, it should diminish its emphasis. A vector analysis would uncover what is actually happening as part of a strategic exercise geared to ensuring that an institution is not being exposed to unnecessary downside revenue risk. Since growing very large is difficult, investments in these fields must be limited and measured. RIUs with fields in the SE quadrant are destined to be niche players.

114 of 628, or 18.15 % of all incidents occurred in the SE quadrant. The average RIU had 2.92 incidents in its SE quadrant. Using the ratio method, the correlation between the SW quadrant and ΔMS was -.341. This is a moderate inverse relationship that suggests that the fewer the number of incidents that an RIU has in this quadrant, the better will be its market performance. Using performance groups, any institution with 5 or more incidents in its SE quadrant has virtually no chance of being a market outperformer.

Finally, the SW quadrant is populated by incidents that represent fields that are of strategically low value to RIUs, and which operate in market segments that are relatively small and may also be contracting. The somewhat negative connotation suggested by this description is not necessarily reflective of what is the more probable reality. The story of the SW quadrant may lie in the notion that all RIUs are, to varying degrees, comprehensive institutes of higher education. Fields such as Mathematics, Economics, or humanities and other disciplines that are outside of the realm of this study, enhance comprehensiveness and as a consequence, can lead to an interpretation of the SW quadrant that could be called the sustaining fields. That is, the vitality of a comprehensive university may be at least in part sustained by the academic activity occurring in the fields in this quadrant, even though their ISI is small. Perhaps activity in these fields helps maintain the critical mass necessary to achieve an elite research intensive status by helping RIUs sustain their comprehensive makeup.

Incidents in the SW quadrant also represent fields that are, with the exceptions shown in Table 10, fairly close to market weight. A visual review of the Strategic Portfolio Arrays of all RIUs reveals which RIUs are significantly under-weighted in any incidents in their SW quadrants. Significantly over-weighted incidents will spill into the SE quadrant, further supporting the notion that incidents in the SE quadrant are unstable.

Table 10
RIUs with Underweighted Portfolio Components in their SW Quadrants

RIU	Market segment	Weighting
Columbia University	Electrical	Under
Columbia University	Chemical	Under
Stanford University	Economics	Under
University of California at Los Angeles	Earth/Geol	Under
University of Colorado	Earth/Geol	Under
University of Pennsylvania	Physics	Under
Yale University	Ocean	Under
Yale University	Computer	Under

Since the value of research being performed by the RIUs' fields in the SW quadrant is relatively small, the impact on institutional efficiency that results from being offweighted in these fields is low. However, the system-wide impact may be of much greater significance.

There were 283 of the 628 incidents in the SW quadrant or 45.06 %, by far the largest proportion and more than twice the number in any of the other quadrants. Using the ratio method, the correlation between the number of incidents in the SW quadrant and ΔMS was the strongest at .398. When using the means of the performance groups, the correlation is a nearly perfect .930. In numeric terms, an RIU with 7 to 10 incidents in its SW quadrant is almost sure to be a market outperformer, whereas an RIU with 6 or fewer incidents in its SW quadrant is sure to be at market performance or a market underperformer. Another way of expressing this relation is by stating that RIUs with less than 43.0 % of their incidents in the SW quadrant have a very low probability of achieving a market outperformance result. However the relationship is viewed, those RIUs with a higher proportion of their incidents in their SW quadrant are most likely to be market outperformers.

Interpretation of the Statistical Analysis

The correlation and R^2 statistics describe certain aspects of the relationship between variables in the context of the specific circumstances and general environment that are presented in the literature review in Chapter Three. Correlation provides insight into the probability that one variable will be a certain value, based on the value of another or others. In this study, the terms *independent* and *dependent variable* are viewed with the explicit recognition that this is not experimental research; there was no control group or comparative analysis. This research uncovers preexisting relationships, the strengths and predictability of which are hereafter described by stating the correlations, R^2s, σs, and *SE*s of the constant and co-efficient in the prediction equations.

Probability can be a powerful predictor. Although it is often better to know the reasons why an outcome has occurred, it is not always critical; only that there is some certainty that the expected outcome will reoccur. This is particularly valuable when probabilities are relatively high and when the actions to be taken are being repeated. For example, a coin can be tossed over and over to prove that the chance of heads is 50-50, even though the next roll may still be tails. Even if the chance of winning an election is very high, the probable winner can still lose. Like an election, the resource allocation decisions made by RIUs can only be made once. Once resources are committed, they should be considered as sunk costs, because, as Massy puts it, research capacity is sticky (1996). However, the extended time periods during which strategy unfolds enable a process of progressive investment and monitoring that can act as a hedge against a large scale failure. RIUs can pursue a strategy and, after specified periods, if the milestones are not being met, a reassessment can be undertaken and adjustments made. A hard assessment should include an often difficult introspection as to whether the strategy was incorrect or the result of a failed execution. (Were the right people hired? Did they produce the expected output?) Of course, such a lack of conviction may also be a barrier to achieving full potential. Each RIU must examine its own history and decide the extent to which it is prepared to press forward with a strategy that has a relatively high probability of success, or not.

Probability in this study is reflected in the strengths of the correlation between the independent variable represented by the RIU strategies, and the dependent variable which is represented by the change in share of the ARM actually realized by the RIUs during the study period (ΔMS). The range in the R^2s found between any RIU strategy and ΔMS was from .0013 to .406. Using the ratio method, the minimum R^2 values were found in the derivative variable called 2nd Smallest. In this case, the second smallest value that occurred among an RIU's quadrants was determined. For example, Indiana University had 0.50 of its incidents in its SW quadrant, 0.42 in its NE quadrant, 0.08 in its NW, and 0.00 in its SE quadrant. The NW quadrant, with a value of 0.08, had the second smallest proportion of incidents. With an R^2 of .0013, the strategy of managing the proportionate number of incidents in the 2nd Smallest quadrant provides virtually no predictability of ΔMS. Likewise, the R^2 of the SW + SE strategy was .0025. If the objective of an RIU is to maximize ΔMS, pursuing either of these strategies is not the answer.

At the other end of the spectrum, the highest R^2 found in this study was .406. This was achieved by a strategy to maximize the spread in the values between the Largest and 2nd Largest proportionate number of incidents and providing the Universities of Missouri and Wisconsin, and Cornell University, which were outliers, are removed from the population. In other words, if the RIU in question is not the Universities of Missouri and Wisconsin, or Cornell University, there is quite a high probability that a market outperformance can be achieved by pursuing a strategy that maximizes the value between the proportionate number of incidents in an RIU's Largest and 2nd Largest quadrants.

The highest R^2 that was found without removing any outliers from the population was .387. This relationship, as displayed in Chapter Four, Table 7, was achieved by combining all three derivative strategies with the NW - NE - SW combination strategy. While this composite strategy will be discussed in greater detail in the following section, it essentially means that those RIUs that had (a) the greatest spread between the value of the quadrant with the largest proportionate number of incidents as compared with the proportionate value of incidents in all of its other quadrants and (b) the highest remainder when the proportionate number of incidents in its NE and SW quadrants was removed from its NW quadrant, had quite a high probability of realizing a greater ΔMS. *This is the winning strategy.*

The relatively high value of the R^2 of the winning strategy means that 38.69 % of the variances of the data in the winning strategy and ΔMS are in common. In other words, as ΔMS moves up or down, 38.69 % of those changes can be attributed to the winning strategy. This explains a relatively large proportion of the variability of the data sets. There a good chance that a high ΔMS will be achieved if the winning strategy is adopted, since the .622 correlation that underlies this R^2 is considered to be a strong correlation in general and, as described in Chapter Three, a very high correlation in this particular circumstance. The strategies that are most strongly related to ΔMS are identified as those having an R^2 value of greater than .360 % and can be found in Chapter Four, Table 7. These selected strategies are presented in Table 11 for convenience.

Table 11
The Strategies with the Highest Correlations to ΔMS

Strategy employed	R^2
Largest - Smallest and Largest - 2nd Smallest and Largest - 2nd Largest and NW - NE - SW	.387
Largest - 2nd Smallest and Largest - 2nd Largest and NW - NE - SW	.384
Largest - Smallest and Largest - 2nd Largest and NW - NE - SW	.382
Largest - 2nd Largest and NW - NE - SW	.377
Largest - Smallest and Largest - 2nd Smallest and Largest - 2nd Largest and (SW + NE) - NW - SE	.361
Largest - Smallest and Largest - 2nd Smallest and Largest - 2nd Largest and NW + SE	.361
Largest - Smallest and Largest - 2nd Smallest and Largest - 2nd Largest and NE + SW	.361
Largest - 2nd Smallest and Largest - 2nd Largest and (SW + NE) - NW - SE	.360
Largest - 2nd Smallest and Largest - 2nd Largest and NW + SE	.360
Largest - 2nd Smallest and Largest - 2nd Largest and NE+SW	.360

It is notable that all of the strategies listing in Table 11 are composite strategies that include both derivative variables and combination variables. In addition, all of the composite strategies contain the derivative variable Largest - 2nd Largest. The strongest relationships all contain the combination variable NW - NW - SW. Despite the fact that, at .507, the Largest - 2nd Largest variable has the highest correlation to ΔMS of any individual variable set, its contribution to the overall R^2 is relatively low. Multiple regression revealed that the Largest - Smallest variable had the lowest Beta, the highest significance, and is therefore the biggest contributor to the overall relationship between this strategy and ΔMS. The reason for this could be that SPSS takes the individual strategies in a certain order, regardless of the order in which they are input into the analysis window. Nevertheless, the software must be trusted to produce the correct result.

It is also notable that ΔMS is highly variable. That is, relative to the number of data points, there is high degree of variability. This is reflected in the comparatively large value of $\sigma_{\Delta MS}$. Considering that 38.69 % of the variability can be explained, the probability of achieving a certain ΔMS by adopting the winning strategy is quite high. High variability is also true, albeit to a marginally less extent, for the other strategies listed in Table 11. That is, their σs are relatively high as compared with the range and number of data points in the population. This information is presented in Chapter Four, Table 5. A high degree of variability in the strategies employed by the RIUs is consistent with the notion that the American higher education system is comprised of a highly diverse population of institutions, including among research intensive universities. It also makes intuitive sense that a broad range of strategies would have a correspondingly broad range of possible outcomes. The relatively high correlation between the strategies listed in Table 11 and ΔMS strengthens the notion that there is a definitive relationship between strategy and performance in this context. If the data were clustered into a small area, they might still be highly correlated, but it would be less clear as to exactly which strategy points were correlated with which ΔMSs. A broadly distributed population of both sets of variables makes this determination more conclusive.

Examining the winning strategy, the relatively high σ is also reflected in the relatively large *SE*s of both the regression constant and coefficient that form the predictive equation produced by SPSS. Since the Largest - Smallest is the most significant component variable to the overall R^2 of the winning strategy and ΔMS, it will be used as the example. The predictive equation for the Largest - Smallest strategy has a coefficient of 69.78 ± 23.88 and a constant of -29.77 ± 9.80. If the equation was applied, without using the standard error factors, to the arithmetic mean of the Largest - Smallest, it should produce $\overline{\Delta MS}$. The value of $\overline{\Delta MS}$ is minus 2.277 and the arithmetic mean of Largest - Smallest is 0.394. Adding and subtracting the *SE*s will establish a range for ΔMS as Formulae 6 demonstrates.

Formulae 6: Using the Predictor Equation

a. (Coefficient ± *SE*) x Strategy + Constant ± *SE* = ΔMS

b. Coefficient x $\text{Mean}_{\text{Largest-Smallest}}$ + Constant = $\overline{\Delta MS}$

   69.78 x 0.394 – 29.77 = -2.277

c. (Coefficient + *SE*) x Strategy + Constant + *SE* = ΔMS_{high}

   (69.78 + 23.88) x 0.394 + (-29.77 + 9.80) = 16.93

d. (Coefficient - *SE*) x Strategy + Constant - *SE* = ΔMS_{low}

   (69.78 - 23.88) x 0.394 + (-29.77 - 9.80) = -21.49

The predictor equation used without the error factors produced a result that is exactly equal to $\overline{\Delta MS}$, and this verifies that the equation itself functions correctly. However, the range of ΔMS that adding and subtracting the *SE*s produce is quite broad. For example, the market perform group is formed by a range of $\pm 0.5\sigma_{\Delta MS}$ or a range of ΔMS of -11.69 to 7.13. The Largest - Smallest predictor equation produces results that far exceed the market performance group range. $\pm \sigma_{\Delta MS}$ establishes a range of ΔMS from -21.09 to 16.54. ΔMS_{low} was -21.49, just outside $\overline{\Delta MS}$ $-\sigma_{\Delta MS}$ and ΔMS_{high} was 16.93, barely within $\overline{\Delta MS}$ $\sigma_{\Delta MS}$ and creating a range totaling 38.42, more than half of the range of the entire ΔMS population of 71.45. This analysis points to the reality that the R^2 of the Largest - Smallest variable only explains 18.75 % of the variability of ΔMS and confirms that the populations are widely distributed within the range. On its own, this variable is a moderate to weak predictor. Yet, it is the most important component of the winning strategy.

The largest R^2 among the components of the winning strategy is the Largest - 2nd Largest variable. The R^2 in this instance was .257. Using the predictive equation relevant to this variable, and applying the same analysis used above for Largest - Smallest, the ΔMS_{low} and ΔMS_{high} produced were -12.10 and 7.53, respectively, a range of 19.63. This is a range that is barely outside of the market perform group boundary and a much tighter band in relation to the range of the entire ΔMS population. As would be expected, the higher the correlation between variables, the more predictable will be the variables, and the more accurate will be the value produced by the prediction equation. Given the R^2 of .387, the predictive value of the winning strategy to a given ΔMS is quite high.

There is additional analysis that could be done on the data produced in this study. However, the thesis question asks whether there is a relationship between the research strategies employed by the RIUs and the strategic results that they achieved. This statistical analysis demonstrates that such a relationship does indeed exist. The thesis question goes on to ask whether these strategies produce these outcomes. If the word *produce* is meant to suggest a causal relationship, this statistical analysis cannot make such a determination. This distinction is settled in Chapter Six.

Description of Winning Strategies

Given a better understanding of the nature of the statistical relationship between the selected RIU strategies and ΔMS, it is now reasonable to explore which strategic configurations correspond most closely with a market outperforming strategy. An important interjection is to reiterate the purpose of this part of the explanation. Reputation is the major factor in the long-term success of universities generally, and of RIUs in particular. Reputation grows out of departments that house prestigious faculty. Faculty achieve a high level of prestige by performing outstanding research, which is usually reflected in a relatively large value of research performed. Research performance, especially federally funded research, is the best indicator of institutional reputation. Since research performance reflects institutional prestige, universities are compelled to generate as much research as possible. In this, the goal of the faculty (the agent in this context) and the institution (the principal) are aligned. Competition for research funding is intense, and this thesis proposes that the use of an increasingly proactive strategic approach to strategy formation and execution will help RIUs better succeed in this market. The following describes some of the strategies that are most likely to yield success in the ARM, as measured by ΔMS.

The strategic configuration that was found to be the most closely associated with a market outperformance and that included all RIUs was a composite strategy comprised of the three derivative variables entitled Largest - Smallest, Largest - 2nd Largest, and Largest - 2nd Smallest, together with the combination variable NW - NE - SW.

When viewed together, the three derivative variables produce a cohesive strategy. Using the ratio method, the *first derivative strategy*, Largest - Smallest, describes a configuration whereby the difference between the value in the highest value quadrant and the value in the smallest value quadrant is determined for each RIU. The difference between these values is the Largest - Smallest. At .433, this strategy correlates positively with ΔMS and implies that an RIU should configure its portfolio such that it has the greatest spread between its most populated quadrant and its least populated quadrant. As seen in Appendix I for example, the University of Pennsylvania (U Pennsyl) had 0.63 of its incidents in its SW quadrant and none in its SE quadrant establishing a spread of 0.63. It has a ΔMS of 24.47, a performance near the mean of the outperforming group. University of California at Berkeley had 0.31 of its incidents in its SE quadrant and 0.19 in its NE quadrant, creating a spread of 0.12. University of California at Berkeley's ΔMS was near the mean of the underperformers at -15.78. The effective strategy is to maximize the spread.

The *second derivative strategy* is Largest - 2nd Largest. This strategy has a correlation with ΔMS of .507 and describes a scenario in which the difference between the quadrant with the highest value and the quadrant with the second highest value was determined for each RIU. As is the case with all derivative variables, the quadrants that contain these values can be different for each RIU and this is what distinguishes this set of variables from the combination variables. Of the three derivative variables, this one is the most revealing because the value of all other quadrants is less than that contained in the second largest quadrant. In other words, by maximizing the spread between the largest and second largest quadrants, the spread between the largest and the other two quadrants will automatically be large; in most cases the maximum spread. Perhaps this phenomenon explains why the correlation between the Largest - 2^{nd} Largest variable and ΔMS is greater than for the other derivative variables. In order for an RIU to achieve this configuration, it must ensure that the proportionate number of incidents in three of its four quadrants is being minimized.

The *third derivative strategy* is Largest - 2^{nd} Smallest and has a correlation with ΔMS of .443. The three derivative variables urge RIUs to maximize the spread between the proportionate number of incidents in the largest and smallest quadrants, the largest and second largest, and the largest and second smallest quadrants. In other words, the best scenario is to have all incidents in one single quadrant. However, the analysis presented earlier in this chapter demonstrates that an RIU with less than three incidents in the NE quadrant of its Strategic Portfolio Array will almost certainly not be a market outperformer. As such, the ideal configuration appears to be to have either three or four incidents in the NE quadrant and all of the remaining incidents in one other quadrant. That will be the only way of maximizing the spread between the value of the largest quadrant and all of the other quadrants on an RIU's Array.

The *final component of the most successful strategy* was the combination variable NW - NE - SW, which was correlated at -.427 with ΔMS. Another way of looking at this strategy is NW - (NE + SW). The reason to make this minor algebraic adjustment is to emphasize the importance of the NE and SW quadrants as keys to strategic efficiency in this research. This variable is negatively correlated with ΔMS in that the more negative the result of the calculation of this combination variable, the better ΔMS is likely to be. In other words, the greater the value of NE + SW as compared with NW, the better the strategic performance of the underlying RIU is likely to be. The best result is when all of an RIU's incidents are in the NE and SW quadrants, and none of its incidents are in its NW quadrant. Such a configuration would produce the largest negative value.

It is notable that the SE quadrant does not directly form part of this strategy and this begs the question as to whether the number of incidents that the RIUs have in their SE quadrants is influencing the strength of the correlation of NW - (NE + SW). A check of the relationship between the SE quadrant and ΔMS shows that, at -.341 using the ratio method, the correlation is moderate. As such, the relationship between the SE quadrant and ΔMS could be influencing the relationship between ΔMS and NW - (NE + SW). This is consistent because, in order to achieve the greatest difference between the NW quadrant and the sum of the NE and SW quadrants, an RIU would need to have zero incidents in its SE quadrant in addition to its NW quadrant. In other words, the best configuration is to have all incidents in the NE and SW quadrants.

When viewed in conjunction with the derivative variables, additional confirmation is provided that the number of incidents in the SE quadrant should be minimized. In fact, the best strategy for an RIU to adopt is to have three or four incidents in its NE quadrant and all of its remaining incidents in its SW quadrant. Importantly, none of the components of this strategy, taken either individually or collectively, contradict each other. In addition, this result supports the earlier hypothesis that incidents that occur in the NW or SE quadrants are unstable and inefficient. The reasoning behind this assertion is that, if the ideal strategy is for an RIU to have all of its incidents in its NE and SW quadrants, then any incidents that are not in these quadrants detract from maximum performance. Incidents that diminish maximum performance are, by definition, inefficient. Stated another way, if the ideal configuration produces the highest ΔMS, then any incidents that are outside of the ideal configuration are inefficient. In this case, the inefficient incidents occur in the NW and SE quadrants. Inefficiency means an allocation of resources to incidents in which the return on investment in research capacity, as measured by ΔMS, is less than it might otherwise be.

Figure 4 shows the Strategic Portfolio Array for Ohio State University. Ohio State has 0.53, 0.21, 0.16, and 0.11 of its incidents in its SW, NW, NE, and SE quadrants, respectively. Since it has three incidents in its NE quadrant, Ohio State University at least qualifies to be among the market outperformers. However, in order to bring its portfolio into a more strategically correct alignment, it should work towards removing the two incidents from its SE quadrant and the four incidents from its NW quadrant. This is the action that would maximize the spread between the quadrant with the largest proportion of incidents (SW) and all of the others, while still maintaining at least three incidents in the NE quadrant.

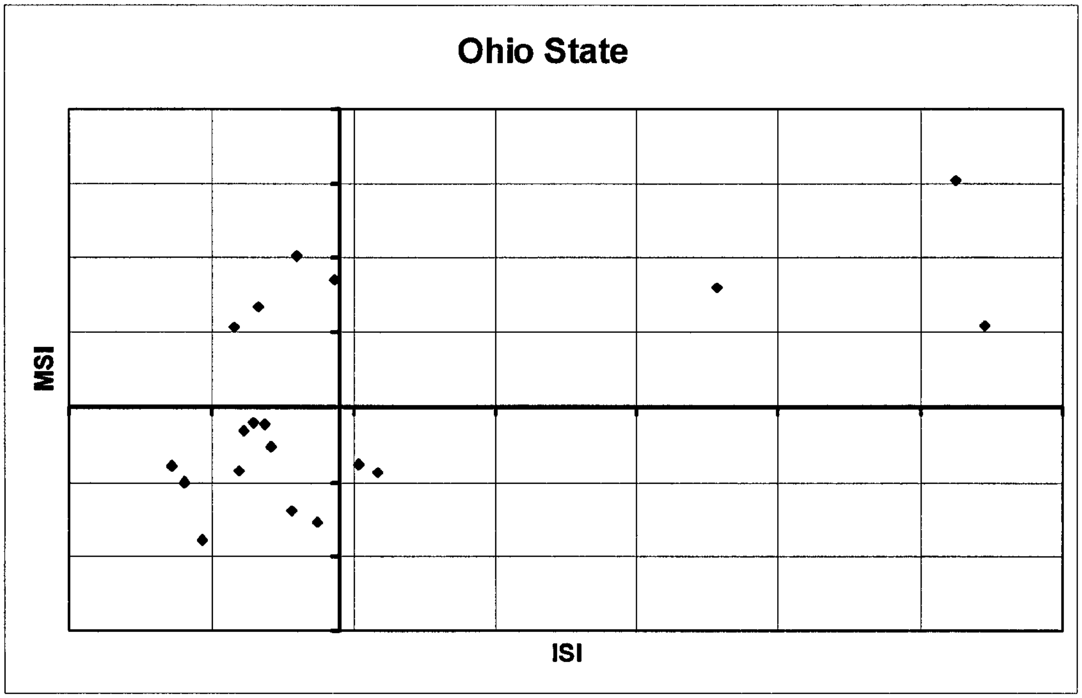


Figure 4. Ohio State University's Strategic Portfolio Array.

As can be seen in Appendix I, no RIU has achieved a perfect configuration on its Array. It seems reasonable that, so long as an RIU is moving in the right direction, its research operations are becoming more efficient and its chance of increasing its share of the ARM is also improving. By inference, this action should also begin to enhance institutional reputation. One place Ohio State University can begin moving towards a perfect strategic configuration is to consider deemphasizing its activity in Agriculture, one of the two fields represented by incidents in its SE quadrant. During the study period, Ohio State University's Percent Change in Share of Institutional Spending in Agriculture declined by 34.49 %. Yet, at $9.429 million of research expenditures in 2000a, Agriculture still represented more than 8 Percent of Institutional Spending in that period and is also substantially market overweighted as compared with the level of Agriculture research in which Ohio State University should be engaged according to the SW to NE bisecting line for Agriculture. Given that Agriculture is already very close to the y-axis on Ohio State University's Array, it would not need to take much action to make this adjustment. Deemphasizing Metal/Mat is also likely to improve Ohio State University's overall return on investment in it research activity. A successful outcome in this part of a strategic effort would leave one incident in Ohio State University's SE quadrant.

Ohio State University also has four incidents in its NW quadrant. Astronomy, while only 0.90 Percent of Institutional Spending in 2000a, grew by 131.32 % of Ohio State University's mix of research expenditures during the study period. This represents rapid growth. Since Astronomy is one of the highest values on the y-axis of Ohio State University's Array, it could move this incident into its NE quadrant without making high risk investments. Of the remaining three incidents in its NW quadrant, Civil Engineering represented $1.306 million of research expenditures in 2000a and was the only field that had a negative Percent Change in Share of Institutional Spending. As a matter of interest, it also had a decline in its share of the national market segment for Civil of more than 16.0 %. If the faculty that produce research revenue in Civil are not attracting funds from the state or industry in this field, Ohio State University should consider withdrawing from this area. Withdrawing from at least one field in its NW quadrant, either Civil, Sociology, or Political, should help this RIU achieve a higher ΔMS. Understandably, none of these latter mentioned decisions would be easy for this, or any university, to make. However, as earlier noted, these do not have to be all or nothing choices. Actions can be taken in measured stages; even subtle movement in the strategically correct direction will eventually accumulate into a significant commitment of resources.

If Ohio State University could move one incident from its SE quadrant into its SW quadrant, and one incident from its NW quadrant into its NE quadrant, and even if it did not remove another incident from its NW quadrant, its Array configuration would be very similar to those of the University of Colorado and Washington University, the number two and four ranking RIUs, respectively, in terms of ΔMS. Is it worth Ohio State University's examining this direction more closely? And, if it chose not to pursue these directions, the principals of research might be stimulated to ask why.

Summary

The boundaries presented at the beginning of this chapter do not necessarily negate the practical application of some or all of the parts of the model described in Chapter Four in its present form for use as a means of interpreting the realized strategies of RIUs. The boundaries, however, do strongly suggest that confirmations be produced which may ultimately indicate that further refinements are required. Even if the model does need significant development prior to its practical use, the nature and types of interpretations offered in this chapter would still be applicable; albeit, the suggested courses of action might be different.

One purpose for presenting the detailed descriptions in the use of the Strategic Portfolio Array is to demonstrate how this quantitative tool can be used by RIUs to improve their strategy making ability. This analysis provides exactly the type of information that allows for a more proactive approach to resource allocation decision making than has been previously available. This is because RIUs can determine, for the first time, by using simple algebra and geometry, what their ideal strategic positions should be in each component of their research portfolio and, by comparing this to their actual status, identify their strategic positions. The Strategic Portfolio Array can then be used for internal examination purposes to identify possible strengths and weaknesses, including inertial direction, of each component of an RIU's portfolio. This information can inform decisions about whether an RIU should adopt a defensive or aggressive demeanor in each of its research interests. When this information is viewed in conjunction with the Arrays of peer groups or a wider set of competitors, opportunities or threats can be matched with institutional objectives. Finally, when viewed against the ARM, the overall institutional performance of each RIU is exposed. As well, the strategic objectives of individual RIUs can be put into the context of the market potential and risks associated with embarking on one initiative versus others, using quantitative analyses.

Strategic choices can be made on any basis, including, as Mintzberg and Rose suggest, as a result of a groundswell (2003). In large, sophisticated, complex organizations, strategy also acts as a means of organizational control (Goold & Quinn, 1990). In regard to RIU research operations, strategic decision making should be increasingly based on quantitative information that can be used in a proactive manner. Even if incrementalism is the current method of planning and implementing an RIU's strategy: that is, even if the influence of the central authorities of university research is, at best, to manage at the margins, over the long term those marginal allocations can accumulate into major areas of investment. The more decentralized is the management of research at a university, the longer will it take for a centrally initiated strategy to unfold. At a minimum, such RIUs should be engage in logical incrementalism (Quinn, 1978).

This thesis provides the quantitative information required to enable these strategic processes to be undertaken.

Another reason for presenting detailed examples of the use of the Strategic Portfolio Array is to explicate the performance indicators that have been introduced, by illustrating how they can be used to undertake the aforementioned analyses. It is hoped that the credibility of each of them will be enhanced through greater understanding. In turn, this will lend credence to the entire thesis model and the method used to generate it.

A statistical analysis was undertaken to establish the relationship between the research strategies of the RIUs and the outcome of those strategies. This is the central question posed in this thesis. The analysis was enabled by the available data, which were translated into a portfolio analysis based on the portfolio theories described in Chapters Two and Three. The statistical analysis was based on the output of the thesis model. The statistical analysis was undertaken in Chapter Four, contextualized in Chapter Three, and is described in this chapter. The statistical analysis demonstrates that there *was* a relationship between the strategies employed by the RIUs and outcomes they produced. Furthermore, the relationship is statistically highly meaningful. Specifically, there is an R^2 of .387 that an RIU will achieve an increased share of the ARM if it adopts a strategy that includes all of the derivative strategies and NW - NE - SW. In the context of Social Sciences studies, in the context of efficacy of strategy studies, and especially in the context of higher education, such a relationship should be ignored only at the peril of long-term institutional performance.

Indeed, the detailed strategic analyses in this chapter presuppose an affirmative answer to the central question posed by this thesis, which is whether the research strategies of RIUs produce results that reflect those strategies. If the conclusion of this thesis was that there was no predictability between RIU research strategies and outcomes, there would have been no need to provide details of what the most effective strategy is, or how to move in the appropriate direction.

If a certain strategy increases the likelihood of achieving a superior market performance, and an RIU chooses not to pursue such a strategy, new accountability questions arise that demand a rigorous response. The answer to; Why not? can now be informed with real data that can include specific performance targets and realistic estimates of what resources will be needed to achieve the objectives.

Chapter Six: Conclusion

There are numerous levels of conclusions that can be drawn from this thesis work, some of which are reliant on others. For example, if the ideal research strategy to which a research intensive university (RIU) can aspire is that described in Chapter Five, then one conclusion of this thesis is that Ohio State University should strongly consider deemphasizing its rate of investment in research capacity in those disciplines that fall within the National Science Foundation's field of research entitled Metallurgical and Materials Engineering in its strategic plans for research. However, the conclusions that follow do not delve into recommending changes in the research operations of individual RIUs. The intention is to focus on the principal conclusions.

All conclusions that follow must be considered within the conditions and qualifications presented earlier in this thesis. Of particular note is the assumption that investments in research capacity result in a corresponding amount of research performance (see pages 18 and 149).

The *first conclusion* that can be drawn from this work is that RIUs clearly exhibit strategic behaviour in their research operations. At a minimum, they have all realized a posteriori research strategies. Each institution's strategy is unique, unfolds in an observable manner and, as a group, are as diverse as the institutions themselves. The research strategies realized by the RIUs can be expressed numerically or visually on a Strategic Portfolio Array.

The *second conclusion* is that change in market share (ΔMS) is a valid indicator of an RIU's actual performance in the academic research market (ARM). More generally, the change in a university's share of the research market provides an inflation adjusted, highly objective, easily derived, and universally applicable measurement of research performance. In addition, some version of ΔMS is currently used in many sectors of the economy. Adopting this indicator will help a wider audience better understand academic research and, in the process, will make academia more accessible to the increasing variety of lay communities who are interested in higher education. ΔMS provides RIUs with concise data about their competitive positions in this critical component of their revenue streams and provides insight into their reputational direction. Specifically, universities can use ΔMS as the primary indicator, or in conjunction with raw performance expenditure data or ordinals, to more accurately measure progress towards their strategic objectives and institutional missions. Finally, ΔMS can be used as a financial indicator to measure return on investments in research capacity. RIUs can observe ΔMS in reaction to investments in research capacity across their own portfolio and in relation to other universities. ΔMS has a high potential utility as both a short term performance indicator and a long-term institutional strategic indicator.

The *third conclusion* is that there is a .62 correlation between the RIUs' research strategies and ΔMS. The strategy that correlated most closely with ΔMS is best described in terms of the Strategic Portfolio Array. The configuration that is most closely correlated with ΔMS is for an RIU to have either three or four of its research portfolio components in the northeast quadrant of its Array and all of the rest of its research portfolio components in the southwest quadrant. For reasons discussed primarily in Chapter Five, uncovering this relationship is highly significant.

The relationship between strategy and performance that has been herein revealed answers the central question posed by this thesis which is whether the research strategies of RIUs produce outcomes that reflect those strategies. A response to this question can most accurately be made by stating that any RIU that attained the ideal research portfolio configuration was very likely to achieve a high ΔMS. Having made this statement, it was noted on several occasions in this thesis that the reasons underlying this relationship remain unknown. The full extent to which this thesis can answer its central question is to establish, with a high degree of certainty, that the relationship between RIU research strategies and the resulting strategic outcomes did exist. This study must be considered a success in this regard.

A *fourth conclusion* of this thesis is that there is a methodology that can be used to expose the strategies of RIUs. The methodology described in Chapter Four yields, for the first time, specific quantitative information about the value of federally funded research that an RIU should perform in each component of its research portfolio in order to be risk neutral. Alternatively, every RIU now has the ability to determine its own research portfolio risk profile as it works to understand whether it is achieving a ΔMS that is sufficient in relation to its level of investments in research capacity. Risk return profiling can be used to study past performance, or to inform proactive decisions by providing quantitative input into strategic planning for research. RIUs can use the methodology to mathematically or visually position themselves in the competitive landscape that is the ARM.

A *fifth conclusion* is that there is a substantial discrepancy between the extent to which RIUs measure and account for their research operations as compared with their other operations. Given that research is at the core of a virtuous cycle that ultimately determines an RIU's strategic achievement, any improvement in the ability to better measure research contributes directly to institutional success. The near void of qualitative or quantitative literature relating to the strategic management of university research is inconsistent with the importance of research to the academic core, to the institutions, to the regions in which RIUs operate, and beyond. This thesis contributes to expanding the literature in this field.

A *sixth conclusion* is that the quality of accountability in the research enterprise can be improved as a result of the enhanced ability to quantitatively measure research enabled by this thesis. Principals of research can now readily determine whether the configuration of an RIU's research portfolio is deviant from the ideal. Deviations expose an inefficient use of scarce resources. Any disparity from the ideal strategy can stimulate many new directions of accountability in the research enterprise. The ideal portfolio configuration is the most efficient in the sense that an RIU will maximize its ΔMS for a given level of investment in research capacity. If all RIUs work towards the ideal portfolio configuration, the system as a whole will become more efficient. This will enable more research to be undertaken with same level of funding.

A *seventh conclusion* is that, from an institutional perspective, research can be managed more proactively than is currently the case. The tools provided in this thesis can be used for this purpose. The extent to which an increased degree of proactively managing research is desirable is a choice for each institution to make.

The *next steps* in this research include confirming the applicability of the model in real world settings. Such a confirmation will include a qualitative analysis, a process that will also help to generalize the model. Additional attributes of the model should be developed, such as enabling a dynamic view of RIU research trends by using rolling periods, instead of the static measurements used in this thesis. A dynamic three dimensional view of the market can be created by stacking the Strategic Portfolio Arrays of all RIUs. This view might reveal emerging market voids and highly clustered or, in other words, highly competitive market segments. The issue of the degree of research intensity should be explored as this might shed additional light on the strategy-performance relationship. This thesis' methodology opens the door for new ways to measure research which, in turn, enable the development of new types of management and accountability tools. These measures and tools should be perfected and put into use. Lastly, the work encompassing this thesis should be disseminated to as wide an audience as possible.

The economic footprint of research universities is enormous (Geiger, 2006). Research intensive universities have achieved their status because of the tremendous support provided by the federal government in the form of funding for research – support that has steadily increased over the very long term to a value that exceeded $30 billion in 2006 (NSF, 2006a). Research is foundational to the function, prestige, and stature of RIUs, to the higher education system generally, and to national interests. Anything that affects federally funded research has a direct impact on research universities. What happens to research universities has an amplified impact on the local, national, and global economy. It is incumbent on research universities, as a collective, to operate in the most efficient manner possible. Each and every university has a special responsibility to perform the best research with the fewest resources. In closing, it is my hope that this thesis contributes to this effort.

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Appendix A: Population of RIUs

The follow constitutes the population of RIUs as defined in Chapter Four, Definition 9:

California Institute of Technology
Carnegie Mellon University
Case Western Reserve University
Columbia University
Cornell University
Duke University
Harvard University
Indiana University
Johns Hopkins University
Massachusetts Institute of Technology
Michigan State University
New York University
Northwestern University
Ohio State University
Princeton University
Purdue University
Rutgers University
Stanford University
University of Arizona
University of California at Berkeley
University of California at Los Angeles
University of California at San Diego
University of Chicago
University of Colorado
University of Florida
University of Iowa
University of Maryland
University of Michigan
University of Minnesota
University of Missouri
University of North Carolina
University of Pennsylvania
University of Rochester
University of Southern California
University of Virginia
University of Wisconsin
Vanderbilt University
Washington University
Yale University

Appendix B: National Science Foundation Fields

The following is the list of the 21 National Science Foundation (NSF) fields used in this study. NSF fields are defined in Chapter Four, Definition 7. These fields serve as market segments in the case of the Academic Research Market (ARM) or as portfolio components in the case of an RIU. The ARM is defined in Chapter Four, Definition 1, and an RIU is defined in Chapter Four, Definition 9.

National Science Foundation terminology	**NSF field as referenced in this thesis**
Engineering-Aeronautical and astronomical	Aero/Astro
Engineering-Chemical	Chemical
Engineering-Civil	Civil
Engineering-Electrical	Electrical
Engineering-Mechanical	Mechanical
Engineering- Metallurgical and materials	Met & Mat
Physical Science-Astronomy	Astronomy
Physical Science-Chemistry	Chemistry
Physical Science-Physics	Physics
Environmental Science-Atmospheric	Atmospheric
Environmental Science-Earth Sciences	Earth/Geology
Environmental Science-Oceanography	Ocean
Mathematical Sciences	Mathematics
Computer Sciences	Computer
Life Sciences-Agricultural Sciences	Agriculture
Life Sciences-Biological Sciences	Biological
Life Sciences-Medical Sciences	Medical
Psychology	Psychology
Social Sciences-Economics	Economics
Social Sciences-Political Science	Political
Social Sciences-Sociology	Sociology

Appendix C: Procedure Used to Access RIU Research Expenditure Data

N.b. Data referred to in Chapter Four, section "Accessing and Processing RIU Data."

Go to http://caspar.nsf.gov
Choose "Data Source" and select "NSF Survey of R&D Expenditures at Universities and Colleges."
Click "Select Data Source(s)."

A new page will open.
 Click the tab "Modify Analysis Variables."
 At the bottom of the page is a box. Choose "Federally Financed Academic R&D Expenditures."
 Click "Select."
Click the tab "Modify Classification Variables."

At the bottom of the page is a box. Choose "Academic Institution (standardized)"
Click "Select"
In the bottom box choose "Academic Discipline, Detailed (standardized)."
Click "Select."
 Scroll up the page to the section "Year."
 For "Display:" choose "Selected Values in Column."
 For "Include Total?" choose "No."
 For "Selected Values:" click "Edit."

A new page will open.
In the box on the right, any values that appear should be removed. Press "Remove all Values."
In the box on the left, choose 1988 through 2002 inclusive.
Click "Add Value(s)."
Click "Save."
The page will return to the "Modify Classification Variables" page.
 Scroll to the section "Academic Institution (standardized)."
 For "Display:" choose "Selected Values in Row."
 For "Include Total?" choose "Yes."
 For "Selected Values:" click "Edit."

A new page will open.
In the box on the right, any values that appear should be removed. Press "Remove all Values."
In the box on the left, choose all 39 RIUs. After selecting each RIU, press "Add Value(s).
Do not press "Save" until all RIU's have been selected.
Once all 39 RIUs appear in the box entitled "Selected Value(s)," press "Save."

The page will return to the "Modify Classification Variables" page.

Scroll to the section "Academic Discipline, Detailed (standardized)."
For "Display:" choose "Selected Values in Row."
For "Include Total?" choose "Yes."
For "Selected Values:" click "Edit."

A new page will open.
In the left box, choose only those fields included in the study. Each time a field or group of fields is highlighted, click "Add Value(s)." Once all fields appear in the box on the right, click "Save."

The page will return to the "Modify Classification Variables" page.

At the top of the page click on "View Table."

The table will open. It can then be copy and pasted, exported or transcribed to an Excel file.

Appendix D: The Academic Research Market (ARM)

The ARM is defined in Chapter Four, Definition 1. The following data are broken down by National Science Foundation Field and by year. The data are in thousands of nominal United States dollars.

		1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Engineering																
	Aero/Astro	93681	114881	126904	137323	150440	159317	165897	183695	171227	183350	170794	183052	180924	254224	245591
	Chemical	85530	100905	110358	117999	126215	142803	150224	161117	173770	165856	169276	178870	195082	214893	228543
	Civil	102168	102165	116999	123635	143628	154327	162948	185896	197741	200357	197086	216317	236401	270707	307939
	Electrical	330379	386630	431820	435877	449459	458418	489022	543647	599810	624262	692549	649815	699803	725808	817403
	Mechanical	192647	214128	238201	251315	268853	309988	325511	339627	334913	322462	350741	387941	382734	416323	507328
	Metal & Mat	121774	130453	139133	153099	143259	150438	155012	175508	190455	222456	221691	217305	225918	240780	262188
Total Engineering		926179	1049162	1163415	1219248	1281854	1375291	1448614	1589490	1667916	1718743	1802137	1833300	1920862	2122735	2368992
Physical sciences																
	Astronomy	83744	87941	112714	136018	158350	165031	181658	206964	182354	182988	187993	272468	276493	259732	277380
	Chemistry	403189	421957	444902	451087	479583	505138	519951	533165	553613	551700	586982	616442	630049	661223	737272
	Physics	579590	606137	652116	679617	708018	708152	725104	761779	757293	803283	817951	867445	900671	926721	970813
Total Physical Science		1066523	1116035	1209732	1266722	1345951	1378321	1426713	1501908	1493260	1537971	1592926	1756355	1807213	1847676	1985465
Environmental																
	Atmospheric	112318	128806	131110	129384	140073	160634	164582	163653	175954	186622	209549	222376	221834	232150	249567
	Earth/Geol	174483	186777	204497	217945	238155	243221	269221	273899	267005	269073	312143	321182	331598	329146	374089
	Ocean	238249	259916	262090	263521	306461	329467	323586	331516	371406	355498	362204	405278	422144	448065	485727
Total Environmental		525050	575499	597697	610850	684689	733322	757389	769068	814365	811193	883896	948836	975576	1009361	1109383
Mathematics		149959	157289	160868	170485	183194	203039	205694	204772	208042	202052	214133	209229	228647	241653	266788
Computer		289129	323833	342321	371549	379798	423319	463029	483410	501578	506348	513479	582811	582699	643583	769761
Life Sciences																
	Agricultural	322446	349450	352804	377281	417741	449963	496177	531505	559673	548427	533532	545033	578929	617625	685686
	Biological	1608398	1736166	1844230	1950008	2136919	2310115	2448331	2490013	2530066	2684706	2938057	3221331	3653857	3871355	4406305
	Medical	2212866	2502586	2671393	2848670	3113366	3369501	3535380	3826912	4023873	4226915	4559278	4865993	5441833	6260185	7230513
Total Life Science		4143710	4588202	4868427	5175959	5668026	6129579	6479888	6848430	7113612	7460048	8030867	8632357	9674619	10749165	12322504
Psychology		140465	153081	163805	186280	214900	234382	241309	248804	258418	271391	298661	309274	350232	398312	474374
Social Sciences																
	Economics	49171	54316	54346	59669	65945	77301	76011	80029	90659	89803	92250	90114	89072	89938	101378
	Political	25163	25884	25364	28541	35045	42827	50270	59649	62248	51768	53115	54052	62718	71963	75761
	Sociology	47782	53883	59989	72023	81710	91078	96677	104420	118963	120578	118950	121951	136678	148343	180752
Total Social Science		122116	134083	139699	160233	182700	211206	222958	244098	271870	262149	264315	266117	288468	310244	357891
ARM		7363131	8097184	8645964	9161326	9941112	10688459	11245594	11889980	12329061	12769895	13600414	14538279	15828316	17322729	19655158

Appendix E: Calculation of MSI

The Calculation of EMS, ΔEMS, and MSI are described in Chapter Four, Definitions 12, 13, and 14.

		1990a	1990a Percent of ARM	2000a	2000a Percent of ARM	Percent Change in Share of ARM	Equalized Value for Percent of ARM (EMS)	Equalized Value for Change in ARM (ΔEMS)	MSI
Engineering									
	Aero/Astro	126369	1.46	206917	1.29	-11.95	0.0365	-0.4391	-0.4026
	Chemical	109754	1.27	196282	1.22	-3.83	0.0346	-0.1406	-0.1060
	Civil	114266	1.32	241142	1.50	13.49	0.0425	0.4958	0.5383
	Electrical	418109	4.84	717076	4.47	-7.77	0.1264	-0.2856	-0.1592
	Mechanical	234548	2.72	395666	2.46	-9.28	0.0698	-0.3412	-0.2714
	Metal & Mat	140895	1.63	228001	1.42	-12.98	0.0402	-0.4770	-0.4368
Total Engineering		1143942	13.25	1985083	12.36	-6.68			
Physical sciences									
	Astronomy	112224	1.30	254813	1.59	22.10	0.0449	0.8125	0.8575
	Chemistry	439315	5.09	635905	3.96	-22.16	0.1121	-0.8145	-0.7024
	Physics	645957	7.48	898279	5.59	-25.22	0.1584	-0.9269	-0.7685
Total Physical Science		1197496	13.87	1788997	11.14	-19.66			
Environmental									
	Atmospheric	129767	1.50	225453	1.40	-6.57	0.0398	-0.2415	-0.2017
	Earth/Geol	203073	2.35	327309	2.04	-13.32	0.0577	-0.4897	-0.4320
	Ocean	261842	3.03	425162	2.65	-12.68	0.0750	-0.4661	-0.3911
Total Environmental		594682	6.89	977924	6.09	-11.57			
Mathemati	Mathematics	162881	1.89	226510	1.41	-25.21	0.0399	-0.9269	-0.8869
Computer	Computer	345901	4.01	603031	3.76	-6.25	0.1063	-0.2296	-0.1233
Life Sciences									
	Agricultural	359845	4.17	580529	3.62	-13.24	0.1024	-0.4868	-0.3844
	Biological	1843468	21.35	3582181	22.31	4.50	0.6316	0.1654	0.7970
	Medical	2674216	30.97	5671560	35.32	14.05	1.0000	0.5165	1.5165
Total Life Science		4877529	56.49	9834270	61.25	8.43			
Psycholog	Psychology	167722	1.94	352606	2.20	13.06	0.0622	0.4800	0.5421
Social Sciences									
	Economics	56110	0.65	89708	0.56	-14.02	0.0158	-0.5154	-0.4996
	Political	26596	0.31	62911	0.39	27.20	0.0111	1.0000	1.0111
	Sociology	61965	0.72	135657	0.84	17.73	0.0239	0.6518	0.6757
Total Social Science		144672	1.68	288276	1.80	7.16			
ARM		8634825	100.00	16056698	100.00				0.1721

Appendix F: Federal Research Expenditures for the University of Pennsylvania

The University of Pennsylvania is one of the RIUs listed on Appendix A. These data are broken down by those NSF fields in which the University of Pennsylvania reported activity, and by year. The data are in thousands of nominal United States dollars.

		1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Engineering																
	Aero/Astro															
	Chemical	1966	3452	1333	953	948	737	693	733	646	720	1026	1282	1300	1016	1697
	Civil	865	123	122	291	229	138	0	0	0	0	0	0	0	0	46
	Electrical	1043	1194	1189	1040	1079	980	1136	1469	1161	1163	896	844	235	517	1101
	Mechanical	596	342	710	916	1016	808	727	767	1161	958	1495	1489	1246	1323	1640
	Metal & Mat	2576	2567	2558	2735	4499	4234	2146	2366	2685	1796	2860	2766	2464	2405	3257
Total Engineering		7046	7678	5912	5935	7771	6897	4702	5335	5653	4637	6277	6381	5245	5261	7741
Physical Sciences																
	Astronomy															
	Chemistry	6337	7046	7330	8168	8059	8642	9342	8184	12181	10423	11283	10624	11992	10112	10158
	Physics	6643	6553	7084	7215	7417	6921	9846	10666	10216	11771	12043	12031	10171	11569	11340
Total Physical Sciences		12980	13599	14414	15383	15476	15563	19188	18850	22397	22194	23326	22655	22163	21681	21498
Environmental																
	Atmospheric															
	Earth/Geol	12	19	41	129	158	93	188	94	98	26	20	29	92	164	38
	Ocean															
Total Environmental		12	19	41	129	158	93	188	94	98	26	20	29	92	164	38
Mathemati	Mathematics	699	741	892	811	1107	1166	1289	1230	1422	1117	731	949	1035	1014	1865
Computer	Computer	4193	5163	6114	6139	5572	5351	5282	5551	6155	5789	5905	7037	7664	7658	9393
Life Sciences																
	Agiculture															
	Biological	23419	24841	26756	27576	30733	40273	47137	54616	59160	63478	74506	89125	102380	112144	125800
	Medical	57724	63136	70201	79448	84302	86023	90033	94615	100931	101955	118314	131420	148823	176736	196534
Total Life Sciences		81143	87977	96957	107024	115035	126296	137170	149231	160091	165433	192820	220545	251203	288880	322334
Psycholog	Psychology	1306	1570	1357	1467	1928	2035	2134	2180	1920	2626	2937	3380	2564	3050	2982
Social Sciences																
	Economics	1479	1105	936	1566	1114	1441	987	1078	1117	1181	1086	1307	1393	1238	1304
	Political	227	158	311	370	486	386	158	128	120	144	57	9	1465	2122	2737
	Sociology	1512	1517	1106	425	664	1157	1556	2324	1624	1673	2420	2247	3184	3249	3755
Total Social Sciences		3218	2780	2353	2361	2264	2984	2701	3530	2861	2998	3563	3563	6042	6609	7796
Total Reported		110597	119527	128040	139249	149311	160385	172654	186001	200597	204820	235579	264539	296008	334317	373647
Total Actual			123810	133747	144451								279013	312434	351996	

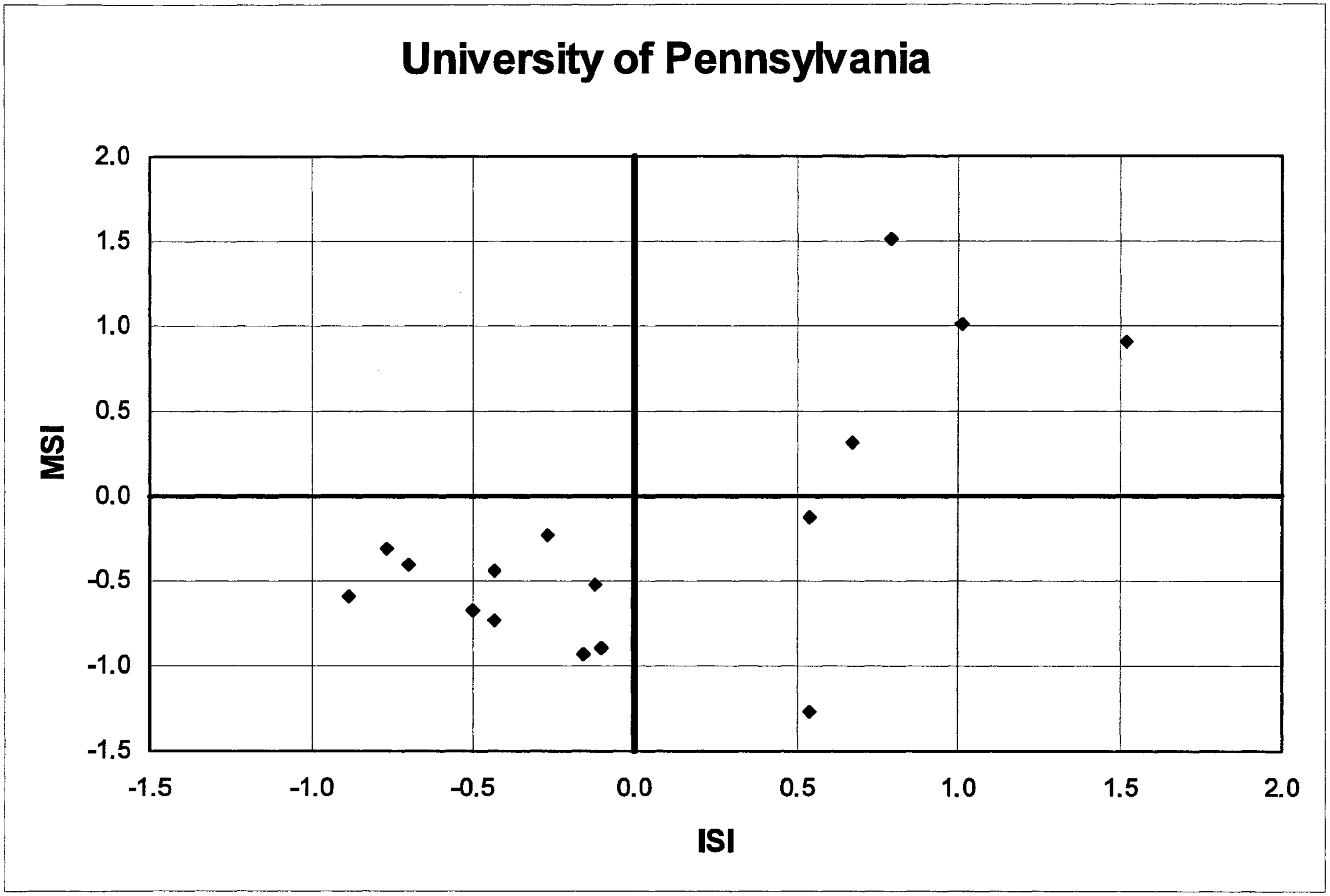
Appendix G: Calculation of ISI

The calculation of EIS, ΔEIS, and ISI are described in Chapter Four, Definitions 16, 17, and 18.

		1990a	1990a Percent of Institution Spending	1990a Percent of ARM	2000a	2000a Percent of Institution Spending	2000a Percent of ARM	Percent Change in Share of ARM	Percent Change in Share of Institutional Spending	Equalized Value for Percent of Institutional Spending (EIS)	Equalized Value for Change in Share of Spending (ΔEIS)	ISI
Engineering												
	Aero/Astro	0	0	0	0.00	0	0					
	Chemical	1730	1.34	1.58	1199	0.40	0.61	-61.24	-70.05	0.0079	-0.8994	-0.8916
	Civil	326	0.25	0.29	9	0.00	0.00	-98.66	-98.78	0.0001	-1.2683	-1.2682
	Electrical	1141	0.88	0.27	719	0.24	0.10	-63.28	-72.79	0.0047	-0.9346	-0.9298
	Mechanical	716	0.56	0.31	1353	0.45	0.34	11.99	-18.38	0.0089	-0.2359	-0.2271
	Metal & Mat	2620	2.03	1.86	2545	0.85	1.12	-39.97	-58.03	0.0167	-0.7451	-0.7284
Total Engineering		6533	5.06	0.57	5825	1.95	0.29	-48.62	-61.48			
Physical Sciences												
	Astronomy	0	0.00	0.00	0	0.00	0.00					
	Chemistry	7515	5.83	1.71	10909	3.65	1.72	0.29	-37.28	0.0716	-0.4786	-0.4070
	Physics	6951	5.39	1.08	11257	3.77	1.25	16.46	-30.03	0.0739	-0.3855	-0.3116
Total Physical Sciences		14465	11.21	1.21	22166	7.42	1.24	2.57	-33.79			
Environmental												
	Atmospheric	0	0.00	0.00	0	0.00	0.00					
	Earth/Geol	63	0.05	0.03	95	0.03	0.03	-6.44	-34.85	0.0006	-0.4474	-0.4468
	Ocean	0	0.00	0.00	0	0.00	0.00					
Total Environment		63	0.05	0.01	95	0.03	0.01	-8.30	-34.85			
Mathematics	Mathematics	815	0.63	0.50	999	0.33	0.44	-11.79	-47.00	0.0066	-0.6035	-0.5969
Computer	Computer	5805	4.50	1.68	7453	2.50	1.24	-26.36	-44.53	0.0489	-0.5718	-0.5228
Life Sciences												
	Agriculture	0	0.00	0.00	0	0.00	0.00					
	Biological	26391	20.46	1.43	101216	33.90	2.83	97.37	65.70	0.6645	0.8436	1.5080
	Medical	70928	54.99	2.65	152326	51.02	2.69	1.26	-7.21	1.0000	-0.0926	0.9074
Total Life Sciences		97319	75.44	2.00	253543	84.92	2.58	29.21	12.56			
Psychology	Psychology	1465	1.14	0.87	2998	1.00	0.85	-2.64	-11.56	0.0197	-0.1485	-0.1288
Social Sciences												
	Economics	1202	0.93	2.14	1313	0.44	1.46	-31.71	-52.83	0.0086	-0.6783	-0.6697
	Political	310	0.24	1.17	1278	0.43	2.03	74.06	77.89	0.0084	1.0000	1.0084
	Sociology	1016	0.79	1.64	2893	0.97	2.13	30.08	23.04	0.0190	0.2958	0.3148
Total Social Science		2529	1.96	1.75	5484	1.84	1.90	8.84	-6.30			-3.3900
Total Reported		128994	100.00	1.49	298563	100.00	1.86	24.47				-0.2119
Total Actual		134003			314481							
Percent Reported		96.26			94.94							
Percent change in reporting					-1.38							

Appendix H: The Strategic Portfolio Array of the University of Pennsylvania

The Strategic Portfolio Array is described in detail in Chapter Four, Accessing and Processing RIU Data, parts 10 and 11. There is a thorough discussion of the Array, its meaning, and its use in Chapter Five.



Appendix I: Presenting the Results and the Analytic Columns

The origin of the following data is described in Chapter Four, Calculating the Results. The meaning of these data is discussed thereafter.

			NUMBER OF INCIDENTS IN EACH QUADRANT				RATIO METHOD				ANALYTIC VARIABLES			ANALYTIC VARIABLES			ANALYTIC VARIABLES		
	ΔMS	# fields	# NW	# NE	# SW	# SE	NW	NE	SW	SE	NW+SE	NE+SW	NW-SW	NW-NE-SW	SW-NW-SE	(SW+NE)-NW-SE	Largest-Smallest	Largest-2nd Largest	Largest-2nd Smallest
Northwestern	36.78	15	3	3	8	1	0.20	0.20	0.53	0.07	0.267	0.733	-0.333	-0.533	0.267	0.467	0.467	0.333	0.333
U of Colorado	34.35	19	3	4	11	1	0.16	0.21	0.58	0.05	0.211	0.789	-0.421	-0.632	0.368	0.579	0.526	0.368	0.421
U of Missouri	31.74	16	1	4	8	3	0.06	0.25	0.50	0.19	0.250	0.750	-0.438	-0.688	0.250	0.500	0.438	0.250	0.313
Washington U	29.31	16	2	4	9	1	0.13	0.25	0.56	0.06	0.188	0.813	-0.438	-0.688	0.375	0.625	0.500	0.313	0.438
U of Pennsyl	24.47	16	0	4	10	2	0.00	0.25	0.63	0.13	0.125	0.875	-0.625	-0.875	0.500	0.750	0.625	0.375	0.500
U of Arizona	21.57	19	2	5	8	4	0.11	0.26	0.42	0.21	0.316	0.684	-0.316	-0.579	0.105	0.368	0.316	0.158	0.211
Cal Tech	15.43	13	0	3	6	4	0.00	0.23	0.46	0.31	0.308	0.692	-0.462	-0.692	0.154	0.385	0.462	0.154	0.231
Case Western	13.33	14	3	3	8	0	0.21	0.21	0.57	0.00	0.214	0.786	-0.357	-0.571	0.357	0.571	0.571	0.357	0.357
U of Florida	12.37	20	4	3	10	3	0.20	0.15	0.50	0.15	0.350	0.650	-0.300	-0.450	0.150	0.300	0.350	0.300	0.350
U of Virginia	11.30	18	3	4	11	0	0.17	0.22	0.61	0.00	0.167	0.833	-0.444	-0.667	0.444	0.667	0.611	0.389	0.444
U of N. Carolina	11.20	11	0	4	5	2	0.00	0.36	0.45	0.18	0.182	0.818	-0.455	-0.818	0.273	0.636	0.455	0.091	0.273
U of Maryland	6.54	18	1	4	3	10	0.06	0.22	0.17	0.56	0.611	0.389	-0.111	-0.333	-0.444	-0.222	0.500	0.333	0.389
Vanderbilt	3.15	16	3	3	7	3	0.19	0.19	0.44	0.19	0.375	0.625	-0.250	-0.438	0.063	0.250	0.250	0.250	0.250
Duke	2.89	15	3	3	7	2	0.20	0.20	0.47	0.13	0.333	0.667	-0.267	-0.467	0.133	0.333	0.333	0.267	0.267
Rutgers	0.78	18	3	3	4	8	0.17	0.17	0.22	0.44	0.611	0.389	-0.056	-0.222	-0.389	-0.222	0.278	0.222	0.278
Harvard	0.41	11	3	3	4	1	0.27	0.27	0.36	0.09	0.364	0.636	-0.091	-0.364	0.000	0.273	0.273	0.091	0.091
Indiana	-0.36	12	1	5	6	0	0.08	0.42	0.50	0.00	0.083	0.917	-0.417	-0.833	0.417	0.833	0.500	0.080	0.417
Michigan State	-3.54	11	1	4	4	2	0.09	0.36	0.36	0.18	0.273	0.727	-0.273	-0.636	0.091	0.455	0.273	0.000	0.182
U of Michigan	-3.56	19	5	2	10	2	0.26	0.11	0.53	0.11	0.368	0.632	-0.263	-0.368	0.158	0.263	0.421	0.263	0.421
Ohio State	-3.85	19	4	3	10	2	0.21	0.16	0.53	0.11	0.316	0.684	-0.316	-0.474	0.211	0.368	0.421	0.316	0.368
U of Minnesota	-4.74	18	5	2	8	3	0.28	0.11	0.44	0.17	0.444	0.556	-0.167	-0.278	0.000	0.111	0.333	0.167	0.278
UCLA	-5.35	18	4	3	9	2	0.22	0.17	0.50	0.11	0.333	0.667	-0.278	-0.444	0.167	0.333	0.389	0.278	0.333
USC	-7.35	19	5	2	9	3	0.26	0.11	0.47	0.16	0.421	0.579	-0.211	-0.316	0.053	0.158	0.368	0.211	0.316
U of Iowa	-7.93	16	2	5	6	3	0.13	0.31	0.38	0.19	0.313	0.688	-0.250	-0.563	0.063	0.375	0.250	0.063	0.188
Columbia	-9.24	17	4	3	8	2	0.24	0.18	0.47	0.12	0.353	0.647	-0.235	-0.412	0.118	0.294	0.353	0.235	0.294
UC San Diego	-11.85	13	3	3	6	1	0.23	0.23	0.46	0.08	0.308	0.692	-0.231	-0.462	0.154	0.385	0.385	0.231	0.231
Stanford	-12.64	18	5	1	9	3	0.28	0.06	0.50	0.17	0.444	0.556	-0.222	-0.278	0.056	0.111	0.444	0.222	0.333
Yale	-12.89	17	2	3	9	3	0.12	0.18	0.53	0.18	0.294	0.706	-0.412	-0.588	0.235	0.412	0.412	0.353	0.353
U of Chicago	-15.22	12	2	4	6	0	0.17	0.33	0.50	0.00	0.167	0.833	-0.333	-0.667	0.333	0.667	0.500	0.167	0.333
UC Berkeley	-15.78	16	4	3	4	5	0.25	0.19	0.25	0.31	0.563	0.438	0.000	-0.188	-0.313	-0.125	0.125	0.060	0.063
U of Wisconsin	-17.34	20	3	4	12	1	0.15	0.20	0.60	0.05	0.200	0.800	-0.450	-0.650	0.400	0.600	0.550	0.400	0.450
U of Rochester	-22.19	14	1	4	6	3	0.07	0.29	0.43	0.21	0.286	0.714	-0.357	-0.643	0.143	0.429	0.357	0.143	0.214
Purdue	-22.29	18	2	3	7	6	0.11	0.17	0.39	0.33	0.444	0.556	-0.278	-0.444	-0.056	0.111	0.278	0.056	0.222
New York	-25.40	11	0	5	0	6	0.00	0.45	0.00	0.55	0.545	0.455	0.000	-0.455	-0.545	-0.091	0.545	0.091	0.091
Cornell	-25.58	18	3	3	9	3	0.17	0.17	0.50	0.17	0.333	0.667	-0.333	-0.500	0.167	0.333	0.333	0.333	0.333
Johns Hopkins	-25.92	20	2	5	10	3	0.10	0.25	0.50	0.15	0.250	0.750	-0.400	-0.650	0.250	0.500	0.400	0.025	0.350
Princeton	-27.57	16	2	4	5	5	0.13	0.25	0.31	0.31	0.438	0.563	-0.188	-0.438	-0.125	0.125	0.188	0.000	0.063
Carnegie Melon	-29.16	13	3	1	5	4	0.23	0.08	0.38	0.31	0.538	0.462	-0.154	-0.231	-0.154	-0.077	0.308	0.077	0.154
MIT	-34.67	18	3	2	6	7	0.17	0.11	0.33	0.39	0.556	0.444	-0.167	-0.278	-0.222	-0.111	0.278	0.056	0.222
Correlation to ΔMS		0.009	-0.154	0.211	0.286	-0.316	-0.170	0.119	0.398	-0.341	-0.453	0.453	-0.468	-0.427	0.453	0.453	0.433	0.507	0.443
Total		628	100	131	283	114					13.11	25.89	-11.32	-19.71	4.39	12.78	15.52	8.77	8.52
Mean		16.10	2.56	3.36	7.26	2.92					0.336	0.664	-0.290	-0.505	0.112	0.328	0.398	0.225	0.219