The Pennsylvania State University

Graduate School

College of Education

KNOWLEDGE CREATION AND TECHNOLOGY TRANSFER IN NANOTECHNOLOGY AT RESEARCH UNIVERSITIES

A Thesis in

Higher Education

by

Radhika Prabhu

© 2007 Radhika Prabhu

Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Doctor of Philosophy

May 2007

The thesis of Radhika Prabhu was reviewed and approved* by the following:

Roger L. Geiger
Distinguished Professor of Higher Education
Professor-in-Charge of the Higher Education Program
Thesis Advisor
Chair of Committee

Patrick T. Terenzini
Distinguished Professor of Higher Education

J. Fredericks Volkwein
Professor of Higher Education

Robert M. Hendrickson
Professor of Higher Education

Mosuk Chow
Associate Professor of Statistics

*Signatures are on file in the Graduate School

ABSTRACT

Universities play an important role in linking science and innovation, especially in emerging areas such as nanotechnology where technologies are heavily dependent on science. This study examines the linkages between the academic knowledge creation and technology transfer process in nanotechnology, with emphasis on the environmental, organizational and individual contexts. The conceptual framework uses theories of power to trace the ascendancy of the tech transfer function from a peripheral to an increasingly core activity. The main research issues addressed include the stratification of nanotech funding, publications, and patents; the impact of interdisciplinarity on knowledge creation and transfer; effects of university policy, structure and strategies on knowledge creation and transfer; effects of organizational culture; and faculty attitudes, life-cycle associated behaviors and role balance in managing their public science and entrepreneurial roles. The methods used include data analysis of key metrics and case studies at two research universities.

Funding, patents and publications in nanotechnology are concentrated at a few universities indicating that regional innovation in nanotechnology could be skewed. In the eleven-year period from 1994-2004, each of these measures has shown an impressive increase. Interdisciplinarity affects the process and structuring of the entire academic value chain in nanotechnology, from the training of students to the evaluation of technology at the tech transfer office. The organizational contexts of knowledge creation create path-dependent conditions for transfer of technologies. Faculty across both institutions belonged to one of two groups of thought; those who believe firmly that tech transfer and research commercialization are part of their academic role, and others who believe that research commercialization is a peripheral role and takes away from their main focus. Faculty life cycle appears to play a key role in the decision to commercialize. Academic scientists who commercialize their research successfully manage both the conflicting role demands of public and commercial science. This study models two paths to the marketplace for nanoscale academic technologies. The first path is a clear case of technologies being ‘pulled’ into the marketplace and the second path relates to technology being ‘pushed’ into the marketplace. The two paths show considerable variation in their focus and the level of involvement at the environmental, organizational and individual level.

The peripheral task of tech transfer at universities is changing due to environmental pressures, and the shifting dynamics of power related with commercialization activities. Policy implications include the need for fostering interdisciplinarity in the academy and actively promoting an organizational culture that values such activity. Through its focus on academic knowledge creation and transfer in nanotechnology, this study advances the discourse on the role of universities in the knowledge economy.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

This work has benefited from the support and encouragement of many people. To Roger Geiger, my advisor, thank you for your support, guidance and encouragement. I am deeply honored to be your student. To Pat Terenzini, my mentor, it is a privilege to know you. Thank you for all the time and effort you have invested in my professional growth, it means more than I can say. To Fred Volkwein, Bob Hendrickson and Mosuk Chow, thank you for all your insights and suggestions which have helped shape this study. I deeply appreciate the constructive feedback provided by Dr. Irwin Feller in the early stages of this work. To Carol Colbeck, it is a joy to know you and I thank you for instilling in me an abiding love for organizational theory.

This dissertation would not have been possible without the faculty members and administrators who took the time to participate. I appreciate your willingness in sharing your candid views on nanoscale research and technology transfer. To my co-students at the center, Lisa, Susan, and Maureen, thank you for your friendship. To all the wonderful people at the Center especially Sally and Beverly, thank you for your encouragement and support.

I am blessed to be part of a loving and caring family and would like to thank all my elders for providing me with a strong sense of roots. I am deeply grateful to my parents for their unconditional love, support and encouragement. I am so proud to be your daughter and I thank you for the many sacrifices you have made to ensure my growth and happiness. To my husband Vittal, thank you for your love, strength and support. Your deep appreciation of knowledge sparks my own and I am happy to be on life’s journey

with you. To Maithili, my sister and best friend, you are very dear to me and I deeply appreciate your love and understanding. To my brother-in-law Manoj, thank you for your friendship and support. To my nephew Mihir, you are a source of great joy and happiness to me and I wish you the very best life has to offer. To all my friends and members of my extended family who are too innumerable to mention here, your presence in my life has enriched it deeply.

This effort is dedicated to my daughter Anika Sachi Prabhu who taught me about the profound joys and tribulations of motherhood. I miss you and I will always cherish you.

Chapter 1

Introduction

1.1 Background

What do Carbon Nanotechnologies, Cambrios, and Konarka share in common? These are university spinoff firms which were formed to commercialize the inventions developed at Rice, MIT, and the University of Massachusetts-Lowell in the area of nanotechnology. University founded technologies such as Google, Lycos, the V-chip, and the cancer drug Taxol, have changed the way we treat cancer, watch television, and surf the net. Since the passage of the Bayh-Dole Act in 1980 which allowed universities the right to patent discoveries arising out of federally funded research, numerous academic research inventions have been successfully brought into the marketplace. US universities are increasingly engaged in patenting their inventions and transferring technologies to the marketplace. In 1980, fewer than 250 patents were issued to universities. In 2004, that number rose to 3,800. In the same time frame, 4,543 university start-ups were generated, of which two-thirds are still in operation. In the ten year period since 1995, US universities have more than doubled their rate of spinoffs and are disclosing inventions at twice the rate (AUTM, 2004).

Research intensive universities in the US are an integral part of the innovation system and play an important role in advancing the knowledge economy. In 2004, total R&D expenditures at universities and colleges in the US totaled $42 billion. Universities are the leading performers of basic research, accounting for 54% of basic research and 33% of basic and applied research conducted nationally (NSF, 2006). Feldman et al. (2002a) contend that knowledge drives innovation, and universities are major actors in the "production, diffusion and deployment of knowledge". The modern university has been described as a "knowledge conglomerate" (Geiger, 2004), with a diverse array of activities that need significant resources for its upkeep, creating strong resource dependencies. Slaughter and Rhoades (2004) believe that universities are engaged in "market and market-like behavior" reflecting the reality of the new economy. Focus on knowledge as the prime component of interest, as well as the movement away from social welfare for all to empowering individuals as economic entities, has changed the way universities operate.

Academic science has become strongly entrepreneurial, and the sole focus on research as advancement of knowledge is changing to the dual focus of advancement and commercialization (Etzkowitz et.al, 2000). Since the 1980s, American universities have shown an increasing interest in transferring knowledge and commercializing it (Zucker et al, 2001). Characterized as "academic capitalism" by Slaughter and Leslie (1997), and "post-academic science" by Ziman (1996), this commercial environment and the resultant ties between university, industry and the government is described as the second academic revolution by Etzkowitz (1997).

Across nations, governments are linking academic science to international competitiveness through policy initiatives thereby encouraging universities to commercialize their discoveries (Johansson et al, 2005). Public policy is placing a lot of importance on science-based entrepreneurship because important "wealth-creating" industries like biotech, computers and telecommunications depend heavily on science (Henrekson and Rosenberg, 2001). The American competitiveness Initiative (ACI) introduced by President George Bush in his 2006 State of the Union address recommends $5.9 billion in FY 2007 and more than $136 billion over 10 years to increase investments in innovation-enabling research in physical sciences and engineering at key federal agencies, including the National Science Foundation (NSF), the National Institute of Standards and Technology (NIST) and Department of Energy's (DOE) Office of Science. One of the expected outcomes of the ACI is nanofabrication and nanomanufacturing that will transform lab science into new industrial applications. (http://www.whitehouse.gov/stateoftheunion/2006/aci/aci06-booklet.pdf).

Universities play an important role in linking science and innovation especially in emerging areas such as nanotechnology, where technologies are dependent heavily on science. Nanotechnology is essentially the ability to purposely manipulate matter at the molecular level. It is the understanding of phenomena at the nanometer (10^{-9}meter). The term "nanotechnology" refers to the science and the resultant technologies created at the nanoscale in several disciplines across the physical and life sciences. Nanotechnology has seen significant investments both from federal and state governments in the hope that research will translate into economic leadership. The moneys invested in the National Nanotechnology Initiative (NNI) are the most since the investment in the space race. Given the planning and the organization of the nanotechnology enterprise, it is important to study the results derived from it.

According to the National Science and Technology Council the "impact of nanotechnology on the health, wealth and lives of people could be at least as significant as the combined influences of microelectronics, medical imaging, computer aided engineering and man-made polymers developed in the century just past" (NSTC 2002, p. 11). The National Science Foundation estimates the market for nanotech products at $1 trillion in 2015, and 800,000 new jobs are expected to be created. The 21st Century Nanotechnology R&D Act authorized a multiyear commitment of $3.7 billion; an important part of the bill charges the department of commerce to aid in the transition of federally funded R&D into commercial and military products. A significant portion of these monies are awarded to universities by NSF and other mission agencies making universities an important site in the knowledge creation process in nanotechnology.

Unlike biotechnology which is housed in the life sciences, nanoscale science is of equal interest to both the physical and life scientist. Although science has gained an appreciable understanding of matter at the atomic level, the ability to purposely manipulate matter at the molecular level is the mantra of the nanotechnology revolution. In 1959, Richard Feynman charged his audience with the vision of new discoveries if one was able to fabricate materials at the atomic/molecular scale. The creation of the Atomic Force Microscope and the Scanning Tunneling Microscope enabled the "invention of the method of inventing" (Zucker and Darby, 2005), allowing for the visualization and manipulation of matter at the nanoscale and has provided the necessary instrumentation for advances in this science.

The National Nanotechnology Infrastructure Network (NNIN) funded since 2004, is a NSF initiative to build integrated nanotech facilities at major research universities. Currently this initiative is spread across 13 research universities including Cornell, Stanford, University of Michigan, Georgia Institute of Technology, Howard, Penn State, UC-Santa Barbara, University of Washington, University of Minnesota, University of New Mexico, University of Texas-Austin, Harvard and North Carolina State University. The precursor to the NNIN was the National Nanotechnology Users Network (NNUN), started in 1994 with nanofabrication facilities at Cornell, Stanford, Penn State, Howard, and UC-Santa Barbara. These facilities allow for nanofabrication in the areas of semiconductors, advanced materials, silicon devices, and quantum electronics (http://www.wtec.org/loyola/nano/US.Review/03_05.htm).

The NNIN funds the creation of instrumentation and cleanroom facilities at universities. Cleanrooms are lab spaces where the air is continuously filtered so as to remove the pollutants that cause problems in fabrication at the molecular level. Class One cleanrooms have only one speck of dust per cubic foot of air and most of the universities in the NNIN network have Class 100 cleanroom space or better. These funded initiatives have resulted in cleanroom space shared by academic and industrial researchers as well as a training lab for a nanotechnology-ready workforce.

With the creation of the NNI, the federal government is proactively trying to nurture the growth of nanotechnology and shape the outcomes of the nanotechnology revolution. This objective has gained importance because nanotechnology is considered by many as the next industrial revolution which will determine the global competitiveness of national economies in the near and distant future. State governments are also investing in nanotech initiatives in an effort to become the ‘Nano-valleys’ of the future. According to Geiger et al. (2005), state policies vary in their nanotechnology initiatives. California, New York, Texas, and Illinois have adopted upstream strategies, making investments in basic research and infrastructure to systematically grow innovation as compared to other states which have adopted more downstream strategies, investing in proprietary research for shorter term economic payoff. Figure **1.1** shows global investments in nanoscale research and signifies the importance of nanoscale research and its expected payoffs as perceived by national governments.

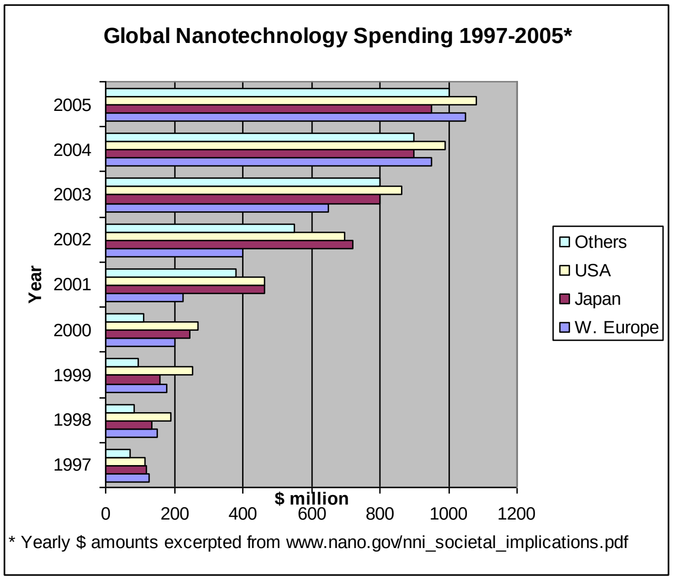

Figure **1.1**: Global nanotechnology spending from 1997 to 2005

In 1997, US spending on nanotechnology lagged behind Japan and Western Europe, but in the succeeding years it has mostly outstripped that of other nations, closely followed by Japan and Western Europe. Worldwide spending in nanotechnology has risen from $430 million in 1997 to $4 billion in 2005. The total investment in the US has more than quadrupled in the past five years, rising from $270 million in 2000 to $1081 million in 2005. More than 20 states have made financial commitments to nanotechnology related R&D that totaled more than half of the NNI budget in 2003. It is generally believed that private sector R& D exceeds public sector R&D by almost a factor of 2 to 1 in the US (NSF, 2003). If this pattern holds true of nanotechnology as well then the private investments in this area are significant.

1.2 Significance of Study

It is estimated that by the year 2015, almost half of all the products introduced in the chemicals, electronics, pharmaceuticals and other sectors will be enabled by nanoscale science and engineering (NSF, 2003). Early indications show that academic research in nanotechnology has found its way into the marketplace through the creation of start-up companies. In 2000, Richard Smalley, Professor at Rice University and winner of the Nobel prize in chemistry for the discovery of fullerenes or buckyballs, co-founded Carbon Nanotechnologies which produces single wall carbon nanotubes. In 2001, researchers at the University of Massachusetts founded Konarka, which makes power plastic from polymers and nanoengineered materials that convert light to energy. In 2003, professors at MIT and the University of California at Santa Barbara co-founded Cambrios, which uses molecular biology for the synthesis and assembly of new materials and nanostructures made of custom materials. There are many other examples of such university based start-up activity in nanotechnology and a common thread appears to be that the founders of these companies are generally well acknowledged leaders in their research area merging their professorial and entrepreneurial roles.

Academic technology transfer has been studied from several disciplinary lenses and at different units of analysis, from the environmental to the social-psychological level. Literature has focused on the role of universities in promoting economic development (Feller, 1990; Bercovitz and Feldman, 2006), ties between academic science and the success of the firm (Zucker et al, 2001), effect of university proximity on industry patenting (Jaffe and Adams, 1989), growth in university patenting (Henderson et al, 1995), the embryonic nature of university patents (Jensen and Thursby, 1998) and the effects of the Bayh-Dole Act on patenting (Ziedonis, 2001). Geiger (2004) has studied the effects of the university's close ties with the marketplace, and Slaughter and Leslie (1997) have focused on the redefinition of faculty roles. Owen-Smith (2001) has analyzed the organizational dynamics and the accumulative advantage in patenting performance by universities. Literature has also focused on faculty attitudes and technology transfer performance (Jacobi, 2001, Strasler, 1998), effects of a variety of resource factors on technology transfer performance (Powers, 2001), the organization of the tech transfer office and success in tech transfer (Hakson 1998, Kuhns 1999), and new mechanisms such as the use of equity in lieu of licensing fees used by universities to enable tech transfer (Feldman et al, 2002b). Additionally studies have focused on the emergence and importance of university spin-off companies (Shane, 2004; Lowe, 2002), and the disciplinary influences on patenting by Powell and Owen-Smith (1998).

This study advances the discourse by examining the linkages between the academic knowledge creation and the technology transfer process and focusing specifically on nanotechnology. The importance of studying the academic research process and transfer dynamics in nanotechnology is grounded in three factors:

- The organization of nanotechnology research and the creation of the NNI is considered by many as the most organized federal science initiative since the space race. The policies are aimed at enabling nanoscale science and technology and bringing the results to the marketplace. Research monies, infrastructure and collaborations are being fostered by federal, state, and local initiatives. This creates a dynamic environment in which the intertwining of public and private science and the resultant organizational change at research universities can be studied.

- The organization of nanotechnology is important to understand because of its interdisciplinary moorings. Nanotechnology is not housed in one discipline but fundamental discoveries will arise from the intersection of these disciplines including material science, engineering, medicine, environment, physics, and chemistry. For institutions as well as for funding agencies this will be a challenge because rewards are generally aimed at meeting standards within disciplinary structures.
- Additionally, focusing on nanotechnology enables a comparison with the case of biotechnology where ties between industry and academic researchers enabled the growth of the enterprise. Science and technology are closely intertwined in nanotechnology, as in biotechnology, and university science can be expected to play an important role. Nanotechnology appears to share several of the same key characteristics noted in biotechnology. The nature of the science requires large research teams and heavy capital investments and lends itself to readily commercial applications.

A research university has many diverse objectives; although the chief objective is the advancement of knowledge and creation of human resources, a stated objective, especially at land-grant universities has been that of translating knowledge into economic gain for the region and country. The objective of this study is to examine the linkages between academic science, technology transfer and commercialization in the area of nanotechnology at research universities in the US. Specifically, it deals with how academic science gets expressed and translated into private science in terms of patents and spin-offs. The study focuses on the knowledge creation process, the organizing conditions of knowledge, creation of knowledge stocks like papers and patents and organizational barriers and facilitators. It is the recognition and nurturing of these linkages which will enable the fruition of the dollars poured into basic funding of research. Another reason to study these factors is the increasing status perceived by universities who commercialize their results. The increasing intertwining of the public and commercial science realms with their disparate objectives creates conflicts in the academy and necessitates the realignment of organizational policies to manage both spheres.

This study has important implications for policy and practice in higher education. As connections between public science and private science are being fostered by funding agencies in emerging interdisciplinary areas such as nanotechnology, how do universities and individual faculty members make the transition between the two realms seamless, organize such work, and facilitate it through culture, strategies and policies?

1.3 Chapter Structure

The next chapter will detail the conceptual framework and research questions that form the basis of this study. The theoretical framework in which this work is grounded will also be detailed in the next chapter. Chapter 3 will review relevant literature and Chapter 4, focuses on the methods used for this study. The results from the data analysis will be detailed in Chapter 5. The two case studies and the findings from the interviews will be analyzed in Chapter 6. Chapter 7 discusses the findings, implications and limitations of this study and its relevance to policy and practice.

Chapter 2

Research Questions and Conceptual Framework

The previous chapter introduced the importance and relevance of this study. This chapter begins by describing the knowledge creation and technology transfer process at universities. It also details the research questions and the conceptual framework that are fundamental to this study. The theoretical foundations are described in the discussion on the conceptual framework.

2.1 Knowledge Creation and Technology Transfer at Research Universities

Figure **2.1** depicts the academic research, transfer and commercialization process. The external environment provides opportunities and challenges in the form of grants and partnerships at the federal, state, and industry level to the science base of the university, i.e., the faculty. The goals and mission of the university affect the manner in which its policies and culture evolve and impact faculty work and role perceptions. Knowledge transfer to the external environment occurs in many forms: by faculty serving on industrial advisory boards, through faculty consulting, and through university-industry consortia. Transfer of protectable intellectual property to the external environment occurs under the auspices of the Technology Transfer Office (TTO) at universities. The TTO evaluates the technology, files for patent protection, and markets the technology to companies in the relevant field of use. The TTO also provides assistance for research commercialization activities including creation of faculty spin-off firms.

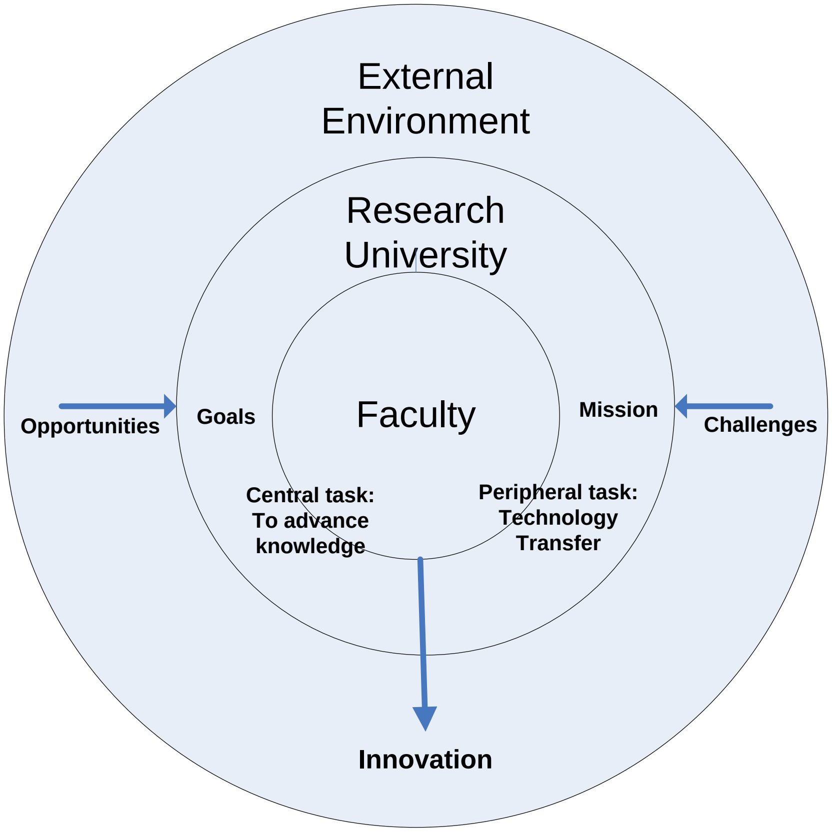

Figure **2.1**: Modeling Research and Transfer Process dynamics

‘Core technology’ as defined by Thompson (1967), relates to the arrangements through which central tasks of the organization are performed. This definition encompasses the skills of the workforce utilized to perform central tasks. In this context, faculty members are part of the core technology of a university. The central task of a research university is to advance knowledge and create human capital. Although most universities acknowledge the role of technology transfer and commercialization as part of their mission and organizational goal, it is positioned organizationally as a peripheral activity, and does not form part of the central task of the university. A good indicator is the position of such activities on the promotion and tenure dossiers, where they are in essence, relegated to the periphery.

Although positioned peripherally, the technology transfer function has been gaining in visibility and prominence on campus over the last two decades. A simple way to model the maturity of the process of technology transfer is to review the start date of the tech transfer office at universities. Data shows that the technology transfer activity at most research universities has moved away from the introductory phase into the early maturity phase of the life cycle. Of the eighty-nine research universities whose start dates could be identified by the Association of University Technology Managers (AUTM, 2004) data, it is apparent that most of the tech transfer offices became operational in the eighties. There were significant number of early adopters; 23.5% of these universities had technology transfer offices before 1979, 50% in the period between 1980 and 1990, and 26% came into being after 1990. The introductory phase in the late eighties and early nineties was characterized by the formalization of the technology transfer operation at most universities, and policies to support these activities.

The dot.com boom and the biotech era further propelled academic patenting and commercialization into the mainstream. Most research universities now have a visible technology transfer unit on campus. This indicates organizational commitment to the task of tech transfer and research commercialization. Unfortunately, success at tech transfer, when measured by licensing revenues, can be claimed by only a handful of universities including Columbia, MIT, Stanford, and the University of Wisconsin. These acknowledged leaders earn considerably higher licensing revenues as compared to their counterparts. Although the idea of technology transfer is widely spread and supported across research universities, only a few universities show remarkable productivity. It is clear that there are differences in the way technology transfer occurs at universities.

The borders between science and technology are amorphous in fields such as nanotechnology, which leads to an increased intertwining of public and private science at universities, and provides an interesting case for understanding the organizational challenge inherent in blending the two realms.

2.2 Research Questions

This study focuses on the interaction of environmental, organizational, and individual factors that link knowledge creation and technology transfer in nanotechnology at research universities in the US. The research questions examine stratification, interdisciplinarity, organizational policy and structure, organizational culture, and faculty roles as detailed below.

1. To what extent is nanotech research and technological output, measured in terms of funding, papers and patents, concentrated or dispersed across research universities in the US? Does the pattern resemble that in biotechnology?
2. How does interdisciplinarity, inherent in fields such as nanotechnology, affect the process of academic knowledge creation and transfer? What structural dimensions does it take?
3. How do university policies, structure and strategies influence knowledge creation, transfer and commercialization in nanotechnology?

4. What effect does organizational culture have on the creation and transfer of knowledge at the nanoscale?
5. What are faculty attitudes towards public science and proprietary for-profit science? How do faculty members blend the role demands of public and private science?

An expected outcome of this study is to model the paths which move academic research to the marketplace in nanotechnology with emphasis on the organizational, individual, and environmental constraints of knowledge emergence.

2.3 Conceptual Framework

Fig 2.2 depicts the conceptual framework which positions knowledge creation and technology transfer as iterative processes each informing the other. All knowledge that is created is not transferred or disseminated. In a research university, much of the knowledge is disseminated as publications. Some elements of knowledge are expressed in the form of patents and vested in spinoffs for further commercial development. Knowledge transfer can occur in many forms, however, for the purposes of this study, technology transfer is limited to the creation of patents and spinoff firms by faculty members. Publications are created within the domain conditions of public science, and patents and faculty spin-offs are organized under the domain of private science. The intertwining of these two realms creates interesting organizational dynamics for the research institution. The outputs of public and private science overlap as is depicted in Figure **2.2** .

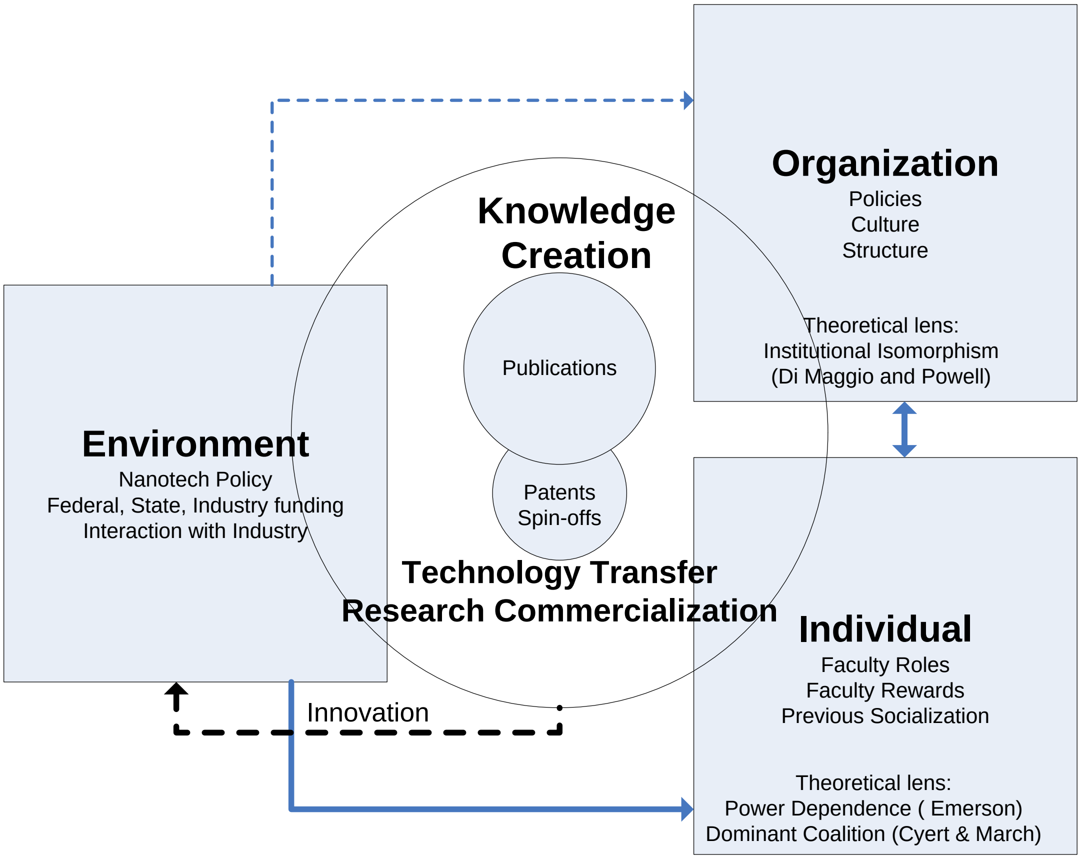

Figure **2.2**: Conceptual Map

Knowledge is not created in a vacuum; environmental, individual, and organizational variables all exert forces on the manner and substance of knowledge creation and transfer. The conceptual framework emphasizes the following key variables that impact knowledge creation and transfer at each level of analysis:

1. Environmental level of analysis - Figure 2.2, depicts a direct relationship between environmental and individual faculty level variables. Stimuli from the external environment in the form of federal policies such as the NNI initiative, federal support for nanotechnology, industry support and funding affect the manner in which faculty work, and impact the creation and transfer of knowledge. The

relationship between the inputs such as ‘nano’ funding dollars and the outputs, i.e., nanotech patents and publications can be hypothesized in a simple manner. It can be expected that universities attracting higher amount of inputs will also be the ones with a higher number of publications and patents.

2. Organizational level of analysis - The line connecting environmental and organizational level variables in Figure 2.2 shows an indirect effect of environmental variables on faculty work that is mediated by the organization Environmental variables impact organizational policies and structures which in turn impact faculty work. Conversely, faculty members through their role enactments shape organizational policies and culture. Policies that either support or negate entrepreneurial behaviors, a culture that either does or does not value both the tenets of open and for-profit science and the structuring of this interaction directly impacts the way faculty enact their roles. The differences in organizational culture, policy, and structure, which constitute a unique mix for any given university, affect knowledge outputs and provide for meaningful comparisons across universities. Supportive cultures, with resultant alignment of policies and structure, can be expected to result in increased knowledge outputs.
3. Individual level - Faculty role behaviors are predicated on their perception of what is valued and rewarded in the organization, and their community of practice. Institutional reward systems carry clear indications of work that is valued and rewarded. Faculty ability to blend public and private science roles is dependant on organizational policies, culture, and structure. Because faculty members are the prime movers in the academic enterprise, they wield considerable influence on

organizational change dynamics. Through the skillful use of power bases, faculty can realign organizational goals and reshape role expectations. The knowledge created at the individual level under organizational auspices and manifested as publications and patents are then transferred to the environment. This relationship between the knowledge created and the environment is depicted in Figure 2.2.

Each of these three levels of analysis offer complementary hypotheses to understand the knowledge creation and transfer process. The environmental level impacts knowledge creation and transfer through its policies and by introducing variable levels of input into the system. The organizational level adds another layer of complexity through its unique mix of policy, culture and structure. Additionally, faculty roles and perceptions of reward systems affect the manner of knowledge that is created and transferred. The goal of this study is to create an integrated framework to understand the ways by which these variables affect the process of knowledge creation and transfer in nanotechnology by integrating key insights from each of these levels of analysis.

The concepts of “power”, the “dominant coalition” and “institutional isomorphism” provide relevant theoretical bases for this study. A premise of this study is that technology transfer is moving from being a peripheral activity and gravitating to the center due to the skillful use of power bases by faculty members. Testing this premise necessitates the understanding of the concept of power and its various manifestations in an organizational setting.

An additional premise in this study is that universities are being increasingly driven to adopt similar policies with regard to the tech transfer function. The concept of institutional isomorphism helps explain the pressures faced by universities and contextualizes policy shifts with regard to tech transfer. The relevance of these concepts to the study is noted in further detail in the following sections.

2.3.1 Power and the Dominant Coalition

The concepts of power have been used in analyzing budget allocations at universities (Hackman, 1985), the role of subunit power on organizational decision making (Salancik and Pffefer, 1974), and the role of power and influence on strategic decision making (Finkelstein, 1992). Rhoades and Slaughter (1991) have also used power to understand how university policies are shaped with regard to tech transfer.

Several researchers have studied the concepts of power including Emerson (1962), French and Raven (1968), and Pfeffer and Salancik (1974). Emerson's (1962) theory holds that an individual has power over another if that individual can exert the necessary force to make the latter do something that they otherwise would not do. The power of one entity over another is equal to the dependence of the second entity on the first. Power then is situational and changes from one relationship to the other. According to Emerson (1962), power is not situated in the individual, instead it is embedded in the social relation between two actors. In this view, the flip side of power is dependency; the dependency increases if the goal is very important to the person and if there are no substitutable resources to be had. The power of one individual over the other also relates to the amount of resistance of the dependent actor that can be overcome by the powerful actor. Power relations between two actors need not be imbalanced. Reciprocal power can alter the dominance pattern of power relations. However one party may still hold a power advantage and there may occur balancing changes that reduce the advantage. Power of one actor over the other can be reduced if the latter reduces the importance of the goal or finds acceptable substitution. Alternatively, the first actor can increase his motivational interest in what B wants, thus acceding some of the power, or can be the casualty of a coalition building exercise which allows another actor to come into the network reducing A's power (Daft & Noe, 2001).

According to Bradshaw and Boonstra (2004), power can be manifest or latent, and individual or collective in nature. Power is observable as well as interpreted through the use of language and symbols, which are not at first glance evident. French and Raven's (1969) typology of power includes five sources of personal power. These are:

1. Power based on expertise: An actor is considered powerful if he possesses the knowledge and skills that are considered to be valuable by others. Weber's conception of bureaucratic power arising out of expertise is similar to this idea.
2. Power based on legitimate authority: This power derives from the organizational arrangement of work and the formal role which imbues power to the individual.
3. Power arising out of referent sources: This source of power derives from the trust that others have in the individual due to the traits and characteristics the person possesses. This ability to influence others makes the person powerful. This power can influence others in the community of practice to be like the person whom they identify with the most.

4. Power can also arise from the ability to issue rewards and the use of coercion to influence others.
5. Lastly, power can arise out of association. If an actor is part of a network of powerful people, each person of that network becomes powerful in his own right.

Bradshaw and Boonstra (2004) note that the sources of power mentioned above are manifest sources of personal power which are observable. The latent sources of personal power are not observable and are resident in an individual's understanding of economic, social and political consciousness, the ability to be skeptical and critically detached from dominant practices of the day, and the use of defiance; the ability to say no. As opposed to individual power, there is power in the collective as well, and those sources are based on a group's control of scarce resources, the criticality of the task which the group performs, the centrality of the tasks, the visibility afforded to the group, the flexibility and autonomy in positions and the power to build coalitions.

Cyert and March (1963) have elucidated the theory of the dominant coalition. In this view, organizations are composed of coalitions and each group tries to impose their goals on the system. Organizational goals are set by members through the process of negotiation. At any given time there are conflicting goals in an organization and some are solved through the process of negotiation and others are not. According to Thompson (1967), the more uncertain the technology and the environment, the larger the increase in power bases and the larger the dominant coalition. As the membership of the dominant coalition changes in response to the environment so do the goals of the organization, indicating the shift in power bases. According to Pfeffer and Salancik (1974), power resides in those units which bring in the resources that matter most to the organization.

A combination of power arising out of expertise, referent sources, and association, all come into play while analyzing knowledge creation and technology transfer. This study focuses on the manifest sources of individual power, while acknowledging that latent forces are also at play. Power is a relevant construct in this study because even though technology transfer is a stated goal at most research universities, it remains a peripheral activity in most cases. An important hypothesis for this study is that power arising out of faculty work in advancing knowledge in the public sphere is being leveraged to move private science into the mainstream of faculty work. This power, situated in the individual and the collective has the ability to move the technology transfer function from the periphery to the center. In nanotech, science and technology are closely intertwined which adds another layer of complexity to faculty power relations with industry. The tacit knowledge which resides with the inventing academic scientist is a key enabler in such science-based industries and has the ability to create dominant power relations with industry partners.

2.3.2 Isomorphism

In an organizational set, isomorphism is understood as a decrease in variation and diversity on key measures. The maturation of the technology transfer activity at most universities, and the presence of Association of University Technology

Managers(AUTM), which has been in existence for more than a decade has spread the idea of best practices in technology transfer. Tech transfer activities can now be said to be in the third generation of evolution and a probable hypothesis is that universities are approaching similarity in process and structuring of the tech transfer function.

The premise of the concept of institutional isomorphism by DiMaggio and Powell (1983), is that as organizations effect change they become increasingly similar. Trying to impose a rational frame on uncertainty brings about similarities in structure, culture, and output. Isomorphism as defined by the authors is both competitive and institutional. Within the area of institutional isomorphic changes there are three mechanisms of isomorphism which are 1) Coercive, 2) Mimetic, 3) Normative. Coercive isomorphism is an artifact of pressures placed on the organization by entities on which they are dependant. This implies a force which cannot be resisted because resistance creates trouble for the organization. Mimetic isomorphism occurs when organizations look to other organizations that they deem to be successful and imitate them, because they expect this will lead to success. The core idea behind mimetic isomorphism is that uncertainty prevails in the environment, leading organizations to model themselves on other, successful organizations. Normative isomorphism in organizations arises due to professionalization; formal education creates standardized professional education which creates pools of virtually indistinguishable professionals across organizations. Socialization behaviors in organizational fields also create similarity among pools of people. As people are trained in a similar fashion, chosen for their jobs on similar criteria, their approach to decision making also tends to be similar, because legitimate behaviors are mandated by professional standards.

Organizations can face all three types of isomorphic pressures, but the three mechanisms are a result of differing forces and may have different outcomes. For mimetic pressures, the underlying hypothesis indicate that the increasing uncertainty between means and ends, and the increasing ambiguity in goals, will make organizations model themselves after other organizations that they perceive to be successful.

As any organizational function approaches maturity, its features become well defined. Institutional benchmarking across peer universities is a common practice at research universities. Initiatives like the Committee on Institutional Cooperation (CIC), which is a consortium of twelve universities which includes the Big Ten universities and the University of Chicago are routinely involved in aligning academic practices. It stands to reason that technology transfer policies will have parallels across comparable institution types. For the purposes of this study, technology transfer policies at the two universities are used as illustrative cases on which isomorphic activity is measured.

The concepts of power and isomorphism help in understanding the increasing centrality of the tech transfer function and the spread of best practices and similar policy environments for tech transfer. However, organizational change occurs slowly and it occurs in a differential manner at different types of organizations. Universities, as organizational entities, share a unique set of traits that are illustrated below and the conceptual framework has to be reviewed against this backdrop.

2.3.3 Universities as organizational entities

Universities as organizational entities differ significantly from other forms of organizations. They are set apart due to the nature of their goals, which are ambiguous. They are ‘people processing” institutions, whose clients have a voice in institutional policies, and their technology is problematic due to the diverse needs of their client base (Baldridge et al, 1977). Universities are structurally configured as professional bureaucracies (Mintzberg, 1979), that rely on the knowledge and skill base of their professional members, the operating core, which form the heart of this system. Cohen and March (1974) have described academic organizations as an “organized anarchy”, a system lacking central coordination and control. In an organized anarchy, autonomous units are capable of setting independent goals and carrying them out within a broader framework. March and Olsen (1976) have pointed out that there is a loose coupling between intentions and action/behavior. At the organizational level, there is loose coupling between an organization’s normative structure and behavioral structure (Scott, 1998). Weick (1976) has characterized educational institutions as being loosely coupled. If intentions and actions are loosely coupled, actions may precede intentions rather than the other way around which renders planning an irrelevant exercise. Loosely coupled systems have the advantage of being able to adapt to diverse changes in the environment as compared to tightly coupled systems. A loosely coupled system is a good source for “localized adaptation”; one element can be modified and adapted to any contingency without disturbing the whole system. This nature of loose coupling makes it difficult to implement systematic change. According to Cameron (1989), loose coupling allows for innovations but tight coupling is required to introduce change in the system.

Universities have also been characterized as open systems (Pfeffer and Salancik, 1974), and political systems (Baldridge, 1971). According to Scott (1998), the open systems perspective points out that all organizations are dependent on exchanges with other systems and survival depends on the environmental influences. Boulding (1967) created a classification of systems based on their complexity where the lower levels typified physical systems, the mid levels typified the biological systems, and the upper levels the human and social systems. In Boulding's classification, the systems progress on a spectrum of complexity with each lower level system being incorporated into the higher level one. The higher order systems are more loosely coupled and more open to the environment. Open systems are those which undergo self-maintenance based on resources from the environment. According to Buckley (1967), open systems are capable of both processes; those that maintain the system form and structure and also processes that change the system. Managing both processes gives rise to system stability as well as growth.

Combining the above perspectives leads to the identification of universities as open systems engaging with the environment for resources. Furthermore, universities are political systems where there is ongoing negotiation amongst actors, and they are loosely coupled which means that innovative ideas are difficult to disperse across the whole system. These three characteristics of university functioning are relevant to this study because they impact the manner in which knowledge is created and transferred.

Together, the concepts of power, the dominant coalition and institutional isomorphism form the theoretical lens through which this study is framed. This theoretical base is used to analyze the findings from the case studies and develop an integrated framework for analyzing knowledge creation and technology transfer in nanotechnology.

Technology transfer has been studied from several disciplinary perspectives and at varying levels of analysis. The next chapter discusses literature on knowledge creation and tech transfer and its relevance to the study.

Chapter 3

Literature Review

The previous chapter described the conceptual framework and the research questions that frame this study. This chapter reviews literature related to the key concepts detailed in the conceptual framework. It begins by detailing the economic and social attributes of knowledge and the modes of knowledge production. It is followed by a description of the various factors that impact technology transfer at universities. Additionally, it traces the link between universities and the environment, the role of faculty as individual actors and the case of biotech. The chapter concludes with a summary of findings and the relevance of the literature reviewed to the study.

3.1 Knowledge Creation

The attributes of knowledge are different when viewed through an economic or sociological lens. In economic terms, knowledge is ‘non-excludable’, ‘non-rival’ and cumulative in nature (Feldman and Masard, 2002). Knowledge cannot be restricted and spills over to other economic agents, which makes it ‘non-excludable’. Multiple agents can be involved in the consumption of the same knowledge while not reducing the benefits the other enjoys, which gives knowledge its ‘non-rival’ attribute. Furthermore, knowledge builds on prior knowledge leading to a cumulative capacity.

According to Feldman and Masard (2002), two events happening simultaneously are shaping the knowledge economy. Increasing amounts of resources are being devoted to knowledge production and management, and new communication technologies are enabling rapid diffusion and reducing the costs of transmitting knowledge. However, there is a difference between knowledge and information. Information can be reproduced at low cost, but knowledge includes a cognitive capacity that cannot be easily reproduced. There is an inherent contradiction between the public and private dimensions of knowledge. The former places emphasis on free and widespread use whereas the latter implies the use of restrictions on accessing such knowledge. Tacit knowledge is a natural control mechanism that allows the creator of such knowledge a competitive edge which persists until the knowledge is completely codified.

Several social theories show that the creation, diffusion and utilization of knowledge play key roles in understanding economic and social behavior (Rich, 1981). In weberian terms, possessing knowledge/expertise forms a foundation for holding bureaucratic power. Knowledge has several dimensions including social, political, economic, and ideological dimensions and is developed in a cultural context. These differing facets exert inexorable pressures on both the process and substance of knowledge creation. As the largest single source of funds, and through its Science and Technology (S&T) policies, the federal government exerts a strong influence on how and what kind of scientific knowledge is created. Scientific knowledge creation is affected by the formal and informal interactions between scientists and the organizations under which they work together.

Basic research is conducted with practical goals in mind. The knowledge created may not be in an application context but with a practical goal in mind, which lends itself through some additional codification to application (Rosenberg and Nelson, 1994). David, Mowery and Steinmuller (1994) allude to two types of linkages between basic and applied research. The depth and number of such links determine, to some extent, the economic returns from discoveries in any given discipline. These links also affect the use of this knowledge in other disciplines, and affect the use of basic research results in applied research. They term these two links 'homotopic mappings' and 'analogic links'. "Homotopic mappings" refer to the manner in which knowledge can be created in one context, and can be mapped onto another problem seamlessly regardless of the difference in contexts. Scientific knowledge can be applicable to problems that are quite distant to the original concerns that generated such knowledge, if the knowledge can be homotopically mapped to different disciplines or to applied research. The effect and speed of progress is greater if theories can be homotopically mapped. "Analogic links" are based on the assumption that what is true in one field is also important in another. If broad analogic links are present then scientific information in that field will contribute to progress in another as well. In nanotechnology, where a variety of disciplines are focused on similar problems, if theories developed in one area can be mapped onto another, the speed at which discoveries will flow will be much greater. Interdisciplinary work has the potential to bring researchers together where such linkages can broaden the scope of work by applying solutions or its variants discovered in one discipline to another.

In interdisciplinary research, scientists can approach a problem with a paradigm different from those shared by others in the group, which can lead to both opportunities and challenges in the advancement of knowledge. “Scientific knowledge like language is intrinsically the common property of a group or else nothing at all. To understand it we shall need to know the special characteristics of the groups that create and use it” (Kuhn, 1996, p.210)

An important premise in this study is that the organizational, individual, and institutional constraints of knowledge emergence affect the manner in which nanoscale technologies are reaching the marketplace. Therefore a discussion of the organizing conditions of knowledge production is relevant to this study. Gibbons et al., (1994) detail a shift in the way knowledge is being produced from a traditional, disciplinary and cognitive, ‘Mode 1’ context, to knowledge that is created in a transdisciplinary, social, economic, and applications, ‘Mode 2’context. The distinguishing feature is the focus of the problem. In Mode 1, problems are solved within the confines of a particular disciplinary set of codes. In Mode 2, the application context determines the way the problem is solved and transdisciplinarity is critical to the solution. In biotechnology, where there is increased interaction between academics and industry, the predominant mode of knowledge production appears to be Mode 2. In Mode 2, production and distribution of knowledge are closely intertwined. It is reasonable to conclude that knowledge when created in an application context lends itself readily to marketability, and solutions to problems that can result in creation of wealth and economic growth.

In Mode 2, technology interchange replaces the concept of technology transfer. Universities learn from industry and vice versa and the research process is stimulated by this interaction. A university interfaces with industry at many levels; as donors, as corporate research partners, and all these linkages inextricably shape research agendas in a variety of ways that may be invisible.

Although Gibbons et al., position Mode 2 as the emerging or new mode, critics have pointed out that these two modes have coexisted in the history of science (Rip 2001). It has also been suggested that these two modes are not dependent but interdependent forms of knowledge production. Knowledge produced in Mode 2 may find favor with policy makers because the actors involved in the process include stakeholders and end users (Jacob, 2000).

Nanotechnology is not housed in one discipline but fundamental discoveries will arise from the intersection of disciplines such as materials science, engineering, medicine, environment, physics, and chemistry. This presents a challenge for universities and funding agencies because rewards are generally aimed at meeting standards within disciplinary structures. Gibbons et al (1994) argue that institutional rewards and organizational arrangements at universities do not favor transdisciplinarity. On the surface, this argument is sound because the American university is characterized by the presence of the academic departments rooted in their disciplines. The academic department in American universities as compared to the organization of the European chair replaced the “hegemony of the single professor with the collegial controls of the disciplinary group” (Clark, 1995, p.155). The rewards favor those who work within the specified norms and confines of their disciplines. However universities have always been adept at fashioning organizational accommodations that facilitate new interactions with external clientele, while buffering the core and focusing on their stated mission.

3.2 Universities and Technology Transfer

A significant marker in academic technology transfer is the Bayh-Dole Act passed in 1980, which allowed universities the right to patent discoveries arising out of federal contracts. Before this Act each funding agency determined the ownership of the patents arising out of federally funded research (Matkin, 1990). The basic premise set by the proponents of the Act was that much translational work needed to be done before a research idea evolved into a commercially viable product. The firms investing in this commercialization would not be interested in doing so if the patent belonged in the public realm. In essence, the Bayh-Dole Act was enacted to bring the ideas created from basic research into the marketplace. It would be incorrect to assume that the Bayh-Dole Act was the first impetus that made the universities focus on their patent policies, but the Act did propel universities to set into place organizational elements to facilitate licensing and patenting.

The initial impetus for university technology transfer activities was provided by external influences including national and state imperatives. However, in the 1990's, technology transfer activities were carried out more as a result of institutional priorities rather than as a response to external influences Even though licensing, patenting and creation of new companies have shown increased activity at universities, the economic impact of university technology transfer activities are difficult to assess because such initiatives are still in the early stages (Feller 1997).

Matkin (1990, pg 5) defines technology transfer as "the transfer of the results of basic and applied research to the design, development, production and commercialization of new or improved products, services or processes”. Technology transfer is considered a special case of knowledge transfer because in many cases what is transferred is not the technology itself, but the knowledge that can result in the technology. However, technology transfer requires constant exchanges with the transferee and is generally not a one step process. Technology transfer also includes a wide array of activities that strengthen relationships between industry and the university and bring academic research into the marketplace.

The technology transfer office (TTO) plays an important role in facilitating the commercialization of research. There is a positive correlation between the investments that universities make in technology transfer activities, including the composition of their TTOs, and success in technology transfer (Haksson, 1998). Technology transfer offices that meet both the traditional demands of the universities and the commercial demands inherent in their environment have more licenses, patents and royalties as compared to those technology transfer offices with only an institutional orientation (Kuhns, 1999). According to Bercovitz et al (2001), university organizational structures have an impact on technology transfer performance leading to differential outcomes in patenting and licensing and sponsored research. TTO’s organized as matrix structures have benefits in some areas of performance.

Technology Transfer activities at universities have been mostly measured by examining patents, licensing revenues and the number of spin-off companies created. Jensen and Thursby’s (1998) survey of 62 research universities shows that most of the technologies licensed are in the embryonic stage, and there is great need for the inventor to be part of the commercialization process. When they are licensed, most inventions are just ‘proof of concept’. The study found that the majority of the inventions licensed were based on federally funded research, and some type of reward is necessary to induce faculty involvement with industry.

Henderson et al., (1995), posit that a look at university patents prove to be informative because they are manifestations of research that is judged by the university to have some commercial potential and changes in patenting could be a reflection of the changes within the research community or could signal a shift from basic to applied work. 1500 patents were issued to universities in 1992, as compared to 96 US patents in 1965. University patenting has increased more rapidly than overall patenting in the economy and also more rapidly than university research spending. According to the authors, university “propensity to patent” has been increasing at the same time that overall propensity to patent has been decreasing. The increase in university patenting is also steadily continuous since the 1970’s, which means that the patenting trend had started before Bayh-Dole Act was put in place, although the Act sustained the impetus. The study also found that the best institutions are producing patents, on average, of lower quality, and there was an increasing trend of patents from smaller institutions that were not as highly cited. In essence, the sheer increase in patents does not mean that the impact of patents is higher it may be that the patenting threshold has fallen. Findings of another study (Ziedonis, 2001) suggests that the decrease in the quality of patents observed after the passage of the Bayh-Dole act was due to newer universities entering the technology transfer realm and not due to a change in research incentives at existing universities.

Powers (2001) studied the effects of a variety of resource factors on three measures of technology transfer performance, namely formation of start-up companies, number of IPO companies to whom a university has licensed a technology, and the level of licensing income received by the university. Levels of federal and industrial R&D were positively related to the number of start up companies formed. Institutions with medical schools had fewer start-ups and the presence of a research park was not significantly related to any of the dependent variables. The quality of the science and engineering faculty was significant and positively predictive of licensing income. The public or private status was not significant on any of the three measures of technology transfer performance.

A study by Owen-Smith (2001) finds that institutions that have been successful in patenting continue to do so, and patterns of success and failure are based on the organization's ability to capitalize on opportunities. There is the presence of a band of universities who continue to do well in patenting. These institutions also perform quite well in the public science realm, in terms of high impact publications and grants. The ability to organize both public and private science is attributed to institutional culture. 'Accumulative advantage' in public science is driven by reputation and status, but in patenting takes on the shape of organizational learning. Early patenting experience and organizational mechanisms for tech transfer are necessary but not sufficient to be among the top patentors. Technology transfer offices play a key role in creating the right kind of conduit between faculty research and patentable discoveries. The economic and human resources that the university brings to bear on patent activities create a culture where faculty are more prone to disclose their inventions and enter the patenting race. In the life sciences, patenting and high quality research is closely intertwined (Powell and Owen-Smith 1998). Faculty members in different disciplines have differing conceptions on the benefits derived from patent protection and those differences lead to different reasons for disclosing inventions. The importance of organizational culture in facilitating tech transfer has also been noted by Matkin, (1990). Institutions that are successful in technology transfer programs have supportive faculty cultures for entrepreneurship among other factors. It is difficult to successfully pursue the disparate goals of academic science and commercial goals in the same institutional setting and there are benefits from splitting up these two disparate activities in an organizational context (Johansson et al, 2005).

Leadership is also a key component in the development of innovative activities at universities. Hall (1997) notes the presence of strong leadership and vision by Stanford's Vice-Provost Frederick Terman as a major force behind the emergence of Silicon Valley. There are several reasons for the increasing importance of university based spin-offs (Brett et al, 1991). There is increased potential for revenues as universities can become equity partners in such ventures. Many rationales exist for the creation of such companies; promoting the state's economic development agenda, creating local jobs and retaining good faculty, being socially responsible in turning ideas into products of value and the creation of income for the university. The net increase in jobs since 1981, in the US, has been due to small and medium sized firms. There is considerable variation among spin-off activity at research universities and it is concentrated at a few universities in the US (Shane, 2004). The author attributes the variation to three sources, differential university policies with regard to spin-offs, the expertise of the technology transfer office and the culture and stated goals of the university. Institutional quality also has a positive effect on the rate of spin-off creation. Faculty members are incentivized to start companies, as financial gains in a spin-off are higher as compared to a patent which increases the likelihood of spin-outs (DiGregorio and Shane, 2003). Founders tend to retain their academic positions even when they commercialize their results (Johansson, et al., 2005).

Although royalties appear to be the main form of revenue generation from patents, universities are also using the mechanism of equity participation in lieu of licensing fees. A study by Feldman et al (2002a) finds that the age of the technology transfer mechanism is related to the use of equity in lieu of licensing. The older the technology transfer operation, greater the use of equity. Such innovative mechanisms can be considered a signal that universities are learning from their technology transfer experience and using new mechanisms thereby increasing their risks and rewards from technology transfer activities.

3.3 Universities and Economic Development

The first economic development approach adopted by universities is to develop human resources, i.e., graduates. The second approach is to strengthen industry oriented research through research consortia and cooperative research centers, which move faculty research from a knowledge based orientation to product and process concerns. In addition, they provide technical assistance to specific clients and allow industry access to university facilities. Through these interactions universities impact economic development in several ways (Allen and Norling, 1991).

The importance of the university in regional innovation is well-documented. Etzkowitz et al. (2000) posit that innovative regions have networks of people that share information across institutional boundaries. The entrepreneurial university takes the lead and becomes the coordinator between the organizations. There are three stages in the development of a ‘regional innovation environment’; they are the creation of knowledge, consensus and innovation spaces. The knowledge space relates to the concentration of related R& D activities, the consensus space is the venue that brings together different actors from differing organizational backgrounds to generate new ideas and strategies, and the innovation space is the organizational arrangement that facilitates the realization of goals in the consensus space.

In their analysis of regional innovation, Gibson and Smilor (1984) define a ‘technopolis’ as made of seven segments which include research universities, large and small tech companies, state, local and federal government and support groups. A high quality research university is a defining feature of the technopolis; it is a necessary but not sufficient condition for economic development. The research university by attracting funds, fostering R&D, attracting key resources in the form of students, generating companies and spinning off companies is a key resource for companies in the region.

Basic research makes up two thirds of academic research and approximately half of the nation’s basic research since the 1960s, has been conducted by universities. High technology industries which boomed in the 1990s drew heavily from basic research (Geiger, 2004). Federal funding for universities is justified by the ‘market failure’ argument, which holds that basic research leads to basic knowledge that is good for society overall. However, private firms cannot invest in such efforts because they cannot appropriate the results of such investments, and hence the government has to step in and fund such efforts (Mowery and Nelson 1999). The ‘social contract model’ makes the case that public funding of basic research ultimately benefits society because professors provide the ‘seed corn’ that result into new products and processes (Slaughter and Leslie, 1997).

Academic research spillovers into commercial markets have resulted in unanticipated technological advances, an example is the funding of military and defense related research, especially in the areas of computing and aircrafts, during the war years (Rosenberg and Nelson, 1994). Public R&D supports basic research and technologies for public use such as defense and civilian technologies. In some cases, basic research has impacted the growth of civilian technologies. Biotech, for example, has seen a high rate of public funding and basic research has had a clear impact on commercial technologies and applications (Mowery,1994).

At several times in the history of its evolution, the university has been asked to demonstrate the link between the knowledge they produce and economic development. According to Cantlon et al., (1991), the land grant institutions of Michigan and Pennsylvania were founded because the universities of the time were not making the link between discoveries in science and economic development. The Morill Land Grant Act introduced the concept of utility and practical knowledge. Indeed, the need to link knowledge production and wealth creation is not new and has been expressed by the patrons of the university in many forms across the decades. However, the changing tenor of relationships with government and industry has called into question the Mertonian norms of science where science is best served when decisions relating to its growth are left to scientists themselves with the scientific community exercising checks and balances (Jacob, 2000).

However, it is important to note that the American university has been shaped by a variety of social and economic forces through the centuries and has made organizational adaptations to meet the demands of the changing environment. Gibbons (1984) suggests for a group to thrive in society they must receive support or legitimation from other dominant social groups. Science at the beginning needed ‘the support of princes, academia and the church’. In the interest of survival, science had to explain its purpose and find different ways to express itself to these different patrons. The princes and the church have been superseded by the federal and state governments, industry and the public. And in the current era, these patrons are interested in stimulating economic growth and encouraging the link between knowledge production and wealth creation.

Innovation is not a unidirectional sequence of activities but a more complex sequence linked through several feedback loops. According to Audretsch (1995), knowledge is now a new factor of production along with that of land, labor and capital. This input is different from other factors because the economic value of knowledge is uncertain. Interestingly, according to the author, the link between knowledge inputs like R&D, and outputs such as patents strengthens as the units of observation are aggregated. It is strongest at the unit of countries and at the industry level but falters as it reaches the firm level. Countries with the most R&D investments are the most innovative but at the firm level it cannot be said with certainty. This is because knowledge cannot be bounded across organizations and spillovers may lead to innovative activity which cannot be captured at the firm level.

Audretsch and Feldman (1996) find that innovative activity in industries which depend heavily on new knowledge tends to cluster geographically as compared to other industries which are not as dependent on new knowledge. Innovative activity is highly clustered in those industries where tacit knowledge is important. Also the role that tacit knowledge plays in innovation is higher in the early stages of the lifecycle of the industry before any dominant standards have been established. Smaller firms are able to leverage the huge investments in R&D made at universities as well as large corporations.

According to Mowery and Ziedonis (2001), university based research effects on innovative activity are through two channels a) through knowledge spillovers from universities to firms; and b) a purposive channel utilizing mechanisms such as licensing and formal relationships between industries and universities. Their study analyzed patents at three universities focusing on both citations and licenses to these patents. They found that there is a consistent tendency for knowledge flows through market transactions to be more geographically localized than those operating through non-market spillovers (i.e. licenses are close by in geographic terms, people who cite could be far-off) Exclusively licensed university patents are more localized geographically suggesting that they contain a high amount of tacit knowledge needing contact with the inventor.

According to Brouwer (2005), US firms are increasingly looking to university inventions for a competitive advantage. As compared to their own inventions which they can time, external inventions force firms to innovate and accelerate the rate of technological progress.

3.4 Industry-University interaction

The 1970’s saw the generation of important relationships between industry and university due to declining federal funding. In addition, decreasing economic competitiveness made policymakers look at turning basic research into marketable products. The “transmission belt” metaphor of basic research spawning applied research, and therefore the development of products is being replaced with the view that technological development raises issues that inspire basic science, and therefore basic science is in some way consumer driven (Geiger, 2004).

Feldman et al., (2001) find that university-industry relationships take on many complex forms, for example, they take the routes of sponsored research, philanthropy and licenses. Several factors, including university and company characteristics, and the national policy and legal framework affect the evolution of such relationships. Universities are social as well as economic entities. Their relationship with industries is influenced by social and behavioral norms and economic conditions that vary significantly between countries and types of universities. Some industries are more able to draw from university research than others. Generally, engineering and applied science research have more input to firms than basic science research (Cohen et al., 1998).

Several problems exist with industry-university alliances, including the problems created by the organizational differences between the two partners which lead to ‘different timetables for expected results’. Since invention is only one facet of technological innovation, there are several other factors that can cause a barrier to technological innovation (Johnson, 1984). There exist barriers for faculty participation because institutional reward structures do not take into account faculty participation in such relationships (BHEF report, 2001). Critics have also contended that increase in patenting and licensing of academic research to the private sector in the cause of effecting economic growth may actually be ‘depleting the soil of human intellect’ and the public domain (McSherry, 2001).

Centers are one type of Organized Research Units (ORUs), and universities have long used this organizational accommodation to house research that did not fit well into departmental structures. ORUs have been an effective mediator between societal knowledge demands and knowledge produced by academic researchers and has been important in steering university research towards applicable knowledge (Geiger 1990). ORUs have encouraged collaborative work between faculty in various disciplines and have served as a mechanism to attract increased funding from agencies that favor a cross-disciplinary perspective. ORUs are research hubs and perform about half of all university research. In areas such as biotechnology, ORUs require huge investments and generally have been financed by multiple sources, including private, public and university funds (Geiger, 2004).

3.5 Faculty

There are differences in the way different fields approach patenting. According to Owen-Smith and Powell (2001), physical scientists have a ‘relational’ approach to patenting whereas professors in the life sciences have a more ‘proprietary’ one. In the physical sciences, time-to market is a key element for successful technology commercialization and many physical scientists tend to take a leave of absences for starting up companies. However, life scientists actively span public and private science domains as they work at the university while starting firms. Starting a company is a good way for scientists to create access to additional funding avenues, in addition to appropriating the value of created Intellectual Property (IP).

Authors studying the life-cycle models of scientists (Diamond, 1984; Levin and Stephan, 1991; Stephan and Levin, 1996), suggest that early on in their careers, scientists invest in human capital to establish their expertise and build a reputation. In the later stages of their careers, this reputation is used as a chip in accessing economic returns for their investment. Peak productivity is different amongst fields, for example, physical scientists peak earlier as compared to historians and English professors. This finding is important to this study because faculty life cycle may play a key role in the decision to commercialize research.

Scientific work occurs under different organizing conditions that effects how knowledge is created. Paisley (1968) has analyzed these associations as work in several spheres including “invisible colleges” which is a geographically dispersed group. These invisible colleges connect professors across regional boundaries and create seamless teams across organizational boundaries. The sociological analysis of the basic research community stemming from Merton’s work notes that a small number of faculty members receive a disproportionate amount of recognition. This is a self-reinforcing process leading to the creation of self-maintaining elite groups. These elite members form the heart of the scientific enterprise and cross-fertilize ideas across the network leading to innovation (Nelson, 1981).

Different expertise in individuals leads to the existence of different lenses through which information is interpreted. Interdisciplinarity is generally understood as work conducted using multiple lenses, whereas disciplinarity generally connotes similarity of belief. However, even among disciplines, growth has led to increasing complexity and fragmentation. Most disciplines have been fragmented into smaller communities that share similar concerns. Early interdisciplinary scholars did not demolish boundaries but moved across them whereas contemporary interdisciplinarians eagerly challenge accepted notions and beliefs and integrate work as compared to merely adding together several beliefs (Lattuca, 2001).

The academy may have collectively and positively embraced the notions of interdisciplinarity, however, faculty rewards continue to be deeply entrenched in disciplinary structures. Fairweather (1993) notes that the values embedded in faculty reward structures emphasize the relative importance of teaching, research, and service. Organizations establish mechanisms for motivating and rewarding their employees to encourage high productivity and high performance. Through extrinsic rewards such as salary increases, fringe benefits, promotion, and recognition, organizations reflect their values. While the higher education environment may consist of a number of extrinsic incentives and rewards, the institutional rewards system is dominated by the promotion and tenure process. In their examination of faculty commitment to their universities, Neumann & Finaly-Neumann (1990), find that faculty work, attitudes and behavior vary across career stages. Behavior and attitudes as well as commitment of new faculty is dominated by their desire for security and fear of a negative tenure decision. Faculty commitment to their university differs across fields and also varies across the three career stages of Assistant, Associate and Full Professor.

Faculty are more likely to disclose their inventions if their graduate training has been at institutions that are successful in tech transfer. Newer faculty members are more willing to accept the notion of research commercialization. There exists the effect of a leadership role; if the chair is active in tech transfer, then department faculty are also more likely to disclose inventions. There exists peer effects; if others in their cohort and department are disclosing inventions, there is more likelihood of other faculty members disclosing their inventions (Bercovitz and Feldman, 2006). Studies regarding faculty attitudes on technology transfer (Jacobi, 2001, Strasler, 1998), have found that faculty at more active or successful tech transfer institutions, have more positive views regarding technology transfer than those at less successful institutions. There is a higher likelihood of receiving grants for researchers in those institutions that are considered successful.

3.6 Biotech

Zucker et al, (2001) have found that academic science has strong positive effects on firm success in biotechnology. Commercialization of research necessitates transfer from the researcher to the commercial developer. New knowledge is inherently protected because the codes to systematize it develop slowly. This tacit knowledge can be captured by a firm by working with academic scientists. A good indicator of this knowledge capture is the number of joint articles written by the “firm” scientists and university “star” scientists. All knowledge builds on previous knowledge and the tacitness of knowledge increases as the distance from prior knowledge increases. The inventing scientist becomes the underpinning of the firm’s success because access to the scientist defines access to tacit knowledge that cannot be imitated by competitors. Zucker et al’s study found that firms that collaborated with the university scientist, as measured by joint articles, had more patents and more highly cited patents. In other words, the collaboration between the two had a positive impact on firm success. The number of joint articles could be interpreted as successful knowledge capture by the firm. The underlying argument is that in areas such as biotechnology where there appear to be readily commercial applications, academic scientists have been interacting with firm scientists with positive impact on firm success.

There are several distinctive features in the way biotechnology has evolved. There is a direct connection between basic research and commercial applications, there is no clear division of labor between academic and industrial scientists, and biotechnology has drifted towards big science requiring large teams and large capital investments (Geiger, 2004). In Geiger’s view, the traditional pattern of technology transfer is a barter economy whereas in the field of biotechnology, the pattern is that of ‘biocapitalism’. In the traditional pattern, the knowledge transferred is an intermediate good. However, in biotech intellectual property is transferred, and this reaps the benefits one gets from traditional tech transfer with the added incentive of monetary incentives for faculty members. The enormous amounts of money funneled in by NIH benefit industry by allowing them to tap into the discoveries of academic science and venture capital has also been available to create bio-tech startups. This large subsidy from the government and backing by private capital has seen the rise in commercialization opportunities in this field.

Research networks are essential and indispensable in the field of biotechnology because the science is the same in industrial labs or academia, and the deeper the network, better the chances of discovery. Because the knowledge base is distributed, knowledge cannot be contained within a single firm and access to the network sustains new learning and the creation of knowledge (Powell et al, 1996). In the US, life scientists who are funded by industries tend to commercialize their research more than those scientists without such relationships with industry (Blumenthal et al, 1996).

In biotech, the innovation process has been highly localized mainly because the technological development has been deeply rooted in basic science. In the US, knowledge flows more readily from the science base to industry in biotech because of the existence of academic entrepreneurs (Feldman & Masard, 2002). In biotech there were several big discoveries including the discovery of the double helix in 1953, and the discovery of the gene splicing technique in 1973. These discoveries led to big waves of technological change in the pharmaceuticals industry (Mowery and Rosenberg, 1998).

In the nineties, small firms were the main vehicle of job creation. In industries such as biotech and software, small firms by their very nature have held an innovative edge. Small firms rely on knowledge spillovers from outside sources such as universities. New employees are one of the sources of such spillovers, and small firms are better able to make use of such knowledge due to their flexibility and ability to absorb ideas quicker as compared to larger firms. Small firms thus serve as change agents of the economy. (Feldman et al., 2002c).

3.7 Relevance of findings to study

This literature review has examined the attributes of knowledge and modes of production, the tech transfer process, the role of universities in economic development, industry-university interaction, faculty roles and rewards, and some key features of the biotechnology enterprise. Mapping these terrains is important because this understanding at the environmental, organizational and individual level contextualizes and helps focus the research questions of this study.

The relevance of the key aspects highlighted in literature to this study is manifold. Literature points out that the way knowledge flows is dependent on the conditions under which it was created, and the inherent conflicts between the public and private dimensions of knowledge in nanotechnology will be studied with special emphasis on the organizational context of its origin. This study is focused on nanoscale work conducted by physical scientists and engineers and literature shows that their approach to patenting is a more ‘relational’ approach. Does that approach hold when they are working at the nanoscale or will the increasing intertwining of public and private science fostered by nanoscale policies at the federal level, increasing interaction with life scientists and the implied economic rewards change that approach? It is clear from the literature that the stage of the life cycle matters when it comes to faculty behaviors and outcomes. However does organizational culture outweigh the lifecycle associated behaviors? How do scientists who commercialize their research manage both the role demands of public and private science, what effects does the lifecycle have on faculty entrepreneurial behaviors? What indeed if any is the effect of prior socialization on entrepreneurial outcomes?

Literature shows that prior success is a predictor of continued success in tech transfer. The two universities that form the cases for this study present two contrasts. One university is a private institution, has a smaller faculty base, has prior success in tech transfer and has a higher licensing income from its patent portfolio. The other university is a public institution with a larger faculty base which is considered of high quality in certain areas, has a large patent portfolio but has smaller licensing incomes. However nanoscale science and increased commercialization resulting from nanoscale research is a strategic area of focus for the public university. Does increased organizational commitment negate the effects of prior lack of success in tech transfer? Is the public domain shrinking in favor of the private one in nanotechnology?

Literature reviewed here has shown that university and industry operate on different timetables however isomorphic cultures between the two in biotech have resulted in unclear division of labor. What role does industry play in nanotechnology knowledge creation and commercialization? Tacit knowledge plays an important role in the transfer of knowledge. Nanoscale science has the potential to severely disrupt existing technologies and create new markets thus changing the production landscape. Does this mean that there is an increased role for faculty spin-offs in nanotech? The biotech industry according to the literature review is highly concentrated. Are nanoscale R&D funds, patents and publications disperse or concentrated as was the case with biotech?

The next chapter discusses the methods used to inform the study.

Chapter 4

Methods

This study is concerned with both the process of knowledge creation and transfer of knowledge in nanotechnology, at the individual and organizational level, necessitating the use of both a quantitative and qualitative frame of analysis. The assembly of the database and the plan of analysis are detailed in Section 4.1. The case study method, interviewee criteria and the identification of themes are detailed in Sec 4.2.

4.1 Nanoscale Funding, Publications and Patent Database

The three chief variables of interest in this study are nanotech funding, patents and publications. A database including these three elements was constructed in order to answer the following research question:

- To what extent is nanotech research and technological output, measured in terms of funding, papers and patents, concentrated or dispersed across research universities in the US?

Funding is a key input in the knowledge creation process. The federal government exerts a strong influence on academic knowledge creation though its policies and grant monies. The formal and informal interactions between scientists and the organizations in which they work affects the process of scientific knowledge creation. An important element tracked for this study is publications in nanotechnology. Publications, the artifacts of public science, are an important gauge of knowledge transfer to the public domain. A third element of interest in this study is patents which are a potential indicator of a market channel through which knowledge is transferred. Licenses to patents are a more appropriate indicator of a market channel of interaction between universities and firms, but lack of comprehensive data on licenses to nanotechnology patents preclude this from the analysis.

The elements of the database constructed for this study include nanoscale funding, publications and patents data for 111, Research 1 and Research 2 (Carnegie classification, 2000) universities, in the US. The original 128 institutions which qualified as either Research 1 or Research 2 institutions were reduced to 111 due to lack of comprehensive data for 17 qualifying institutions.

Academic nanoscale funding, in the context of this study, was limited to the grants made by NSF. As part of the NNI, NSF is one of several other federal agencies which provide nanoscale funding to research universities. However, NSF is the only agency where awards in this field are clearly labeled as nanotechnology grants and where data can be accessed publicly and systematically across the years. Additionally, NSF grants to researchers are peer-reviewed grants indicating the perceived quality of research by the scientific community researching at the nanoscale. The time frame chosen for analysis was 1994-2004. 1994 was chosen as the first year of analysis because around this time frame nanofabrication facilities at universities were being funded by the NSF.

To gather information on NSF funding at the organizational level, the FASTLANE (www.fastlane.nsf.gov) website which contains detailed information on NSF grants was accessed. The search strategy was to search for nanoscale awards using the string ‘nano*’ in conjunction with each of the names of the 111 research universities. To facilitate analysis over time, each grant amount was disaggregated and apportioned over the years of the grant for each university and an aggregated total was calculated for each of the years from 1994-2004. To access data on publications in nanoscale science for these 111 research universities, a search of the Institute for Scientific Information (ISI), ‘Web of Science’ database was conducted using the string “nano*” and the name of the university to access the number of yearly journal publications. The search was limited to the Science Citations index (SCI) which indexes publication and citation information from over 5,900 journals. Patent data was collected from the Unites States Patent and Trademarks Office (USPTO) website. Searches were conducted on the USPTO website using the university name (and variants) as assignee and nano* in all fields. The data elements detailed above were captured in a database along with other variables including the public/private status of the university, geographical location and AUTM data for three years from 2001to 2003. AUTM conducts an annual survey of technology transfer activities at universities and presents a comprehensive source of information on key tech transfer metrics. The AUTM data elements of interest for this study were the number of patents, licensing revenues, the number of companies started and the year of tech transfer office creation.

Admittedly, the use of the term nano* as a search strategy for analyzing funding, patents and publications is limited. However, Huang et al (2004), in their analysis of nanoscale science and engineering patents provide a keyword list which details that more than 85% of the patent data they gathered was captured by the use of the search term ‘nano*’. The list of patents extracted by the search criteria mentioned above was distributed to the key administrator in charge of nanotech patents at the tech transfer office at both the universities which served as case studies. There was a marked discrepancy between what was perceived as a nanotech patent by the TTO officer and the list handed to them. About a third of the patents on the list were classified as ‘true’ nanotechnology patents. However both TLO’s acknowledged that there was no clear definition of what constituted a nanotechnology patent, and definitions were constantly being revised. This discrepancy in numbers constitutes a significant finding in itself; the definitions of nanotechnology are in constant revision and the identification of key stocks of knowledge is hindered by the lack of such definitions.

In addition to descriptive statistics, a distance metric was computed using the Euclidean distance formula for the two output measures namely patents and publications for each university. This metric allows for peer identification and institutional benchmarking among these 111 universities. The analysis of the data are described in further detail in Chapter 5.

4.2 Case Studies

The discussion so far has centered on the nanotechnology funding, patents and publications of research universities in general. However this picture is not complete without a detailed examination at the university and faculty level of analysis. There are important differences in the way universities organize knowledge creation and transfer activities. The case study method provides a rich environment for understanding complex dynamic phenomena and is a suitable tool for the analysis of organizational change.

Multiple case studies allow for cross-case analyses and richer interpretation of work (Eisenhardt, 1989; Yin, 1991). For this study, cases were structured at two levels of analyses at the organizational and the faculty level. This multi-level approach allows for better triangulation of data (Yin, 1991).

Two research universities, one public (BSU), and the other private (MPU), were chosen as the cases for this study. The main differences between both universities lie in their size, their location and their tech transfer performance. BSU is a large state university with significant research expenditures and well ranked programs, but has not yet seen any blockbuster technology emerge from its tech transfer office. On the other hand, MPU is a medium sized private institution which has handled blockbuster technology and outranks BSU in terms of licensing incomes. In addition, MPU is generally acknowledged as having a supportive tech transfer and commercialization culture as compared to that at BSU. These contrasting characteristics allow for an interesting analysis of the process of knowledge creation and tech transfer in nanotech at these universities.

Identification of faculty participants was conducted in a three-stage process. Information derived from preliminary dialogue with key administrators at both universities was used to create a list of faculty members conducting work at the nanoscale. This list was augmented by searches of the university’s web pages with the intent to locate nanotechnology centers, if any, and the faculty associated with them. An additional step was to identify the recipients of the NSF nanotech grants at both universities. As can be expected there was an overlap among faculty identified from this three-stage process and seven faculty members consented to be interviewed for this study.

Semi structured interviews were conducted with seven professors working at the nanoscale across several disciplines including chemistry, physics, electrical engineering, materials science and engineering and chemical engineering at BSU and MPU. Seven administrators who play key roles in central administration and technology transfer units were also interviewed. Furthermore, a faculty administrator consented to be interviewed with regard to both roles. In addition, document analysis of key artifacts such as the technology transfer policies, conflict of interest policies and previous technology transfer performance were analyzed. Organizational communication such as technology transfer reports were also analyzed. The interviews were conducted to gain an understanding of how knowledge is being produced in nanotechnology, and how technology is being transferred to the commercial world.

Interviews lasted anywhere between 40 to 90 minutes and were taped with interviewee permission. All identifying data was stripped before transcription, and to preserve confidentiality, pseudonyms were used in all transcribed interviews. The data analysis procedure was an iterative loop of identification and classification of themes. After an initial analysis, 10 distinct themes emerged from the data which were further refined to 8 discrete categories. Each theme reflects the key findings keeping in mind the research focus and the unit of analysis. ‘Working propositions’ describing hypotheses grounded in data were derived from the themes. As is true of qualitative data (Eisanhardt, 1989), findings are not generalizable to the population of research universities but the propositions derived from the research can be tested under other case conditions. Chapter 6 details the key propositions derived from each theme.

Chapter 5

Results from Data Analysis

The preceding chapter discussed the methods used in this study and the construction of the database. This chapter presents descriptive statistics that elaborate the nature of the key variables, i.e., nanotech funding, patents and publications. The construction of the Euclidean distance metric for peer analysis and institutional benchmarking is also described.

The success of Silicon Valley and Route 128 has often been linked to universities in their region, namely Stanford and MIT. In theory, the more the number of knowledge inputs, the higher the innovation in any geographic region. Knowledge spillovers tend to be concentrated geographically in the same region as where the knowledge was created and universities play an important role in this development. According to the logic of the knowledge production function, innovation clusters in regions with the most amount of knowledge creating inputs, which also tend to be the region with the most amounts of knowledge spillovers (Feldman et al, 2002b). It is reasonable to hypothesize that research universities with a higher number of ‘nano’ patents and publications will act as the nucleus around which innovation activities can be expected to cluster. The objective of this analysis is to identify the concentration, or lack thereof, of nanotech knowledge inputs and outputs at research universities.

NSF funding, patents and publications in nanotechnology are the three chief variables of interest on which data was collected for this study. A list of the research universities included in the analysis are detailed in Appendix A. In aggregate, total nanotech NSF funding for the 111 universities in the eleven year period from 1994-2004, was $1.42 billion, total publications numbered 26,453 and total patents numbered 4010. (excluding the UC system where totals could not be disaggregated at the university level, n=100). Table **5.1** details the descriptive statistics for the three key variables that indicate the wide disparity in performance among these 111 universities.

Table 5.1: Funding, Patents and Publications 1994-2004

		NSF "nano" Funding	"Nano" Publications	"Nano" Patents
N	Valid	111	111	100
	Missing	0	0	11
Mean		$12,833,047	238	40
Standard Deviation		$16,227,264	198	44
Minimum		$1,051,070	19	1
Maximum		$136,456,250	1,088	277
Sum		$1,424,468,196	26,453	4,010

5.1 NSF Nano Funding

Nanotechnology funding has seen an impressive increase in the eleven year period from 1994 to 2004. NSF funding, as estimated by the procedure described in the previous chapter increased tenfold, from around $33 million to $348 million. The increase appears to reflect two complementary facets; one, that the scope of work being conducted at the nanoscale has increased dramatically in the nineties and continues to be on the rise. Another interesting facet, detailed in Chapter 6, is that pragmatic researchers have increasingly used the term “nano” in grants and papers, thus increasing the visibility of such work. As is evident from the trend in Figure **5.1**, funding for the years before the NNI initiative was relatively flat, and shows a decidedly upward trend from 1999 onwards.

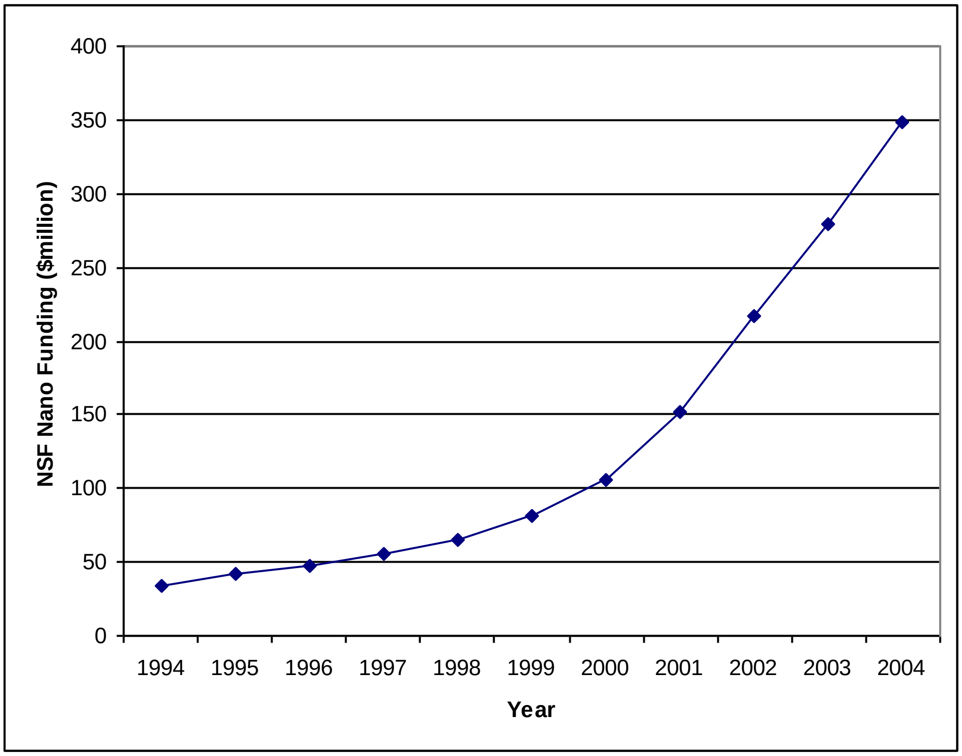

Figure **5.1**: Nanoscale funding trends at research universities; 1994-2004

Public universities make up 68.4% (n=76) of the sample and account for 56.5% of the funding ($804 million). Private universities made up 31.6% (n=35) of the sample and accounted for 43.5% of the funding ($620 million). Figure **5.2,** contrasts the average funding performance of the private universities in the sample with the public universities. Analysis of the funding performance by type of control indicates that private universities performed better on average than their public counterparts on the NSF funding measure.

Cornell's impressive NSF funding performance appears to be a significant factor in the difference between the two institutional types.

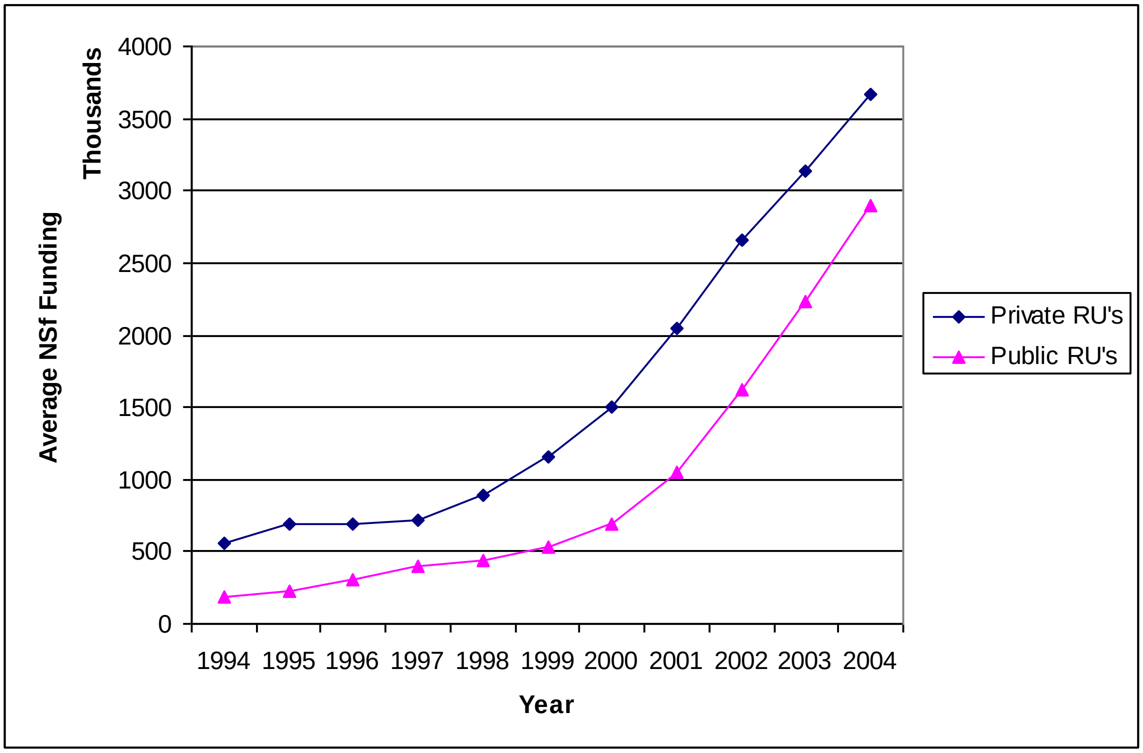

Figure **5.2**: NSF Nano Funding: Average performance of Public vs. Private RU's

Figure **5.3** details the identification of universities as Tier 1, Tier 2 or Tier 3 performers with respect to their nanotechnology funding performance. The skewed distribution indicated in the histogram reveals that a small number of the universities receive significant NSF funding. The identification of universities as belonging to each tier is based on their distance from the mean. Universities whose funding performance placed them 1 standard deviation above the mean were identified as top performers, and listed in the Tier 1 category. Similarly those universities whose funding performance placed them between the mean and 1 standard deviation were identified as Tier 2 performers. All universities whose funding performance was below the mean were listed in the Tier 3 category. To illustrate further, all universities that had nanotech funding in excess of $29 million, across the eleven years of analysis, could potentially be part of the Tier 1 group. However, the $30.9 million shown in Figure 5.3 indicates the actual lower bound of funding performance for the universities placed in Tier 1, in this instance. The rationale behind the creation of these three tiers was to identify the top performers with respect to nanotech funding.

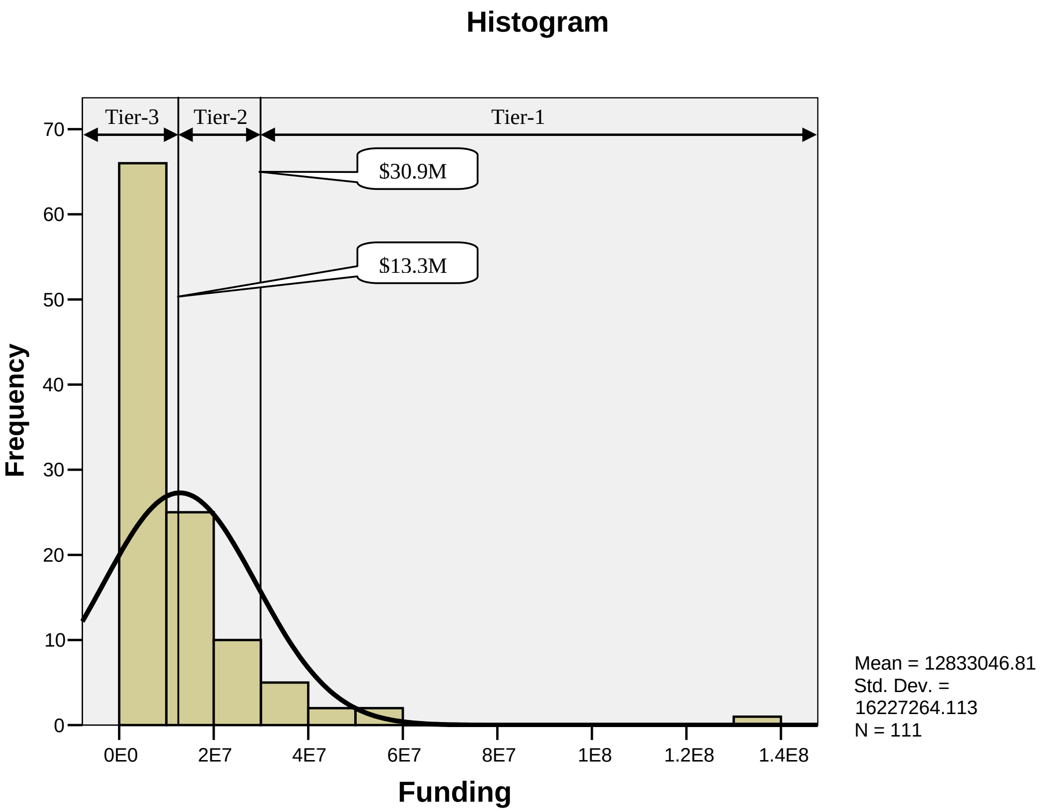

Figure **5.3**: Identification of Tier1, Tier 2 and Tier 3 ‘nanofunding’ performers

Another interesting pattern is the concentration of funding observed in the data. When ranked by aggregate funding dollars for the period 1994-2004, the Tier 1 research universities shown in Figure **5.4,** accounted for 35.2% of the funding dollars in the sample. The listing of the Tier 1, 2 and 3 universities is detailed in Appendix B.

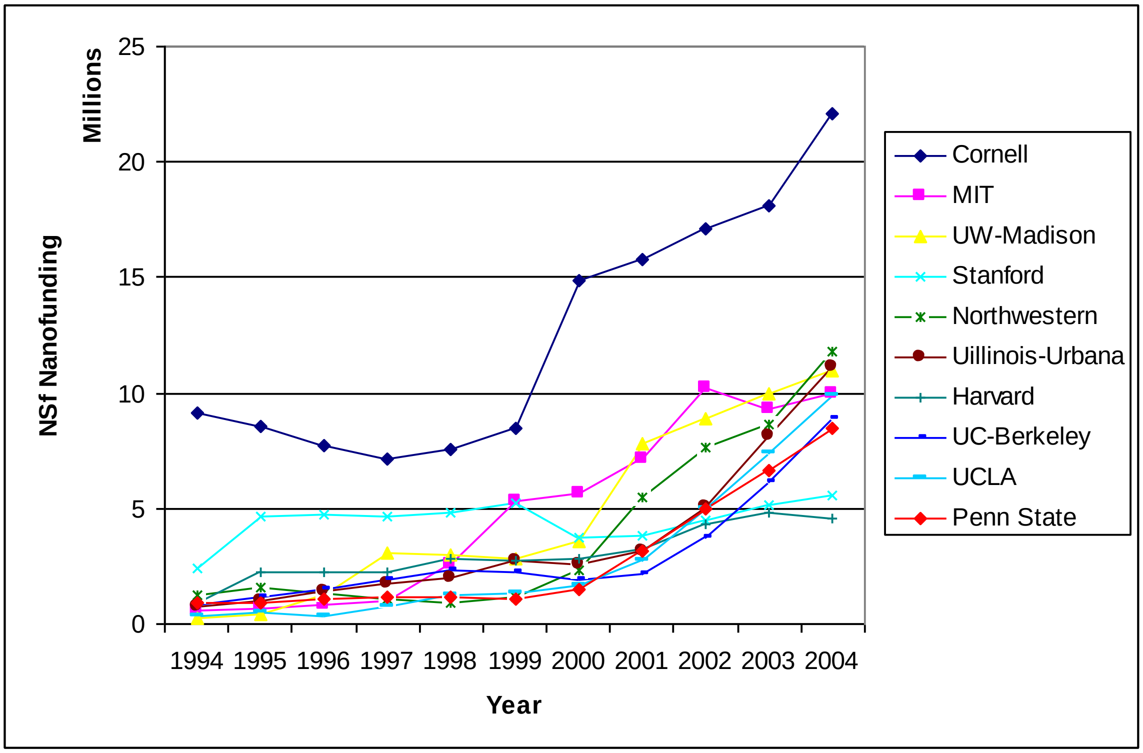

Figure **5.4**: Funding performance of Tier 1 Research universities

Of these Tier 1 performers, Cornell, Penn State and Stanford were part of the original Nanotechnology Users Network (NNUN), initiative that received funding for nanofabrication facilities and instrumentation from 1994. In addition to the three universities mentioned above, Harvard is a new entrant to the 13 member National Nanotechnology Infrastructure network (NNIN). The impressive nanotechnology funding at Cornell is the result of several large grants in the area of nanobiotechnology.

A comparison of NSF nanotech funding with research expenditures at these Tier 1 universities leads to some interesting conclusions. For comparison purposes, AUTM data on research expenditures for 96 of the 111 universities in this study was gathered for the years 2001-2003. Data for the remaining 15 universities was unavailable. Universities were ranked on their average performance for these years and universities were identified as being Tier 1, (1 standard deviation above the mean), Tier 2, (between the mean and 1 standard deviation) and Tier 3 (below the mean). A list of these universities is detailed in Appendix C. All universities listed in Figure 5.4, with the exception of Cornell and Northwestern, appear in the Tier 1 list of universities as per AUTM research expenditures. Cornell and Northwestern are part of the Tier 2 group as per AUTM research expenditures, but nevertheless perform well on nanotechnology funding. Although exploratory in nature, the comparison indicates that nanotechnology funding is generally going to universities with well established research expertise. However, Cornell and Northwestern appear to be doing particularly well at attracting research funds in nanotechnology.

5.2 Nano Publications

As is evidenced in Figure **5.5** , publications showed a decidedly upward trend from 1995 with a sharper increase after 1999. This trend is similar to that noticed in the NSF ‘nano’ funding and also in keeping with the finding by Zucker and Darby (2004), which shows that the overall publishing rate in nanotechnology took off in the nineties.

Publications in nanotechnology produced at these 111 research universities increased more than seven fold from 718 to 5299 publications in 2004.

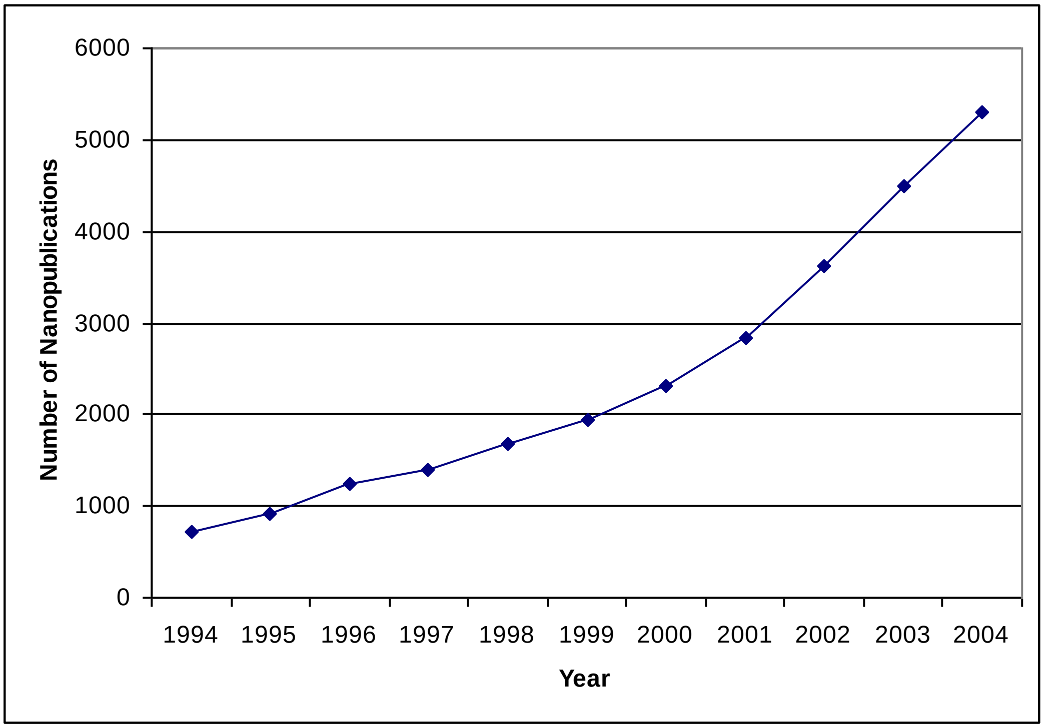

Figure **5.5**: Nanopublications at Research Universities; 1994-2004

Public universities make up 68.4% (n=76) of the sample and account for 66.6% (17,616) of the publications. Private universities made up 31.6% (n=35) of the sample and accounted for 33.4%(8,837) of the publications. Analysis of the average publications performance by type of control, illustrated in Figure **5.6**, indicates that private and public universities performed about the same on average.

The publications included in this analysis were limited to journal articles and in some measure, represent the university's strength in the area of public science. Citations represent a quality measure to assess publication impact, however lack of systemic data on citations to these specific articles precluded this measure from the analysis.

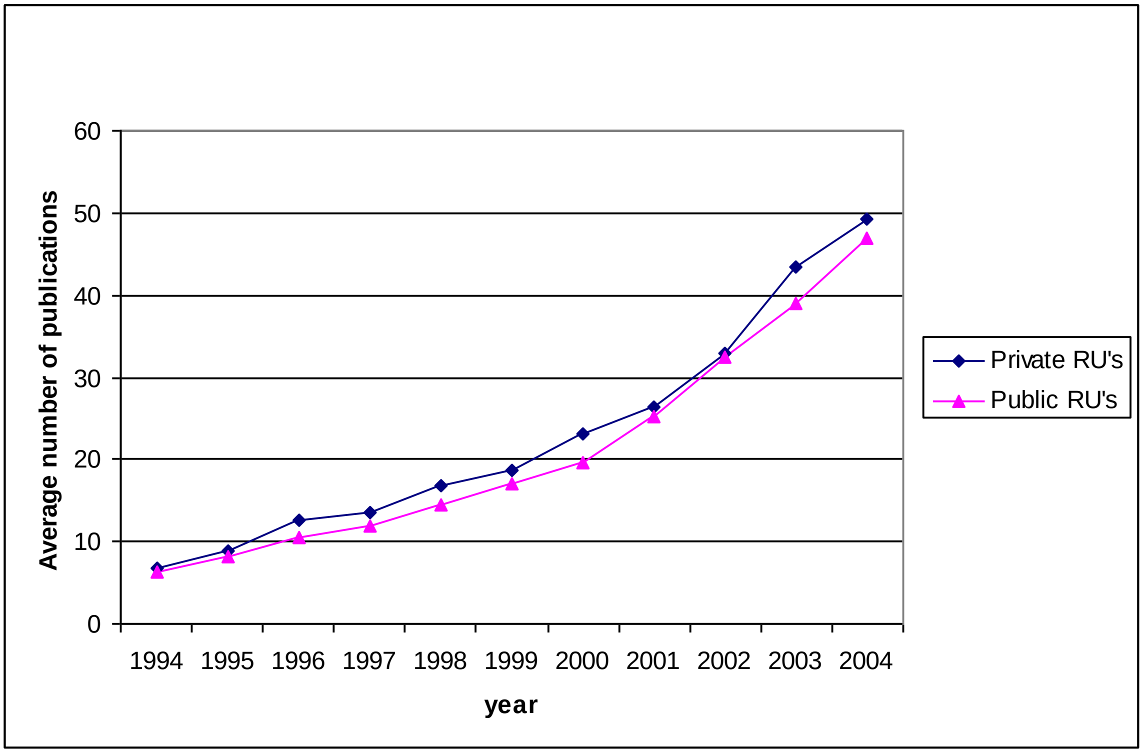

Figure **5.6**: Nano publications: Average performance of Public vs. Private RU's

Figure **5.7** illustrates the identification of the Tier 1, Tier 2 and Tier 3 performers with respect to nanopublications. Universities appearing in the Tier 1 listing had publication counts of more than 444 patents across the eleven years of analysis. In contrast to funding performance, publications show a more even distribution. However, it is clear that a few universities show impressive publication counts. Publications provide a key measure of knowledge transfer to the public domain without restrictions on use. It must be noted however that no inferences can be made about the quality of the publications. Additionally, no adjustments could be made with respect to size because the number of research faculty engaged in nanoscale work at each university is unknown.

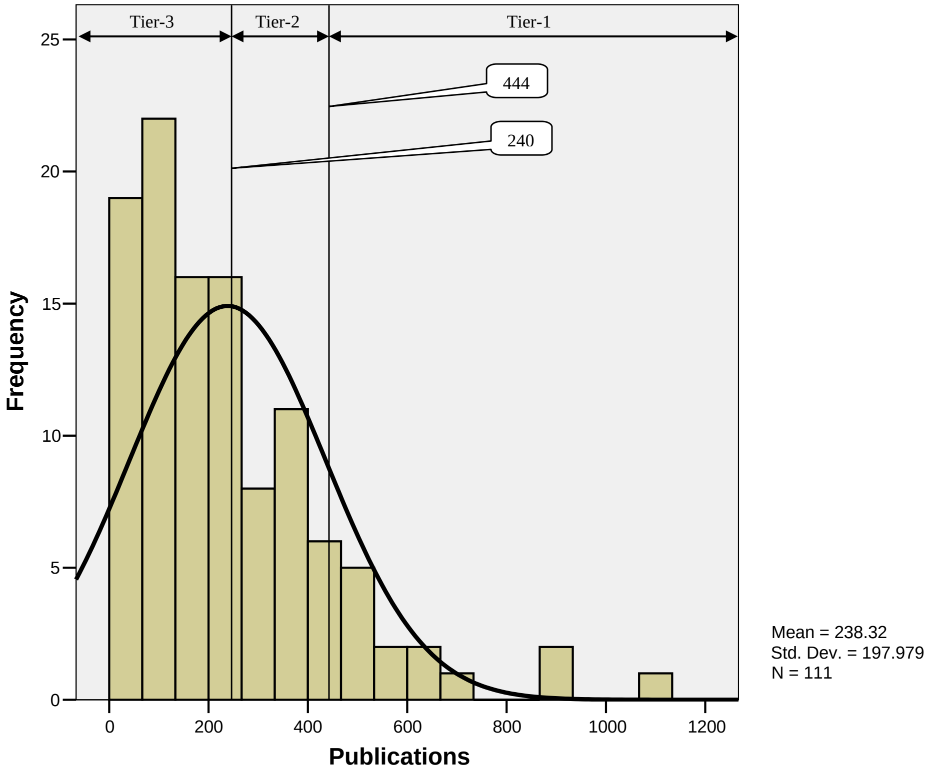

Figure **5.7**: Identification of Tier1, Tier 2 and Tier 3 'nanopublication' performers

Similar to the pattern observed in funding, publications also appear to be concentrated at a few universities. When ranked by aggregate publications for the period 1994-2004, the Tier 1 research universities shown in Figure **5.8** accounted for 35.1% of the publications. The Tier 1 universities were identified similarly as described in Sec 5.1 and a list of the universities in each tier is detailed in Appendix D.

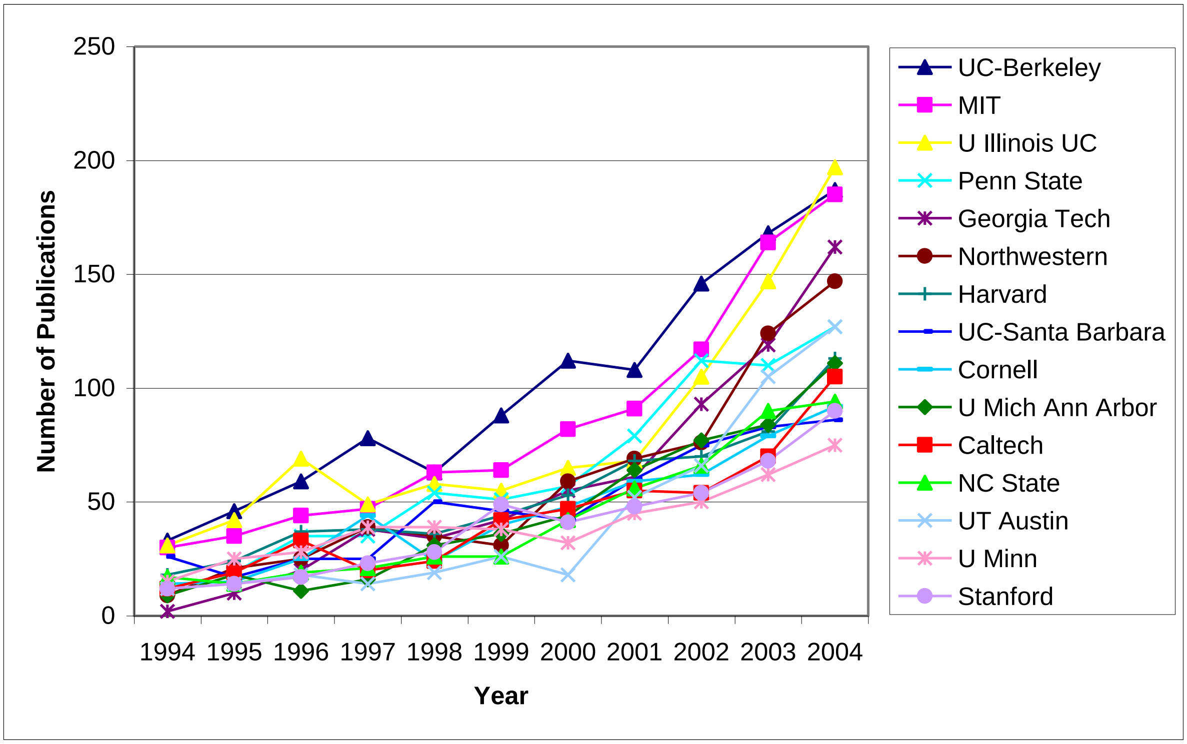

Figure **5.8**: Nanopublications Performance of Tier 1 universities

UC- Berkeley is the clear leader in this category producing more publications than all other universities in almost all the years under study. Eight of these universities, UC-Berkeley, MIT, U Illinois-Urbana, Penn State, Harvard, Northwestern, Cornell and Stanford also appear in the Tier 1 funding list. Table 5.2 lists the composition of the Tier 1 performers on each key measure, i.e., nanofunding, nanopublications and nanopatents Georgia Tech and North Carolina State lag behind the other universities mentioned in

Figure 5.8 on NSF nanofunding measures but do considerably well on nanopublications. A reasonable explanation for this is that Georgia Tech and NC State are performing better than their input levels would warrant, indicating efficiency in production. However, a rival hypothesis is that nanotech funding for Georgia Tech and NC State may primarily be from other sources such as DOD and other mission agencies. It must be reiterated that grants from the NSF are only part of the resources available to nanotech researchers. Grant data from mission agencies are not publicly accessible and thus precluded from this analysis.

5.3 Nano Patents

The patenting data in nanotechnology at 100 research universities show an increasing trend with a slight dip in nanotechnology patents issued in 2000(Figure **5.9**). The University of California system patents are not included because they could not be disaggregated by campus.

Patents indicate another mechanism of knowledge transfer. As compared to publications, rents are charged to access these patents in terms of licensing fees. The time taken from invention disclosure to actual issue of patents is variable, and depends on a variety of factors including the time taken by universities in deciding whether to patent and the length of the queue at the United States Patent and Trademarks Office (USPTO).

Patents issued to the 100 research universities showed a four fold increase, from 145 patents in 1994, to 567 patents in 2004. The pace of growth in patents is less than that noticed in funding and publications.

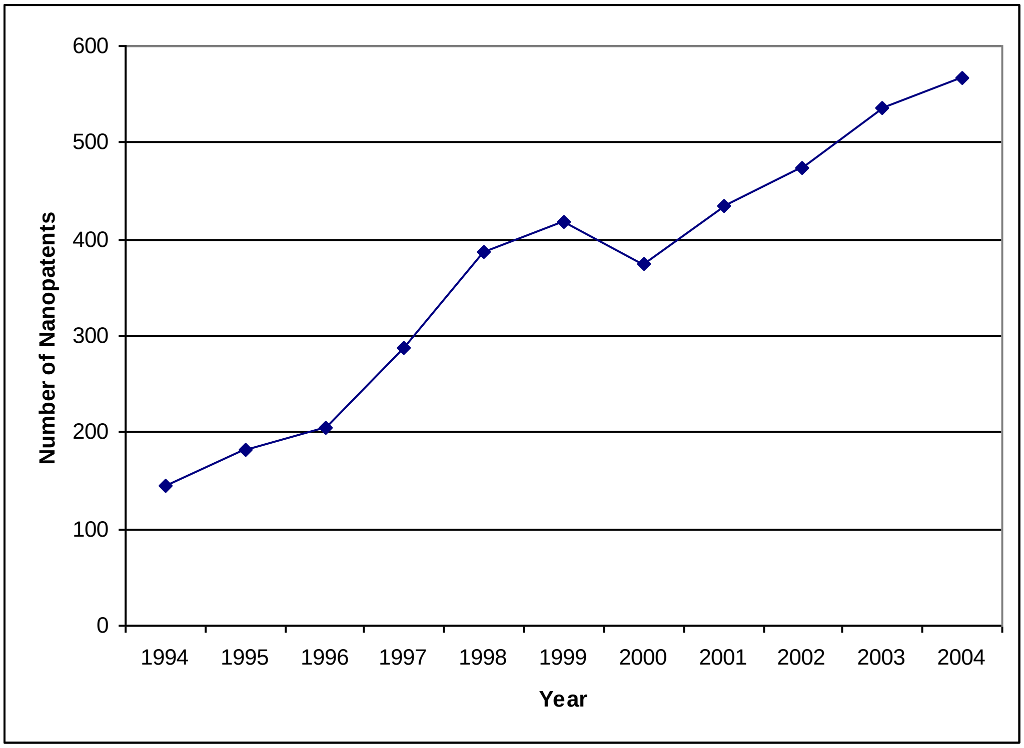

Figure **5.9**: Nanopatenting at Research universities;1994-2004

Public universities make up 66% (n=68) of the sample and account for 53.9% (2,163) of the patents. In contrast, private universities made up 34% (n=35) of the sample and accounted for 46.1% (1847) of the total patents. Of all the three chief variables under consideration, it is clear that private universities have a significant edge (Figure **5.10**), when it comes to patenting. The private universities performed better on average every year as compared to their public counterparts. However, it must be reiterated that

University of California patents are not included in this analysis. Inclusion of these data could potentially alter the results presented here.

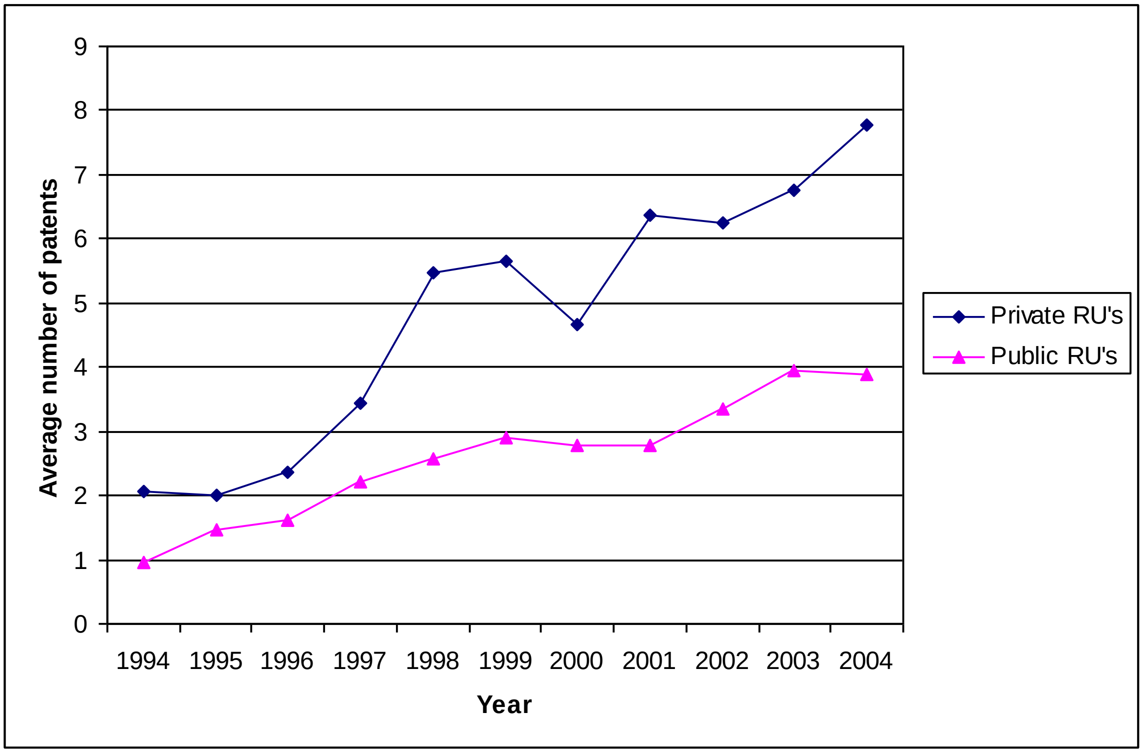

Figure **5.10**: Nanopatents: Average performance of Public vs. Private RU's

Figure **5.11** illustrates the identification of the three tiers, similar to those identified for funding and publications data. Universities with an issued patent count of 93 and more, across the eleven years of study, were part of the Tier 1 listing. Similar to the pattern noted in funding performance, a few universities appear to do extremely well in patenting. A list of the universities in each tier is detailed in Appendix E.

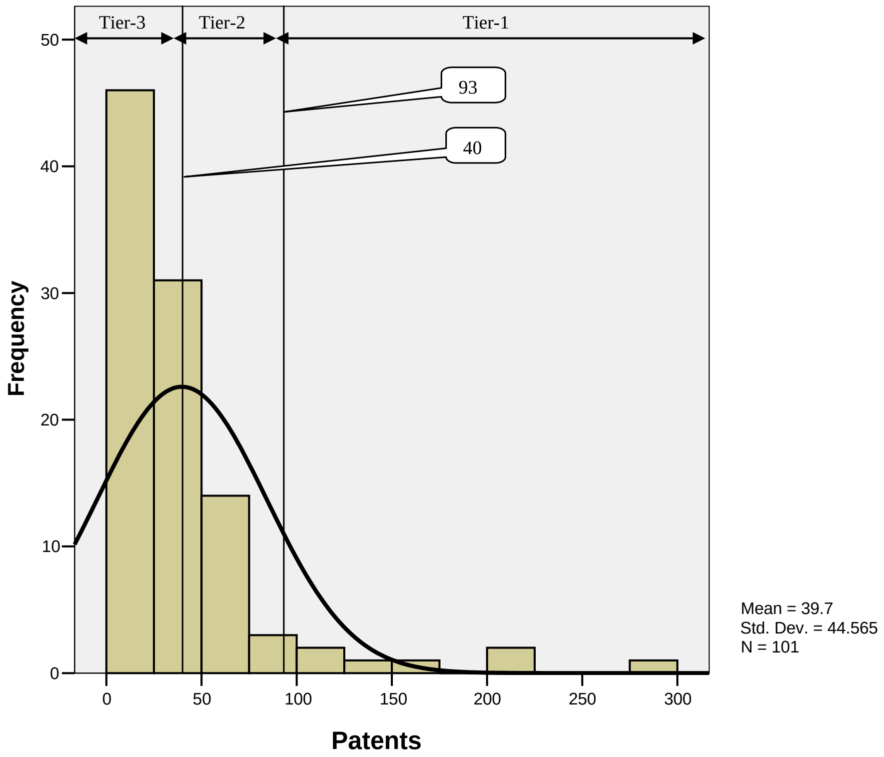

Figure **5.11**: Identification of Tier1, Tier 2 and Tier 3 'nanopatent' performers

When ranked by aggregate patents for the period 1994-2004, the Tier 1 research universities shown in Figure 5.12 accounted for 34.5% of the publications. Consistently across all three measures, the Tier 1 universities hold about 35% of funding, patents and publications.

When compared with the trends in funding and publishing which showed smooth upward trends, patenting trends are noisier. When compared with the Tier 1 performers in funding and publications, only three universities remained stable across all the three categories namely MIT, Cornell and Stanford.

One might ask whether these universities are exceptionally better at nanotech patenting or whether they tend to patent more across all fields of study? For comparison purposes, AUTM data on issued patents for these universities was gathered for the years 2001-2003. Similar to the data on research expenditures, universities were ranked on their average performance for these years and universities were identified as being either Tier 1, (1 standard deviation above the mean), Tier 2, (between the mean and 1 standard deviation) and Tier 3 (below the mean). A list of these universities is detailed in Appendix F.

All universities listed in Figure **5.12** with the exception of UT-Austin and University of Pennsylvania appears in the Tier 1 list of universities for overall AUTM patents data. UT-Austin and U Penn are not as prolific at patenting when compared with the other universities in Figure 5.12, however, this analysis indicates that their nanotechnology patents portfolio shows better than normal performance. Although exploratory in nature, this finding indicates that generally universities who have good overall patenting performance also have good patenting performance in nanotechnology. However, some universities do seem to be performing better in nanotechnology than their overall performance in patenting would warrant.

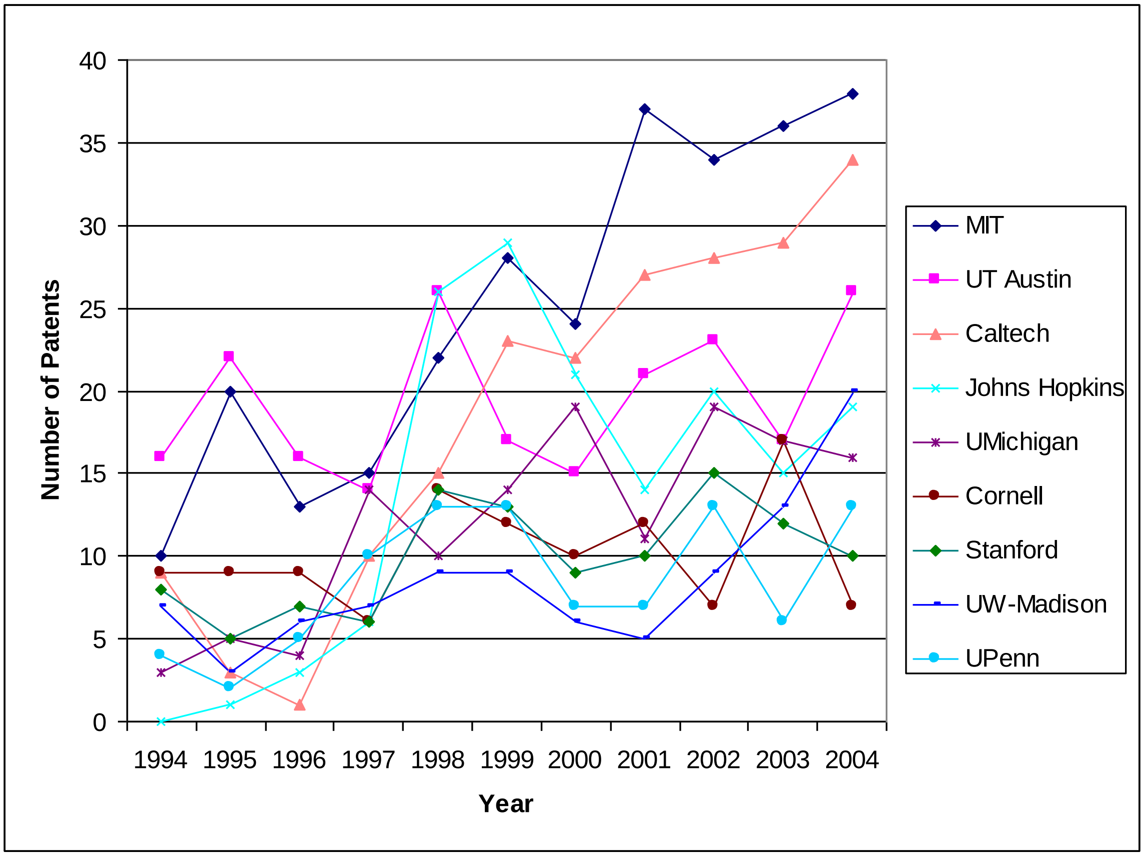

Figure **5.12**: Patenting performance of Tier 1 research universities

5.4 Distance Metric

Table **5.2** indicates the Tier 1 performers across the three key variables of interest. These universities hold slightly more than a third of the funding, patents and papers in nanotechnology. This concentration is even higher when one considers the top 25 universities in each ranking, which accounted for close to 60% of the funding and patents and about half of the publications in the sample.

Table **5.2**: Tier 1 Universities

Nanofunding	**Nanopublications**	**Nanopatents**
Cornell	UC Berkeley	MIT
MIT	MIT	UT Austin
UW-Madison	University of Illinois at UC	Caltech
Stanford	Penn State	Johns Hopkins
Northwestern	Georgia Tech	UMichigan Ann Arbor
University of Illinois at UC	Northwestern	Cornell
Harvard	Harvard	Stanford
UC Berkeley	UC-Santa Barbara	UW-Madison
UCLA	Cornell	University of Pennsylvania
Penn State	UMichigan Ann Arbor	
	Caltech	
	North Carolina State	
	UT Austin	
	University of Minnesota	
	Stanford	

The analysis in Sec 5.1, 5.2 and 5.3 measured universities on single dimensions. Taken together publishing and patenting performance indicate knowledge stocks and precursors of innovation activity. Using both of these dimensions together to find similarities in ranking provides a useful ranking scheme and provides for institutional peer analysis and benchmarking.

The Euclidean distance is defined as the straight line distance between two points. For example, University A has x_1 patents and y_1 publications and University B has x_2

patents and y_2 publications, the distance between the two universities is given as $\sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$. In this case, the patent and publications data were normalized and the Euclidean distance between the origin and each university was calculated for the 111 universities. This resulted in the creation of distance scores which was used to rank the universities. When ranked by this measure, the top ten organizations accounted for 30% funding, 25% of the publications and 31% of the patents.

Figure **5.13** provides a normalized view of patenting and publishing activity. The universities marked in the chart are the top 25 universities as ranked by the distance metric. Nine of the universities in the top 25 list are private and the remaining 16 are public universities. MIT performs well on both nanoscale patenting and publishing, whereas UT-Austin, Caltech, Johns Hopkins and University of Michigan show high patenting, but moderate publishing performance. UC-Berkeley has the highest number of publications and can be expected to have a strong patenting performance as well however lack of patent data precludes a complete analysis. The top publishing slots appear to be dominated by public universities with UC-Berkeley, UIllinois-Urbana Champaign, Penn State and Georgia Tech leading the way. In contrast, patenting performance is dominated by private universities with UT-Austin being a notable exception.

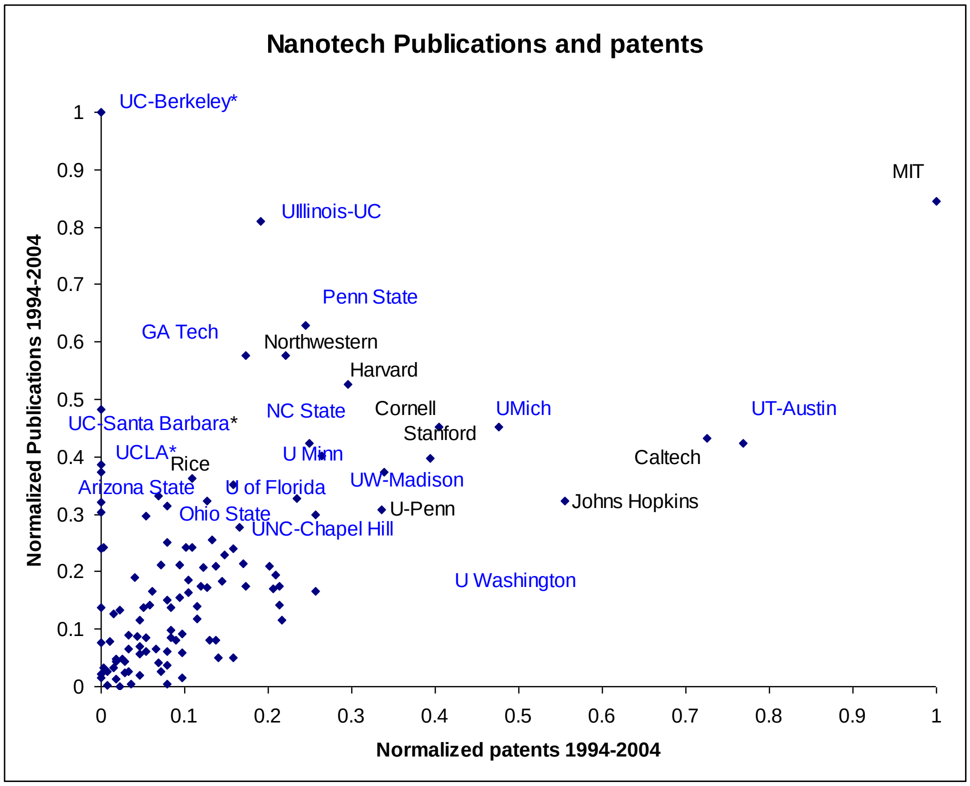

Figure **5.13**: Normalized Publications and Patents 1994-2004

The top twenty five universities as ranked by the distance metric showed disproportionate outputs based on NSF funding as an input measure. As illustrated in Figure **5.14** Cornell has significant nanotechnology funding, but output measures are modest. MIT appears to be an outstanding performer with a strong portfolio of patents and publications, given its funding inputs. Similarly UT-Austin and Caltech appear to be strong performers given their input size. Most of the other universities on this chart are strong on one dimension but not as strong on the other indicating that funding by itself is not the only measure of performance. A reasonable explanation is that organizational processes have an important role to play in knowledge creation and transfer leading to differential outcomes. Arizona State, UCLA, UC Berkeley and UC-Santa Barbara have no patent data assigned to them and their position on the chart is only indicative of their publications and funding.

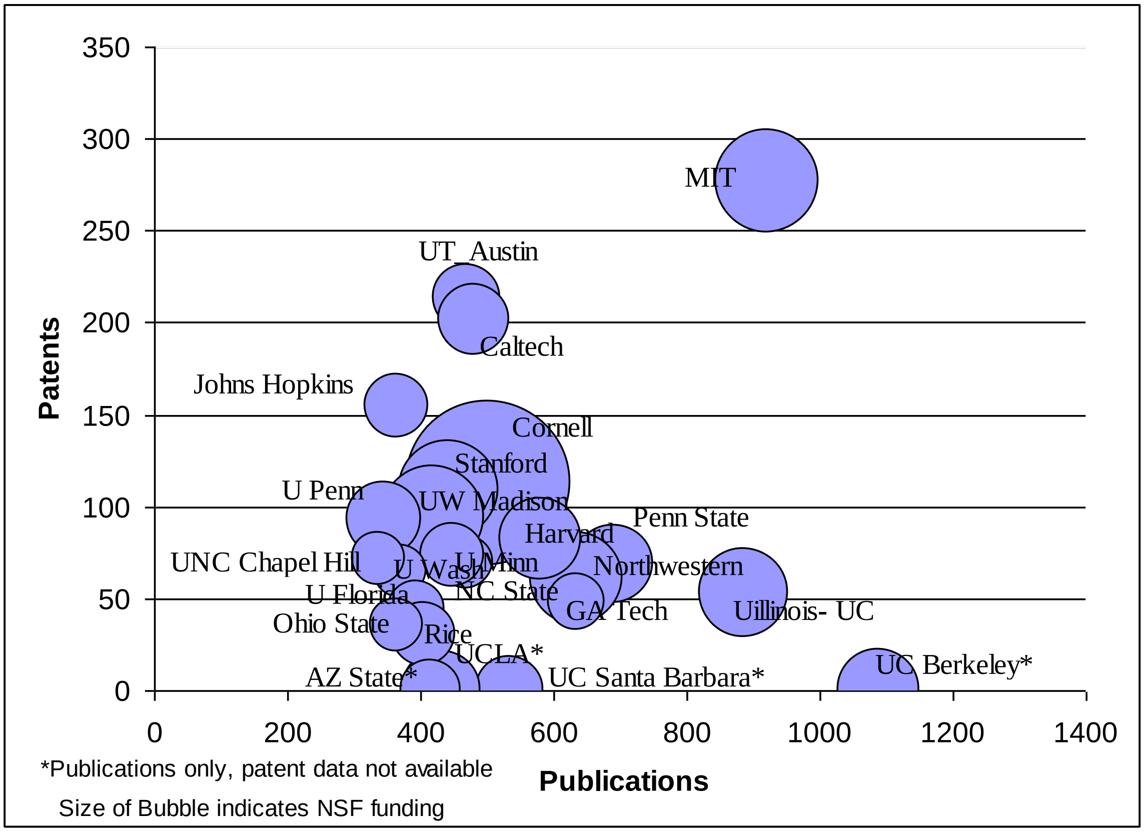

Figure **5.14**: Nanopublications and Patents by funding performance

The creation of distance scores allows for peer analysis and institutional benchmarking. As an example of peer identification, Table **5.3** indicates the nearest peer institutions for Penn State University. Penn State has a Class 10 cleanroom facility for nanfabrication and is one of NSF's National Nanotechnology Infrastructure Network (NNIN) sites. Four of the peer institutions identified in Table 5.3 are part of the Big Ten conference indicating that knowledge outputs at institutions with similar institutional focus may be similar.

Table **5.3**: Nearest Peers of PSU in Nanotechnology Knowledge Outputs

Organization	**PSU-Distance**	**Big Ten**
Pennsylvania State Univ	0	y
Northwestern University	0.058162205	y
Georgia Tech	0.088658054	
Harvard University	0.113803315	
University of Illinois at Urbana-Champaign	0.190281562	y
North Carolina State University	0.205831474	
University of Minnesota-Twin Cities	0.228030796	y
Cornell University - Endowed	0.237676596	
University of Wisconsin-Madison	0.27120412	y
Stanford University	0.274400512	
University of California-Santa Barbara	0.28558683	

The analysis presented in the preceding sections was conducted with a view to answering the question posed about the concentration of knowledge inputs and outputs. The findings indicate that funding, patents and publications in nanotechnology are concentrated at a few universities which can make them the locus of innovative activity in their regions. Public and private universities show differences in their funding and patenting performance. On average, private universities are better at nanotech funding and patenting and perform similarly with respect to publications. The stable performers across all the three dimensions are MIT, Cornell and Stanford.

The importance of universities in regional economic development has been well documented. Many studies show that geography plays a mediating role in academic knowledge spillovers which positively effects innovative output (Feldman and Massard, 2002). University based research affects innovative activity through two channels, through knowledge spillovers from universities to firms and through a purposive channel utilizing mechanisms such as licensing and formal relationships between industries and universities (Mowery and Ziedonis, 2001). Most literature points to geographic concentration of economic effects of university-based research. Technological knowledge cannot be codified completely; it contains important tacit elements which need to be communicated effectively and therefore needs some element of sustained interpersonal communication between the inventor and the user. Inherent in this summation is the fact that there is a limited geographic reach of this channel for exchange of information, which is purported to be the main cause of regional agglomerative tendencies. Jaffe, Tratjenberg and Henderson (1993) in examining the localization of university based spillovers find significant localization effects. Those inventors that cite university patents are more likely to be locally or regionally based in the region of the university patent. Zucker et al (2001), state that much of the knowledge transfer between universities and biotech companies is occurring because of the purposive interaction between academic scientists and firms.

Zucker and Darby (2005) have found that firm entry in nanotechnology occurs where high quality academic science resides and where there is a skilled workforce. Similar to biotechnology, they find nanotechnology firms cluster around certain regions. In biotechnology, significant concentration of funding and patenting activity has been noted. Although funding is disbursed across research programs it goes disproportionately to areas with well established research infrastructures creating concentration of research

(Cortright and Mayer, 2002). The analysis of ‘nano’ funding patents and publications at research universities reveals that a similar trend appears to be true of nanotechnology.

Chapter 6

Findings from Case Study

The previous chapter noted the concentration of nanoscale funding, publications and patents at a few universities in the US. This chapter analyzes the knowledge creation and technology transfer process in nanotechnology through case study data. It begins with a review of the disciplinary affiliations of interviewees, and the research questions around which interview questions were framed. It then describes background information for both universities that are part of this study. The analysis of the data from the case studies is presented as key themes. Each theme reflects the key findings keeping in mind the research focus and the unit of analysis. 'Working propositions' describing hypotheses grounded in data are mentioned at the end of each theme. As is true of qualitative data (Eisanhardt, 1989), findings are not generalizable to the population of research universities, but the propositions derived from the research can be tested under other case conditions. Throughout the description of the key themes, pseudonyms are used to preserve interviewee confidentiality. Faculty members are identified as "Prof." administrators with Ph.D's are identified as "Dr." and other administrators are identified by first names.

6.1 Interviewee Disciplinary Affiliation

Two research universities, one public and the other private were chosen as the cases for this study. Figure **6.1** illustrates the disciplinary affiliations of faculty members, which included chemistry, physics, electrical engineering, materials science and engineering. In addition seven key central administrators and technology transfer officers were interviewed for this study.

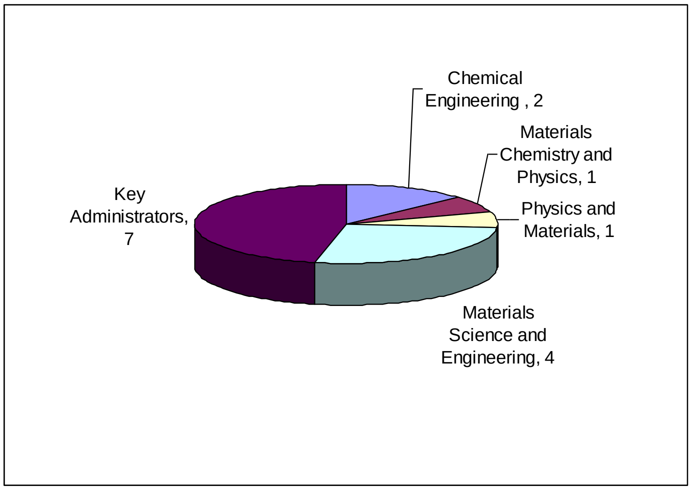

Figure **6.1**: Interviewee disciplinary affiliations

Faculty members and administrators were asked questions that focused on the process of knowledge creation and transfer in nanotechnology. Specifically interview questions revolved around the following research foci:

1. How does interdisciplinarity, inherent in fields such as nanotechnology, affect the process of academic knowledge creation and transfer? What structural dimensions does it take?

2. How do university policies, structure and strategies influence knowledge creation, transfer and commercialization in nanotechnology?
3. What effect does organizational culture have on the creation and transfer of knowledge at the nanoscale?
4. What are faculty attitudes towards public science and proprietary for-profit science? How do faculty members blend the role demands of public and private science?

The main difference between the two universities is in size and technology transfer performance. BSU, the public university, is a state school with a large student population, and a large faculty base. The private university, MPU, has experience with blockbuster technology and generates more licensing revenues than BSU, although BSU shows strong patenting performance. Table **6.1** details the key differences between the two universities.

Table 6.1: Key differences between BSU and MPU

	BSU	**MPU**
Number of students	35,000+	Approx 10,000
Number of faculty	2000+ faculty	1000+
R&D expenditure(2004)	500 million+,	200 million+
Year TTO started	Late eighties	Early nineties
Number of spinoffs (2004)	<5	>5
Number of overall patents (2004)	40+	30+
Nanotech patents	23(self identified)	13 (self identified)
Nanotech publications	500+	200+
Endowment	1+ billion	500+ million

6.2 Case setting-Big State University

BSU is a large public university with significant research expenditures. It is ranked amongst the top 10 universities in several disciplines, and is well known for expertise in the areas of engineering and materials. An analysis of the R&D expenditures shows a healthy mix of federal and industrial funding. Grants from the National Science Foundation (NSF) and the Department of Defense(DOD) form a significant component of the federal dollars granted to researchers. It has a faculty size of more than 2000 members, and a student body of 35,000+ on its main campus. BSU's campus can best be described as a small-town college setting with surrounding commerce situated around the university. The technology transfer office(TTO) has been in existence since the late eighties. Technology transfer policies have been revised in the early and late 1990's. Patenting and company formation has shown slow but steady progress. Although it exhibits a high rate of patenting, appearing consistently in the top 25 list of university patentors, licensing revenues are not consistent with this patenting output. Although there have been some important technologies invented and licensed at BSU, a "blockbuster technology" still has to make its appearance. The TTO office includes an extensive network of offices for managing intellectual property, new enterprise creation and industry sponsored research activities. The technology licensing officers manage casework as per their subject matter expertise, and each has a technical undergraduate degree with additional graduate/professional qualifications. The university has committed incubation space for new ventures including small business assistance facilities. The technology transfer office reports to the Vice-President for Research.

6.2.1 Invention disclosure process at BSU

Once a faculty member discloses an invention at BSU, the case is assigned to one of the Technology Licensing Officers (TLO), depending on the area of expertise. This TLO remains the interface between the faculty member and the TTO. The next stage is the review of the invention disclosure. The invention is assessed on several criteria including stage of development and commercial appeal; market conditions are assessed through secondary market research. The TLO in conversation with the inventing faculty member reviews prior publications, if any, with regard to the invention and discusses potential candidates for licensing who may be interested in bearing the costs of patenting. Filing and prosecuting a US patent costs anywhere between $15,000 and $25,000. The Bayh-Dole Act mandates that the university find the most commercial channel for commercialization of its technologies, and BSU makes sure it does the due diligence with regard to the search for licensing partners. In most cases, a provisional patent is filed and filing the provisional allows for two things to happen simultaneously; it allows for a years worth of time where the technology can be developed further and it allows the TTO to continue the search for a licensee. A full patent is filed automatically if a licensee is found in this period. If no licensee has been found in close to a year, the invention is referred to a review committee consisting of deans, department heads, tech transfer officials and representatives from local business. The review committee decides whether the invention should be sent on ahead for patenting or whether it reverts back to the inventor. In some cases, it is referred to an outside entity which decides whether it would be willing to underwrite the patent costs and file the patent. If all these avenues appear closed, then barring other prior claims, the invention is released back to the inventor. If a faculty spinoff licenses the invention, then the licensing process is similar to that of any other licensee, except that the licensing royalties do not flow back to the inventor if he is also a founder of the company. University spinoffs are provided with resources ranging from identification of outside management talent, and matching inventors with financing options including venture monies, angel monies and state based economic resources. As a rule, BSU does not provide investment dollars for spin-offs. Companies can incubate in the incubator space and a Small Business Assistance (SBA) office provides support if needed.

6.2.2 Policies at BSU

BSU has extensive policies in place with regard to faculty consulting, technology transfer and entrepreneurial activity. Most of the policies focus on conflict of interest, regarding such issues as misuse of university resources, staff and student time, publications, and impediment of student progress. In all cases, core university tasks take precedence. Faculty members have to disclose any significant interests in companies. Faculty are allowed a maximum of one day a week consulting time during their appointment period, with the proviso that it not interfere with faculty work and be in a sphere which will enhance the professional stature of the faculty member. The disbursement of royalties is prescribed as 40% to the inventor, 20% to the originating administrative unit and 40% to the university. It is estimated that more than half of the licenses are marketed through inventor contacts, so inventors remain an integral part of the licensing process. Industrial sponsors have first rights of refusal to technologies which have resulted from sponsored research. Multiple inventors have to decide on the split themselves. At the time the patent is filed, a small amount of money is awarded to the inventors and the split between the inventors sets the tone for future royalty payments. Accepting equity in lieu of licensing is a new strategy adopted by BSU in the last five years.

6.3 Case Setting MPU

MPU is a medium sized private university with research expenditures around $200 million. It is well known for its expertise in the areas of computer science and engineering as well as its several interdisciplinary programs of study. The bigger component of federal grants is derived from the NSF and DOD. Its industrial sponsored component is smaller than BSU, even when one accounts for size. With a faculty size close to 1000, and a student body of around 10,000, it is situated in what could be termed as an urban area. It is geographically situated close to several thriving industries and is also in close geographical proximity to other universities with differing expertise. The technology transfer office has been in existence since the early nineties. Tech transfer policies have been undergoing continual focusing and revision. The TTO has proven effective in licensing inventions and does well in the number of patents generated for research volume. In 2005, MPU’s royalty income was higher than that of BSU as was its rate of start up companies. MPU has had experience with blockbuster technology and appears to be more proactive in terms of company formation. As was true of BSU, the technology licensing officers manage casework as per their subject matter expertise and each has a technical undergraduate degree with additional graduate/professional qualifications. The university has no committed incubation space but surrounding research parks provide adequate infrastructure. The technology transfer office reports to the Vice-Provost for Research.

6.3.1 Invention disclosure process at MPU

As was true of BSU, once a faculty member discloses an invention at BSU, the case is assigned to one of the Technology Licensing Officers depending on the area of expertise. In addition to taking care of ongoing disclosures, the TLO's are charged with proactively meeting with faculty members and attending relevant departmental presentations. Preliminary market information is gathered by the TLO with regard to the disclosure. Any public disclosures of the invention are noted by consultation with the faculty members. In most cases, a provisional patent is filed, and the search for a licensee is carried out. The turnaround time for the decision to file a patent is around four months which is shorter than that of BSU. A recent change at MPU, is the introduction of a group process that replaces the serial process associated with the TTO's decision to patent or not. Prior to the new process, relevant faculty members across campus would be asked their expert views on the invention to aid the patenting decision. Instead, MPU has instituted a process which pulls together alumni, industry members, local business, and at times funding representatives, all at the same time to evaluate the potential of the invention. The inventor faculty member and the TLO in charge of the invention present a short sketch of the invention and then open the meeting to group discussion. The views garnered from these experts provide a good market read about the inventions potential and helps with the patenting decision. In most cases, if no potential licensee is found, a full patent application is not put forth to the USPTO. MPU is proactive when it comes to company formation and believes that new firms contribute to the region’s economic development. To keep local industries in the loop, periodic presentations are made to local industry in concert with the other surrounding universities. As was true of BSU, university spin-offs are provided with resources ranging from identification of outside management talent and including matching up with financing options including venture monies, angel monies and state based economic resources. MPU on occasion does provide companies with investment dollars. Faculty are allowed to incubate in their labs and the surrounding parks provide adequate incubation space if needed.

6.3.2 Policies at MPU

As is the case at BSU, conflict of interest (COI) policies provide multiple safeguards for student and university interests. COI policies are similar in language to those of BSU and place student and university interests before individual ones. Tenure line faculty as well as research faculty are allowed a maximum of one day a week consulting time during their appointment period with the proviso that it not interfere with faculty work. In 2002, licensing guidelines for spin-offs were revised and now it has been aligned so that the new company can access different sources of capital at different parts of its lifecycle. In comparison with BSU, MPU is more generous to its inventors, when it comes to disbursement of royalties. 50% of the net proceeds go to the inventors and 50% to the university, multiple inventors must decide upon the split themselves. Also in contrast to BSU, if asked to by inventors, the university does take a management role in new ventures. If they own more than 10% in the company they generally take a board seat. MPU's policy allows for equity in lieu of licensing, generally 5% for non-exclusive license and 6% for an exclusive license. The extent of services provided by MPU defines the equity stake it takes in the company. A clear menu of choices is available to the startup company. Given its collaborative approach to research, MPU has inter-institutional agreements with several universities. With several of its neighboring universities, the TTO has an understanding in place with regard to handling of joint inventions.

6.4 Key Findings/Themes

The preceding sections detailed the technology transfer policies and process at both universities. This section identifies the key themes that emerged from interview data. Working propositions derived from the analysis of the themes are described at the conclusion of the section.

6.4.1 Background - Faculty patents and research areas

The faculty members in this sample had a self-identified total of 46 issued patents and 10 startups. Patenting was spread across seven faculty members, all tenured, whereas company formation was restricted to three tenured faculty members. Two of the nanotech patents, one at each institution, were self-identified as being almost the standard in their particular industries and therefore widely used. Of the ten startups, eight were in nanotech or closely related areas, and four had been started before the faculty member's arrival at BSU. Patents were spread across BSU and MPU, however detailed study of start-up companies was restricted to those started by BSU faculty members. The faculty members who were identified as having started companies at MPU in nanotechnology either declined/did not respond to the call to participate in the interview process. Information on MPU startups were provided by the TTO. BSU's TTO identified four nanotechnology spin-offs whereas MPU's TTO identified three. The spin-offs ranged from being a "paper company" to those actually producing nanotubes/nanopowders/coatings/nanomaterials. The scale of production was small but one of the companies was in a joint venture to increase that scale. One of the companies had been sold out as the founding professor did not want to make the move to Silicon Valley. This move was wrought by the venture firm backing the company, however, the faculty member retained ties to the company. The earliest founding date for the companies was early 1990's and most of the other spinoffs were founded after 2000.

Faculty research areas were spread across several areas of study including photonics, computer storage, dispersion and assembly of nanoparticles, nanowires, carbon nanotubes, fuel cells, chemical sensing and the physics and processing of micronanostructures. Applications included sensors, communication and computation applications and use of particles as catalysts. When asked whether their work could be classified as science, engineering or technology, most of the answers alluded to the fact that research was conducted on a spectrum and some research fell in all of these areas. Oftentimes when describing nanotech, researchers alluded to bottom up versus top down approaches. In simple terms, the top down approach is scaling down of matter say from microns to nanometers which raises basic issues with the science and technology as contemporary theories fail to hold at that scale. The bottom-up approach deals with issues such as directed self assembly of particles and is considered by many as cutting-edge research, which will lead to second generation products such as deep tissue drug delivery and self-assembled motors. The first generation/near term applications in nanotechnolgy are catalysts and coatings and industries utilizing these applications are being revitalized due to nanotech. In describing self-assembly, Prof Rine commented;

> There are several big challenges with nanoparticles, two of them are controlling the dispersion of the particles, that is to say the particles start as individual particles but then they aggregate together to form larger particles. You loose a lot of the interesting properties they had when they were separate, so you want them to remain disperse and that's one problem Another important problem is the assembly of these particles, so you have wires, you have particles of various types, oxides, metals, polymers and the question is there is no machines that can build this, its too small for a machine to build so you need something called Bottom-Up assembly, you need particles that are smart enough to assemble themselves. That's the second question, how do you control the particles so that they undergo bottom-up assembly. In both cases you are controlling the forces between particles. .. Right now it is the science definitely headed towards the technology. Those two problems, dispersion and self assembly are bottlenecks in the technology; the technology cannot proceed until the science is figured out for particles."

Understanding the novel structures of nanomaterials was a common research topic among the faculty interviewed. This understanding forms the base for the creation of nanodevices in a wide variety of industries. According to Prof Haubert;

> My current research is nanowires and carbon nanotubes. Not all materials make thin tubes, single monolayer wrapped in a cylinder. Carbon is one of them, we specialize in carbon here and when it comes to nanowires, a variety of semiconducting materials that have been discovered for what we

> call bulk devices, devices that are carved out of macroscopic chunks of material so .. we are making these nanowires and nanotubes and we are also determined to understand their physical properties and how they are changed by defects, impurities and quantum confinement effects. We are also interested in exploring long term applications, applications far in the future ..like chemical sensors and light emission, photon protectors.

Science at the nanoscale faces interesting challenges because most of the existing theories need to be redefined, which hamper the march of normal science.

6.4.2 Theme: Conditions of nanotech knowledge production

The main drivers of nanotechnology were enumerated as the migration of microelectronics to the nanoscale, the quest for miniaturization in the mid nineties and the invention of tools like the Atomic Force Microscope(AFM), and the Scanning Tunneling Microscope (STM), that were invented in the eighties. There was a growing recognition in the scientific community that miniaturization, beyond a certain point, could not be possible as existing theories broke down at the nanometer scale. Researchers from multiple disciplines arrived at the conclusion that matter at the nanoscale needed to be further studied as it was a roadblock in their research. Biologists and chemists have long worked at the nanoscale, but now they could deliberately manipulate matter at that scale. An excellent understanding of the evolution of the field was provided by Professor Keely;

> What happened in the microelectronic field was that the typical device that was used for micro (10-^{6}) and a lot of the dimension of the device used in the 70’s, 80’s and early 90’s was in the micrometer dimension. And in the mid to late 90’s places like Intel AMD, Texas instruments discovered in order to cram more and more transistors onto a chip they had to reduce the dimensions of individual transistors and they are now measured in the nanometer regime. Along also with that discovery, was the realization that

> eventually there had to be a stop point where you can no longer miniaturize this device beyond a certain point because when you do that the electron, which is primarily the particle of information technology, the other particle by the way is a photon……it no longer behaves in the way that the understanding of the physics that controls these devices works. You now needed a special type of physics to understand this, so you made a shift from what was traditionally called classical physics where you were dealing with a large number of electrons and photons and you could use statistics to …in other words the laws of large numbers worked. When you got the device to be smaller and smaller, the laws of large numbers no longer apply and part of the reason they no longer apply, is because we are now dealing with a few electrons at a time and each one of them matters now. You begin to think of quantum physics and quantum physics is the physics of small numbers and small dimensions and that point everything you tried to do in microelectronics suddenly became in the nanometer regime or nanometer scale regime. ..Biologist and chemists as I pointed out have been doing this for years, what brought it out was that they could now do it deliberately. Before that I think a lot of it was chance occurrence and a lot of it was natural occurrence.

The federal initiatives in the nineties including the NNI were attributed to the growing push from the scientific community that sent nanotechnology proposals to NSF and other funding agencies in the early 1990’s. This pushed NSF, DOD, DARPA, the Army Research office, the Air Force research office and the Office of Naval Research to get together informally and come up with a study which was a precursor to the NNI. The field received further exposure when Nobel prizes were awarded to the inventors of the STM, and to Richard Smalley at Rice for his work in carbon nanotubes. From a materials science perspective, the nineties proved to be a fertile ground for exploring nanoscale phenomena. Prof. Brinks added;

> “I think exploitation of the potential material properties, miniaturization in electronics, stronger materials made at lower temperatures for ceramic and metal systems, all these things are coming to bear. … Anyone nowadays who doesn’t state that we literally stand on the shoulders of giants is misstating the nature of materials. There was enough of a foundation in about 1990 that we could begin to seriously exploit nanoscale phenomena

> to make unique materials and unique components, and unique devices based on those materials."

The tools which enabled the manipulation at the nanoscale opened up the field to researchers. Prof Rine commented;

> "..Richard Feynman talked about this sometime in 1960-61, 'plenty of room at the bottom', and people have been working in fields for instance like catalysis, some materials science fields, but the tools weren't really there. The analysis for looking at these particles weren't really there for all these cases. Yes, you could examine catalytic activity of nanoparticles but it was difficult to image the particles and other things before the 1990's. The AFM came online in a big way in the 1990's and some other techniques.."

Academic research in nanotechnology took off in the late eighties due to an availability of tools and the evolution of 'micro' to 'nano'. Commenting on the timeline, Prof Bozell noted;

> "That has evolved as my work in microelectronics evolved. Somewhere in the late 1980's, I become interested in the nanoscale. The whole idea of working at the nanoscale became more defined. When I became interested in it, merely dragged along, entrapped in, or entrained in the general migration of microelectronics at the nanoscale. The work that gave birth to nanotechnology, I would say probably started 25 years ago, I would say one of the places that gave birth to this would be the IBM Zurich lab where they did some of the first work, …in parallel with the development of these new characterizations tools, the evolution of microelectronics into the nanoscale, an evolution which today has pushed transistors into the nanoregime."

Alluding to the fact that nanosized particles have existed throughout the history of mankind, several faculty members expressed the opinion that at the generic level nanoscale matter is not a novel discovery of the time. Even back in the 18th century, people were familiar with nanoscale particles. Nanometer scale particles were used to create the color in the stained glass for churches in Europe. Earlier on, when the science base did not support it, nanotech particles presented more of a nuisance than an opportunity according to Prof. Brink;

> I have been working on nano since the mid 70's. Well we called it sub micron and quite frankly trying to make bulk materials through particle routes, if we had nanosized particles, it was a nuisance more than anything else. ….So the fact is that nano has been around since time began really. Many materials wind up with nano-scaled features and you can start with opal. ..When did somebody discover the first opal? When the first aborigine happened to stumble across an opal deposit probably in Australia and that was literally tens of thousands of years ago. …Scientifically for me a watershed is Zsigmondy's book. It was originally written in German in 1909, the English translation was written in 1917. ..Most people do not know about this book. But it's probably the first book on colloid chemistry. ..This is the 1st book which states chemistry of colloids and half of this book I would estimate is on nanoparticulates. He did not call it nano; he called it micron- micron. This is fifty years before Richard Feynman gave his famous speech on bottom-up. Feynman was truly a visionary… There's another wonderful example you probably heard about. Dr. Irons Faraday prepared stable gold colloids; about 1855 in fact they are still in his laboratory. …So nano has been around both at a very generic level, but scientifically at least since Faraday's work.

The limitation imposed by disciplinary boundaries is particularly troublesome in nanoscale science because advances are occurring at the interfaces of disciplines. Researchers are trained within disciplinary paradigms and the understanding imparted within these boundaries is necessary but not sufficient to solve problems. Interdisciplinarity has always been important to the materials scientist, and the chemist but the novel combinations afforded by going to the nanoscale makes interdisciplinarity an imperative. In describing the interdisciplinarity inherent in the making of a device, Prof. Keely commented:

> (working at the nanoscale), It does imply large groups. No one person is well versed in physics, device engineering, biology, chemistry and all the other relevant disciplines. The reason is really very simple; Take a regular Electrical engineer (EE) who makes devices from silicon. His training normally does not include chemistry at the very rigorous level. He only

> stops at one course in freshman year, that is it, chemistry but what has become clear as the years have gone by is that training needs to be modified. And part of the reason is that now you are beginning to deal with atoms and any device that you make you now begin to see the effect of atoms, ….so it became very important for an Electrical engineer who previously did not have to worry about these things to begin to understand these things and one option ..is to bring in a chemist or a physicist who has a much better understanding of these things because that's his livelihood. .. Where does the chemist come in? Because the chemist is actually the one who will synthesize this material from scratch, the physicist does not do that usually, so now you need the physicist and the chemist and the EE to make a single device, so suddenly you have an interdisciplinary field. Where does the biologist come in? If you want to make a sensor where are the best sensors we know of -the human body and biologist have been studying this for many years, not necessarily the human body but in other biosystems.

Study at the nanoscale provides challenges on the science, engineering and technology fronts. The science problem is that theories are not yet well illustrated at the nanoscale, the engineering problem has to do with the mechanics of purposive self-assembly. Commenting on this aspect, Prof Brinks noted;

> A scientific problem in what I work with, which is particulates, a chronic scientific problem that we currently have is what is the nature of the forces among particles that are so fine? We do not know, the basic theory clearly breaks down below about 50 nanometers and of course we are working with particles in the 1-10 nanometer rage, so we simply don't know the predominant forces at this point, whether the particles are in a gas phase, a liquid phase, what are the predominant forces? That is a basic science problem. So an engineering problem, if we make nano sized particles it's extremely rare not to have these particles agglomerate into much larger particulate masses and it often compromises their properties for what we are trying to exploit. So an engineering problem is to break these particles up. You would think we would need an handle on the fundamental forces, that would be extraordinarily helpful, but we could still apply good engineering principles to break these agglomerated masses into primary particles and we have shown that.

There has been significant concern over the safety and environmental aspects of nano sized particles. Safety concerns are a big barrier for mass production. Commenting on the safety aspect of particles, Prof. Brinks noted that nanomanufacturing was an uphill task at this time and before technologies can be made market ready it is important to address safety and economic concerns. Additionally, the work force needed to support this industry is still in the pipeline.

> “For truly to develop a manufacturing culture in nano, you have to have safety, you have to make money; the economics has to be there. Neither one is there right now. We don’t know the safety issues when you get to it. When you work with colloidal silica for a 150 years, and it’s in the lot of food that you eat, but that’s different than oh colloidal tungsten or nanoscale tungsten or nanoscale nickel or whatever. Safety aspect is first. That will stop the development of manufactured articles faster than anything and actually it should. The other issue is economic, can you afford to make the thing and within the economic you have the practicality of any process, the scalability, these are two critical issues. …Most of my students will be experts in nanoparticles. It’s going to take a while I think to develop the infrastructure, the people infrastructure, ….

The new challenges in nanotechnology are not about using nanotech to create a smaller version of something that is in existence but using nanoscale science to create something which would otherwise not exist. This appears to be the distinguishing factor between top-down and bottom-up assembly.

> Prof Rine commented “To me the revelation is, and a (colleague) brought this home to me in a big way. Its not just about making things smaller, but its about doing things that you could never do before, and we have to combine some of the glitzy science that you often see published which is important stuff, don’t get me wrong, and put that with sound principles of how do you exactly process these materials. That’s been missing, so much of the science has been there, but the engineering has not been there in the same way and by that I mean the nuts and bolts.. how do you keep these particles rolling, keep them dispersed how do you scale this up to something enough to produce so that every American and every citizen of the world would have the products that they need. So those are the couple of things that stand out for me, this idea that you are doing things that you never could before and figure out enough of the engineering parts of it so we can do scale up..”

According to faculty, the shorter time to commercialization in nanotechnology has been overhyped. There needs to be generation of fundamental knowledge and there are no easy solutions in fields such as energy; the upside however is the expectation of a big payoff. Industry has an important role to play in developing the area and needs to be fully vested. The small companies do not have the facilities and the know-how to characterize materials. Some of the large companies have a team of researchers working on technical development and they are keeping abreast of new developments in the field.

The only Assistant professor interviewed for this study indicated that he had started work in the area because of his colleagues in the department who were enthused to work in the field. All tenured faculty interviewed indicated that their work in nanotech was underpinned by their research in the area that started much before nanotech appeared in the public consciousness. Prof. Keely noted;

> I did not get into nanotechnology because it's a hot field, it was a evolutionary step, naturally came out of what I was doing…When I was graduate student, in the early 80/s and through the early 80's and 90's….I was working on lasers, semiconductor lasers in particular. What we were doing was creating new materials systems for making more efficient and more powerful lasers. In other words a typical semiconductor laser is only about 250 microns by a 100 microns by maybe 5 microns in length; it's just like a dust speck or grain of salt. But into that layer you have to deposit and include many different materials systems, to extract first of all the exact wavelength that you want, the physical light you are interested in and the power level you are interested in, or correlation, the special characteristics of what make a laser a laser as compared to a conventional light from a lamp like this. While we were doing that we realized we needed layers that were very thin and now are measured in nanometers, no longer measured in microns. Technically we were already doing nanotechnology it was just not called nanotechnology at that time.

Several faculty members indicated that their work at the nanoscale was an evolutionary process and although the word 'nanotechnology' is a recent coinage, the underlying work has been going on for a number of years. Prof. Valcourt added “I have always worked in nano, but I have never called it that”. This refrain appeared common among the faculty members interviewed for this study.

6.4.2.1 Key Findings/Working Proposition

Research at the nanoscale took off in the early eighties due to a combination of the quest for miniaturization, growth in science base, growing researcher interest and the invention of the AFM and the STM. The relabeling of research as nanotech is a pragmatic strategy used by researchers, but academic research in nanotechnology has been around since the late 1980’s. Prior to the eighties, work in nanotechnology was hampered due to the lack of instrumentation, and in some instances, the presence of nanoscale particles was disruptive rather than intended. According to the faculty interviewed, the fundamental science theories are breaking down at the nanoscale and new theories are being generated to make sense of the novel changes. Nanoscale particles are not new phenomena but the ability to manipulate matter purposely is.

Nanotechnology is currently nanoscale science, and to mass produce nanodevices, safety and economic issues need to be addressed. Interdisciplinarity is inherent in getting a product out to the marketplace. Disciplinary training of scientists creates barriers that can be removed only with the addition of different disciplinary and cognitive lenses. Research in nanotechnology falls into two realms; Top down, i.e. making things smaller such as the scale of transistors and bottom up nanotechnology dealing with purposive self assembly, enabling completely new products such as deep tissue drug delivery. Currently, faculty researchers are interested in both bottom-up and top down nanotechnology research projects.

Proposition 1: Bottom-Up nanotechnology dealing with self-assembly has the potential to present several disruptive technologies to the marketplace. These will be solutions seeking problems in the industrial world because they deal with second generation nanotechnology products which create a fertile environment for university start-up activity. The tacit knowledge involved in the creation of these technologies provides the academic inventor with a source of expert power that cannot be rivaled by competitors.

6.4.3 Theme: Nanotech specific new initiatives at each institution

At both MPU and BSU, administrators were asked about novel organizational structures and new efforts to facilitate nanotechnology on campus. At MPU, Dr. Parks who occupies a key administrative position had this to say about their efforts;

> "I think that it is interesting that people think that nanotechnology is the next big thing, frankly it is just one of the things out there. A lot of the people think that when you make things smaller, mini and micro and then nano has to be the next big thing, then pico and then ato. It does not really have to be that way, it is just one area of research, it is an interesting area of research and it pulls together several disciplines but there is nothing particularly magic about nanotechnology as opposed to anything else. So we are approaching it the same way we approach any other area of research. What do you need, what kind of specialties do you need, who we should be hiring, what resources do we need, we are going to go get them".

Further, Dr. Parks commented that the way they came upon nanotechnology was naturally as part of the extension of their work in the computer storage area. Under the direction of the person they hired to head up an earlier Center in this area, and with the environmental push to make more information fit on a chip, the research naturally turned to the nanoscale. Citing that center as the “premier” place to work on materials science related to computer storage, Dr. Parks commented that one of MPU’s widely used nanotech inventions came through this center in the early nineties. This invention which was invented in the early nineties has yet to be displaced in that field of use. At MPU, nanotech patent activity emerged in the early 1990’s, and currently the TTO has noted a lot of activity in the area which they anticipate will result in invention disclosures. Since there is a lag time between funding and disclosures they expect to see more disclosures shortly. Nano-biosensors are a promising technology, and present some of the promising new commercialization opportunities. MPU has recently created a new nanotechnology Center which is aimed at facilitating interaction between researchers from different disciplines and leveraging research funds. Commenting on the creation for a new nanotechnology center Andy said;

> “We had a number of people working independently on nanotechnology here, but frankly nanotechnology is a not a cheap area to get into and I think the idea of having a center where you can have a number of people working together was part of the idea so that they could leverage the different work they are doing to get some of the equipment and things that they would like to have. I think going to back to the interdisciplinary things too as well as lot of them are in Electrical engineering some in Mechanical engineering, we have a number of them in Materials science as well and they all have common needs- I think that was a big part of it”

More than half of MPU’s nanotech patents are licensed; the patents arising from center work are mostly licensed to large companies and others are being vested in startups. Additionally, nanotechnologies have the potential to be applied to a wide range of industries and startup companies provide a good platform for developing and scaling up technologies. MPU identified three university spin-offs in nanotechnology; the first company has a product in place and a well detailed market. The second company is based on a patent that was issued 10+ years ago which indicates the long lags between discovery and commercialization.

An interesting aspect of commercialization at MPU, is that their widely used nanotech patent was created through a center which has close ties with industry. This center, like many other centers, has industry members who at the highest level of membership have royalty-free access to patents. Industry members appear to have adopted this invention widely making it the defacto standard. The condition under which knowledge is produced appears to have a direct effect on its adoption. When asked to comment whether there is a shorter time frame between commercialization and research in nanotechnology, Andy noted;

> Well, yes but I am not sure how much of it is due to a particular set of circumstances. I don't know how much of it is because of the type of technology it is. Especially the things from the (name of center) because that center works very closely with a lot of major industrial players, big companies so it is already working on things that people want to have done because they are close to industry. So that one reason we are getting things rather quickly and the turnaround is rather fast in terms of getting them patented and licensed. Some of the other things we have got like (name of researcher) patent portfolio …that was developed around 1997 and we are now starting to see expressions of interest from industry in that, materials transfer, and that's much more along the lines of what we are used to, where it takes 6 or 7 years between the time we have got something and we start to get industrial interest in it. Yes, things seem to be going faster in nano, but I can't really say that's because its nano, but it might be because it is coming out of a center that was already working on things close to industry.

Nanotechnology facilities at MPU are not as extensive as that of BSU. Its cleanroom space is about a third of that at BSU, but is considered to be adequate for

MPU researchers. Industry members also have access to the cleanroom, and in addition, one of the companies that has moved to be near MPU has cleanroom space that can be utilized by MPU researchers. Recognizing the need to strategically grow into the area of nanotechnology, MPU has hired a “star” professor whose work at the nanoscale makes him a “world expert” and who will be heading their new nanotech center.

MPU appears to be using a branding strategy to successfully grow in this area; branding often used in marketing to ignite customer loyalty and repeat buying is used here to generate prestige. By hiring a star well known in public science circles, it is hoped that research funds will follow. MPU’s strategy is to grow research at the nanoscale in the area in which they have already staked a reputation, i.e. computer storage and also through the new center, focus on other emerging areas. Commenting on this aspect, Dr. Parks said;

> I kind of like the fact that we have been in one aspect of nanotech for a long time because we have been targeting it. What do we need to do, how do we make data storage even better, how do we create better storage because people are going to need it, which means we need to understand the systems, we need to understand the materials and we need to understand the atoms that’s why we need nanotech so that’s the approach we use. ..instead of just saying everybody is doing nanotech, so lets just do some nanotech, lets do buckyballs or whatever, I kind of like our approach and I think we are always going to be working on what people need so that’s a very healthy approach. So I think what’s going to happen here at MPU we are going to be stretching, we are not going to suddenly start a new field and something we have never done. We are going to take what we know and expand it and expand it until its looks like it is productive.

In summary, MPU at an organizational level is approaching nanotechnology as they would any other strategic research area. Having noted that there are research funds and they need to be leveraged, they have started a new nanotech center to bring together people from different disciplines. Their primary focus remains on data storage because that is the research they are well known for. Hiring a star professor to grow this area is a tactic made to further the MPU brand. From a tech transfer view, there is currently research activity at the nanoscale which is expected to result in disclosures. Some of the early nanotech patents in MPU's portfolio were invented in the early nineties. They have what could be termed as a blockbuster nanotech patent that was created at a center and is available royalty free to the center's members. The three startup companies at MPU are disparate in technology focus and are at different stages of the life cycle, but are small in size. Two are in the devices/electronics realm and one is in drug delivery. The technology transfer office at MPU has experience dealing with blockbuster technology in several areas and they expect that nanotech research will seed several start-ups. Licensing timelines for nanotech patents are diverse; some are appearing anywhere between seven to eight years and others created at the Centers are reaching industry at a faster pace but they are provided royalty-free. The value through this route is obviously wider to the community but brings in less revenues to the university.

New efforts at BSU

In contrast, at BSU, there is recognition that nanotechnology is a key strategic area of interest due to its well known research in the area of materials science. BSU's researchers are highly ranked in the physical sciences and nanotechnology appears to be a transformation for the physical sciences in a way similar to that of biotech for the life sciences. BSU is positioning itself to take advantage of its talent in the area of materials science.

According to a key administrator at BSU, the last five years were focused on the development of science and education and workforce development in nanotech. The next five years are going to focus on tech transfer. On the recommendation of the nanotechnology steering committee, all the disparate nanotech facilities on campus have been tied into a seamless users network, which makes it easier for researchers to access and leverage the multi-million dollar facilities on campus situated in different labs. The cleanroom facilities at BSU are almost three times the size of that at MPU, and prove to be a big draw for researchers as well as surrounding industry and other universities. Plans are also on to construct a new building on campus bringing together researchers working at the nanoscale from several disciplines. A third factor at BSU, unique to nanoscale research, is the involvement in state economic development zones anchored in the nanotech/materials research work at BSU. BSU's expertise is in converting materials to devices, which promises new commercialization opportunities.

Recognizing however that nanotechnology research has basically benefited by BSU's active push towards interdepartmental research, the move to a matrix organization and co-funding policies used for large grants, Dr. Alloway added;

> The first big policy shift that actively encourages nanotechnology was really the one that broke down the barriers of doing intercollege and interdepartmental research. Once people knew that they could fill out the (form) and credit really would follow them when they participated in teams then I think you started to see much more team based research and interdisciplinary research take off. Next on the lot, by putting BSU on a matrix organization where colleges and departments form rows, institutes form columns you look for intersections and overlaps between those, that was a very good move and very timely, it ties together with the policy change. I think the institutes are designed specifically for interdisciplinary research, research at the interface between different fields and they should stay there, I think that has a huge impact. I think also the fact that the university has funded and cofunded, provided matching funds for large proposals either for centers or for equipment has been excellent.

Commenting on the drivers of nanotech as synthesis, invention of tools, discovery of new carbon allotropes, miniaturization of transistors and recognition of energy wastage Dr. Alloway further added;

> Nanotechnology is really nanoscale science right now and nanoscience has been driven by discoveries in synthesis of nanoscale materials and in their characterization. And if you really want to know what the drivers are, the drivers are synthesis, the drivers are discovery of new carbon allotropes with unique geometries, the discovery of an invention of really microprobe analyses, on top of that the market force driver of really reducing the scale of transistors continuously, so Moore's law. Maybe a 5th driver is, it is a little weaker but its there, its this whole recognition that we do things in an terribly energy intensive way. Nature accomplishes many things with low environmental impact and high efficiency relatively speaking; you could get hung up on what you mean by efficiency so maybe I should say with high effectiveness. Something as simple as fibers, we cannot make something which has the tensile strength of spider silk. The spider does this with little above ambient temperature, system and you know it carries its tools around with him so to speak.

According to Victoria, close ties between industry and BSU are deeply entrenched in the area of materials research. In nanotech, there's a lot of "window shopping" going on as industries are not quite sure of the technologies they need. The technology transfer office at BSU has noted a rise in collaborative efforts in research resulting in multiple inventors in their nanotech patent portfolio. There is no special effort to market nanotech inventions by the TTO. However they do recognize that the market places different emphasis on different technologies, and nanotech is currently very much in demand and to some extent that affects their marketing strategy. Sensors and advanced detection schemes in a post September 11 world, driven in part by DOD funding, are one of the important areas of nanoscale research at BSU. Commenting on this trend, Dr. Irons said;

> I would say that nanotechnologies-it is a kind of a catch all phrase, it is not just materials science, certainly there is a very strong participation by materials science researchers at BSU. What we are seeing that there are

> collaborative relationships between materials scientists and life scientists, recently we have seen a collaboration between materials scientists and College of Medicine and those are good things. In general we don't really try to have priorities, in this time period we are focusing on nanotechnologies and the next we are focusing on life sciences. I would say that we have to recognize that the market place at different periods of time tends to place more emphasis or focus on different technologies, we went through a biotechnology era, we went through an information science era and we, I would say right now, we are in the nanotechnology era. There does seem to be a lot of focus on nanotechnology, but I would say that BSU's materials research existed long before this and it will exist long after nanotechnology comes and goes, and so we try to promote and advance all of our technologies consistently.

Interdisciplinarity is a common feature of nanotechnology and sensors are a promising new technology that is gathering a lot of interest in a post September- 11 world. There is a new emphasis on detection capabilities for biological and chemical agents and lot of this appears to be driven by DOD funding. According to Eric, work in nanotechnology at BSU appears multidisciplinary with chemists interacting with materials scientists and semiconductor process researchers .

Nanotechnology is not easily defined creating confusion about the research and patents that actually fall under this area. Echoing the relabeling strategy put forth by Dr. Parks at MPU, Dr. Irons said;

> "I have heard a lot of discussion about this but I haven't heard a definition that captures all the concepts of nanotechnology, certainly the size-nanosize is a component of that but I think what makes it a little difficult to try put nanotechnology in a nice neat little box is that when a technology comes into focus, it is sort of put on a pedestal And right now nanotechnology is drawing a lot of attention and well I think people kind of adjust and say well if I find a nanoaspect in my technology, I would draw a lot of attention to that. People kind of bend the definitions a little bit and the technologies that we have been working with prior to this time are now all of a sudden nano something and I think the definition gets a little blurry and that's not necessarily that bad. I think faculty do that in their mind, do it to enhance the likelihood that they will receive funding from funding agencies and so they want to give their research activities a

> certain perspective and so sometimes very appropriately and other times questionably but it does happen so the term gets blurred a little bit."

The people working at the TTO recognize that the marketplace shifts but the basic tasks remain the same regardless of the kind of technology involved. Administartors commenting on company formation noted that nanotechnology was a new wave, but in creating companies the focus still remained on getting "management, cash and technology" to get the enterprise started.

In addition to being interdisciplinary a lot of the inventions at the nanoscale are still at the conceptual level, "they are a twinkle in somebody's mind". Industries appear to be grappling with the same problems and the scale-up factor which is important to industries needs to be addressed. Industries are interested in the fundamental research being conducted at universities and companies are interested in making things "reliable, repeatable and affordable". According to interviewees, large corporations are making investments in researching materials properties and their applications and the some of the smaller new companies are dealing with true science and trying to engineer these materials into products.

BSU has strategically and proactively adopted nanotechnology as a way to showcase its strengths in materials research. This is similar to MPU's strategy to grow its strengths in computer storage. In addition to a policy shift towards greater interdisciplinary linkages and collaboration, BSU's move to a matrix structure is benefiting nanoscale research. A new nanotechnology building is in the works and rationalization of the various nanofacilities on campus has been undertaken so as to leverage the expensive investments. Economic development along the surrounding region has been anchored in BSU’s work in materials science and nanomaterials. BSU has close ties with industry in the area of materials research. Most of the patents are considered early stage. One of the patents that it considers to be a defacto standard has come in through a center, similar to that of MPU, and has seen widescale adoption and is provided royalty-free to members at the highest level of membership. This provides across case validation that the conditions of emergence affects the conditions of adoption, in other words, the way knowledge is created affects the manner in which it spreads and is used.

6.4.3.1 Key Findings/Working propositions

Organizational strategies enabling knowledge creation in nanotechnology ranged from the creation of centers to leverage research monies, hiring of new stars to brand their nanotech programs, cofunding large grants, and creation of new buildings devoted exclusively to nanoscale facilities and research. Earlier administrative moves such as systemic push towards interdisciplinarity, change to a matrix structure to facilitate interdisciplinary work also facilitated collaboration in nanotech. Nanotech facilities need extensive capital outlays and there was an administrative push at BSU to rationalize the way these facilities are used throughout campus by linking the different labs organizationally into a users network. At BSU, there was a more apparent strategic focus on facilitating nanotechnology. TTO’s have been noticing increasing collaboration between materials and life scientists to make sensors and devices which are the early commercial products from nanotechnology. Since technologies can be applicable in a wide variety of industries, start-up activity was the vehicle for commercializing technologies in some instances.

Proposition 2: Research universities will pursue nanoscale funding and commercialization using their recognized domain strengths as the research home and capitalizing on existing brand image. In this study it was noted that both universities are tackling nanotechnology in the areas that they are already perceived to have research strength i.e materials and computer storage.

Proposition 3: The manner in which knowledge is created affects the manner in which it is commercialized and adopted. Patents created through centers provide a lot of value to member companies but do not generate revenue for the university. They are adopted quickly by member institutions providing quick diffusion. The time lag between creation and adoption is shorter in this case as compared to early patents in nanotech invented in the nineties which are just generating interest among industry.

6.4.4 Theme: Interdisciplinarity

Centers and institutes which are placed outside the bounds of departmental structures are an organizational mechanism which allows researchers from different academic disciplines to interface with each other. At both MPU and BSU, new centers for nanoscale research have been instituted headed by “star” researchers whose public science credentials are validated by their widely disseminated publications. Because of its size, BSU has several more centers with slightly different foci for researchers at the nanoscale. Unlike the Integrated Circuits(IC) revolution which was concentrated in electronics, biotech which was focused in the life sciences, nanotechnology does not have a unique research home. The reason is that several disciplines are conducting research at the nanoscale and approaching similar results through different disciplinary lenses. Commenting on this aspect of nanotechnology, Prof. Keely said;

> I don’t think there is a (research) home for it part of it is because different people have different spins on it. As an electrical engineer I have a different spin and emphasis, my colleagues in biology have a different spin and emphasis on what is important, chemists have a different emphasis on it. I will give you a classic example which is very simple to understand. I have a system in my lab for making nanotechnology structures, people in chemistry do it different, the same thing, and the reason they do it different is because that’s the way they understand how to do it. I do it the way I do it, because I do not want to understand too much chemistry. Yet, the end result at the device level is that we both can produce the same end result but just from different approaches

Centers play a major role in defining the research that is undertaken as well as promoting ties that are difficult to ensure within traditional disciplinary structures. Prof. Valcourt credited the center director for his work in nanotech, as part of the center’s direction to grow in that particular area. At MPU, there are several collaborations between computer science researchers and life science researchers. It is a widely held belief at MPU that its rise to preeminence in the seventies and eighties was due to its promotion of interdisciplinary collaboration and the structure necessary to do so, (i.e., its centers and institutes). Organic collaborations among faculty are generally wrought by the often intangible presence of organizational culture. Recognizing that often people collaborate but do not understand each other, a professor in biology at MPU, taught a biology course with no monetary incentive, for faculty in other departments, one night a week. Among the attendees were the dean of computer science and professor of software engineering; the class has gained in popularity every year. In addition to tenure and promotion decisions, interdisciplinarity poses different problems as well for students graduating in nanotech. From an organizational point of view, both BSU and MPU promote interdisciplinarity and have policies in place to do so. Commenting on this aspect, Prof. Keely noted;

> I don't think MPU has any problem with it. I don't know whether other universities do and how they are going to deal with it. They are probably going to begin to address this in the next five years and beyond because you are just getting the generation of people of who are emerging out of these programs. My first Ph.D. student in nanotech just got offered an assistant professorship at U(name), she will start there this fall, and she's an example of a person who you could not quite peg down as a EE or physicist or a material scientist because of the way she was trained. But they hired her in materials science. When they interviewed her ..the EE dept interviewed her but the offer finally came from materials science

Interdisciplinarity affects a core faculty reward in academia; the tenure decision. Commenting on the difficulties inherent in promotion and tenure decisions, Prof. Valcourt said:

> They certainly do it in their writings (promote interdisciplinary collaboration), they say they promote it, but there are always difficulties in the promotion and tenure cases. People have worked in two or three areas, no one knows for sure where they really worked, whether their work is their work in that area or whether it is their colleagues.. If its all in the department, we sort of know he did not do that, the other professor he worked with did it, but on the other hand if its in an other department across campus we don't know who did it, it gets a little messy at that level. But they always say we really promote interdisciplinary research. From my point of view, it worked really well for me. The Center really focused and put a bunch of us together and that's how I could find somebody that I could work with well and we had mutual complementary interests.

At MPU, researchers collaborate with other universities in the region leveraging their expertise in computer science and engineering. To facilitate this effort, MPU has set in place master agreements with other schools. Philosophy and policies across the technology transfer offices vary, but recognizing the collaborative trend they have tried to rationalize and align policies so that inventions can make their way into the marketplace. Interdisciplinarity plays a key role in the creation of inventions. Andy estimated that more than half of the patents at MPU arise from interdisciplinary research, and MPU is always looking for creative new ways to facilitate interaction among its researchers.

Facilitating the growth of nanotechnology is not an easy task at the organizational level and even at the TTO it presents significant problem because it spans several disciplines. Andy, commenting on the organization of the TTO said;

> The way my office is set up right now we have five different people doing what I do as far as licensing goes called licensing officers. We have tried to divide things among them in ways that make sense. We have one person that does software, one person who does biology we have one person who does EE, we have tried to divide things that way, nano does not neatly fit into any of those and so it is kind of difficult to come up with generalizations, because we just have not always thought of things in a category nanotechnology.

An organizational structure promoting interdisciplinarity is hollow without the connections and the culture that allows these connections to be made by faculty researchers. BSU has promoted interdisciplinarity among its researchers and the collegial culture has actively promoted these interactions. Working within the organizational structure of an institute also allows for seamless administration of joint proposals which facilitates the collaborative process. Commenting on the structure that promotes interdisciplinary collaboration, Prof Brinks noted;

> We have the (name of institute) which is I think it’s safe to say is unique as far as American universities and probably in terms of international as well, in that, we have a full time administrator- (name) who organizes, keeps tabs on and connects the right people and facilities with one another to foster interdisciplinary research.. Even better because I have been at other universities, administratively putting together a proposal with diverse individuals is seamless. In other words, I don’t have to worry

> about some Associate Dean negotiating overhead with another Associate Dean from a different college and getting into that level of negotiation

Faculty members commented on the significant number of research grants awarded to BSU for research at the nanoscale by NSF, which are peer reviewed grants and therefore prestigious. Combined with the ‘nano’ characterization facilities on campus, BSU is well positioned to be a leader in certain fields of study. Several administrative pushes have combined to make it so; firstly it appears that BSU developed an early lead due to its strong materials science research, new researchers were hired in the nineties, and in addition nanoscale proposals are peer reviewed through a public process at the university level before sending them out to NSF.

Promoting synergy among large groups of researchers is not an easy task and professors choose their level of participation. Commenting on this struggle, Prof Haubert said;

> BSU, in my opinion, does a reasonably good job getting us together. There are sort of two forces that vie with each other. The university knowing that certain funding is possible groups people together, and tries to foster these relations and that is a positive force. And then there’s a repulsive force in there too where professors that are more comfortable in a single investigator situation and then they are wondering whether they are better off in a collective….. BSU sets the table and whether the professors eat at it or not remains to be seen.

Faculty credited the central administration for the organization of nanoscale research at BSU. In addition, the existing and newly established centers help interaction between colleges and help leverage university funds. BSU’s approach to organization of nanotech research has been proactive and nanoscale research features prominently in its strategic research plan.

BSU's research profile indicates a healthy mix of work in engineering, materials science, and life sciences. The TTO has noted that in recent years more invention disclosures are arising from collaborative work. According to Eric;

> I am beginning to see this mixture of folks who in the past they did not necessarily know they existed in all cases. Now they are finding a need to interact, really interesting opportunities are being created, new scientific discovery areas are popping up as a result of it…. . You hear a name called functionalization used a lot these days, I am going to functionalize a surface of a material in order to attract another material and that's where you see a lot of the marriage of chemistry, biology and materials.

An organization fosters interdisciplinarity through its structures placed outside disciplinary affiliations, but how do faculty members view and interpret interdisciplinary work? To understand this, faculty members at both MPU and BSU were asked about their involvement in large interdisciplinary groups with regard to their research at the nanoscale. From their responses, it was clear that interfacing was required because disciplinary boundaries allowed the advance of knowledge only to a certain degree whereas different disciplinary knowledge allowed the problem to be manipulated through different lenses. By moving to the nanoscale, certain laws relating to material properties no longer hold true and these provide both opportunities and challenges which need solutions from different disciplines. The science of nanotechnology requires interdisciplinarity and the application domain is not well bounded which adds another layer of complexity requiring interdisciplinary interfacing. According to Prof. Brinks, currently unknown areas in chemistry, physics and mathematics which are the core underlying scientific principles are being explored.

Reinforcing the idea that the advance of knowledge in nanotechnology is stymied by disciplinary boundaries, Prof Rine said;

> To answer your question, is it interdisciplinary-definitely. Let me give you an example, in materials science I work with (name) who synthesizes nanomaterials, in this dept I work with (name) who does molecular modeling of nanoparticle forces. In physics (name) and I work on Vanderwaals forces which is a fundamental physics problem, quantum mechanics, ourselves we work on measuring colloidal forces and nanocolloidal forces in addition to some of the other modeling work I mentioned. There's no way I could have gotten into that all by myself, I could not have done it. There's too much expertise there, you have somebody in physics, materials chemical engineering, we are working with (name) in chemistry, (name) in EE there's no way somebody could know that much and that's the challenge.

6.4.4.1 Key findings/Working propositions

From discussions with faculty it was apparent that working at the nanoscale definitely requires interdisciplinary teams because problems and materials require interfacing Physics, Electrical Engineering, Materials Science, Chemistry and Engineering. Progress would not only be much slower, but stymied without the interfacing, as different cognitve lenses are needed for such work. However this does not mean that faculty believed in working in large groups. Facilitating interdisciplinarity cannot be achieved merely by starting centers and institutes, without faculty buy-in the process disintegrates. At MPU, interdisciplinarity is being tackled at the grassroots level in one case, by a professor sharing subject matter expertise with his peers in other disciplines in a class setting.

Interdisciplinary moorings of nanotech provide a challenge not only in the knowledge creation process, but in training students, and at the TTO as well. Nanotech does not fit the division of labor at the TTO's, because nanotechnology is characterized by its focus on scale not discipline. The TTO is generally structured so that each TLO manages technologies in certain disciplines and is trained in that discipline. MPU's TTO estimated that about half of their overall patents are arising out of interdisciplinary work, which means the TLOs have to cross disciplinary boundaries as well to understand the technologies. The organization of nanotech research is rationalized at BSU to enhance university chances at success with funding agencies, placing collective success before individual. The large number of proposals generated by its researchers go through an internal peer review aired in a community setting and only the top tier are submitted to the funding agency.

Proposition 5: Interdisciplinary groupings which are necessary in fields such as nanotech present organizational challenges to the whole academic production and transfer chain.

Proposition 6: Centers and institutes are key to the organization of science at the nanoscale because of their administrative infrastructure which makes it easier to interact with faculty from other disciplines. However they provide a necessary but not sufficient condition for enabling interdisciplinarity. Faculty buy-in is the only means to make such arrangements work.

6.4.5 Theme: Organization culture

MPU's rise from "being a competent regional school to being a national world class power in certain technology areas" was attributed to the vision of a previous president and a group of insightful visionary people. MPU emphasizes collaborative work and all efforts including new hires are aligned so as to promote and preserve this culture.

In addition, MPU has a lean administrative hierarchy which allows for a more nimble and responsive system. Dr. Parks commenting on MPU's culture added;

> I think what is different is that especially engineering but every thing else on campus is done, that is really by an emphasis on collaboration, ..That's what a lot of schools now say they are doing because for the past 20 years government agencies, the NSF, for example, have been pushing this multidisciplinary collaboration, interdisciplinary collaboration, but (in many) schools it does not work and it does not work if you have a lot of prima donnas. And if you are the kind of university that attracts prima donnas to the exclusion of others you don't get those kinds of collaborations. As a result you make great leaps in narrow fields but you don't necessarily work on the kinds of problems that matter to the country…

At both MPU and BSU, it was clear that the primary focus was on research and education. MPU's orientation to tech transfer and economic development was more local given its location in a big city, as compared to BSU whose economic development approach was more global, due to its location in a small college town. At MPU, this local orientation to tech transfer appears to have affected its policies and the culture to work with industry. According to Dr. Parks;

> At this university, we see it not only as one important way to get our research results out to the public but also as something we need to do for our community. (city) is a city that was built on the hard work of the entrepreneurs of the last century. …But then as you know in the 70's and 80's we lost a lot of jobs to foreign competition and they took the city 20 or 30 years to recover. But now you have a city that has a diverse economy, and lots of interesting things happening, lots of high tech things going on and lot of it is related to spinoffs from the university, but the city is still struggling financially. ..We are a city that does not have the economy to support the infrastructure that has been built to support an economy twice the size. People are looking to the university to help and we are doing all we can to help and we think it is important to help, so in addition to the fact that its good to do that anyway to have research results spunoff to the community, we believe that it is one of MPU"S unique mission as part of the community to try and help build the economy.

Commenting on the fact that their endowment per student is small as compared to their key competitors, Dr. Parks noted that faculty are raided every year and they end up winning quite few of those battles due to their collaborative culture. Dr. Parks believes that nanotechnology research with its emphasis on interdisciplinarity will be aided significantly by this culture.

Stating that MPU's philosophy about tech transfer is really proactive, Andy noted that the TTO had a dual purpose charter; one was to take academic research and get it into a form that it is accessible and available to more people. And a secondary purpose is to try and improve the economy of the local (city) area and therefore new ventures were encouraged. Commenting on the entrepreneurial nature of the university, Andy noted that MPU was more willing to take chances on things that other universities would not. At MPU, in comparison to other universities, there is a higher number of researchers who have formed companies and then come back to their academic roles.

At both BSU and MPU, administrators felt that there was no singular advantage/disadvantage in being public or private. There were pros and cons and in the end "it was a wash". Commenting on the difference between public and private universities, Dr. Parks had this to add;

> I can't really say that there is a difference between public and private in how faculty view themselves. It may not be true in every state. I think there are some states where the faculty member is viewed as a state employee and therefore its wrong for him to make money he can't make money on university innovation or the amount of equity he can have in a private spinoff company is capped at some artificial level. These come up more in public universities then they do in private. But private universities suffer from their own constraints, we have a lot of constraints that are imposed upon us by non-profit tax law which in (state) can be very restrictive in certain respects. But there are some non-profit tax laws which make us look less friendly to corporations, … There are pros and

> cons and at the end of the day I think it's a wash, it sort of depends on what interaction you want to talk about, depends on which company or which research sponsor.

At BSU, Dr. Alloway further elaborated on the public private status of the university and its effects on university functioning. Public universities are at a disadvantage when compared to private universities which are "old, well established and have huge endowments". It allows them to take these no-strings attached monies and promote new technology. On the flip side, public universities get a substantial amount of their budget from the state and that allows them to do certain things that the private universities cannot undertake.

There was a consensus among the faculty members interviewed at BSU that the culture was not about 'individual fiefdoms' and was collegial. What is interesting however, is that the culture appears to be more so among certain groups. Prof. Rine commented;

> I don't how you engineer this into the organizational structure, I don't know what it is about the people here, but they are very easy to work with. It would be very interesting to find out what it is about this set of people (people mentioned) what it is about that group that makes them want to work together, I don't know what that is.

The same phenomena appear to be true when it comes to commercialization indicating that subcultures exist at BSU that value entrepreneurial activity more than others. Dr. Irons noted the following about entrepreneurial activity;

> I would say that there are pockets of entrepreneurial activity in the university where certain groups are much more active than other groups and it kind of defies logic. We do not know why that is true it is definitely true.

Stating that creation of patents is not at the highest level of the academic priority list Eric commented;

> Here(at BSU) at least there's very little administrative drive to create patents, the key to that, I think is if you look at how our faculty members are evaluated, you will find that patents are the bottom of the list….Clearly the administrations key focus is on research funds and when you look at the 'nanodollars' flowing into the university as compared to what the tech transfer office generates, they are putting their efforts in the right place…

BSU, according to the interviewees was good with organizing and structuring research, but lagged behind when it came to proactively pushing commercialization. Recent policies however have been aligned towards fostering stronger connections with industry and encouraging translational research. Adding that commercialization if not definitely encouraged is not discouraged at BSU, a key administrator noted that faculty balance of their roles is key and although misuse can occur, they are rare instances, and most of the times graduate students tend to become part of the companies and retain equity. Dr. Alloway noted that "that there is no downside to tech transfer at this time, only an upside and the upside potential is huge". BSU's current philosophy regarding tech transfer is "open minded" and a spectrum of IP approaches are being analyzed to facilitate industrial collaboration. It is necessary for universities to recognize that all industry projects do not include IP creation and some are well bounded research projects that capitalize on faculty expertise and prove to be good training ground for students and post-docs.

Attributing a lack of marketing culture, in part due to its location, which has influenced BSU's culture, Hardy noted;

> The university does not market, they provide public dissemination of research results, but they do not market as we think of marketing in the private sector and in the tech transfer area you got to market. There's a buyers mentality here, because it's a big entity in the middle of a small community and I tell the people that outside (name) of county people don't care who we are. You are listening to the chant in the stadium too much, they don't care, we have to go sell it.

Commenting on the fact that BSU provides a supportive culture for commercialization, Prof. Keely noted the power of the faculty member in commercializing if they chose to do so;

> I think it does (supportive culture for commercialization), and I think this is the kind of thing whether the university likes it or not, they have to support it. ..It is to their advantage to allow the professor if he is interested in doing it to do it because who else would have the best chance of success? It is his idea or her idea and they are going to do their best to make sure they succeed.

6.4.5.1 Key Findings/Working propositions

Tech transfer success is mediated by several factors: institutional history, location, and the local vs. global orientation of the TTO. Entrepreneurial universities tend to create patents and spin offs routinely regardless of the area of expertise, as is the case with MPU where nanotechnology is considered as only one of their areas of expertise and handled just like other areas. At BSU, the change is both top down and bottom up indicating the possibility of a dominant coalition that is moving tech transfer and commercialization towards the center. Peers enthuse others and peer effects exist in both the knowledge creation and transfer process,. The public or private nature of the university does not seem to matter as much as organizational culture. Attitudes towards tech transfer are not uniform across the organization. There is a presence of a subculture which values entrepreneurship more. A lack of marketing culture at BSU hampers tech transfer whereas at MPU, it forms part of their culture.

Proposition 7: Organizational subcultures exist which value commercialization more than others. These subcultures may be in a position to influence organizational policy due to its power base and peer effects. The reputational prestige enjoyed by star scientists when merged with their successful commercialization stories allows for emulation by peers.

Proposition 8: Success in tech transfer is mediated by organizational history, location, and local versus global orientation of the TTO. College-town-based BSU does not have the synergies that MPU shares with its environment, changing the dynamics of tech transfer.

6.4.6 Theme: Faculty balancing of roles

Faculty role balance is crucial to being able to carry out the demands and time constraints posed by research and commercialization. The faculty interviewed for this study fall into two different groups; One set that places the traditional academic principles of research and teaching as their priority and view patenting as part of that role and hope that it provides value to the community. The other set is clearly entrepreneurial in nature, and in addition to patenting they see creation of spin-offs as key to ensuring their technology is carried through to commercialization. Typical of this first group is the sentiment:

> No, I am not a businessman. That is an overt decision on my part. I like teaching, I like doing research. Doesn't mean that I wouldn't encourage one of my students or colleagues to spin off a company if they felt they had the business acumen but I don't. I think I am a pretty fair teacher and a good researcher and that's where God intended me to work.
>
> Some people, it just falls naturally wanting to have spinoff companies, for me I wouldn't do that if they paid me. I want to be a teacher and I want to do research, so I will never do a spinoff company but other people just love it… It takes up too much time. I am a strong believer in teaching and research. I don't think I would be able to do all three, research, teaching and spinoff. In fact almost everybody takes leave of absence to do that and I don't want to do that…Just that it has to be kept in balance and if it goes too far, then we are going to loose out and our students are going to loose out and in the long term we will loose out because there's not the basic science being built up. I certainly am not opposed to a certain percentage of our time being used in patent writing and stuff like that. But we have to keep it in balance.

The second group which contains faculty members who are able to carry out span the boundaries between their role as a professor and their role as an entrepreneur face a tough task; "110% of our time is committed so there has to be special people that believe it is worth it somehow". The faculty who have founded companies view their commercialization role as part of the professorial identity, and champion a seamless blending of roles while maintaining a healthy distance between the two spheres. Typical of this second group is the sentiment;

> Why do I patent? In hopes that there will be some value in what I am patenting, some value to the university, some value to myself. I think it is important as an engineer to do that sort of thing. I think it is important because we need to teach the students to do that. I patent because it is what an engineer should do, and I patent because I think as an engineering professor students should see that and it should be a part of their education
>
> The university has licensed a number of my technologies, and I thought well gee whiz I can do a better job of it, rather than licensing it to some large company which is their modus operandi, I thought why not take it myself and create a company out of it directly. I thought there were several advantages in that; one is that it will be fun and another is once

> again I could involve students, so I gave part ownership of the company to three students and they are very good people and I saw it as a way to create jobs in (location) in particular. ..I consider myself an entrepreneur anyway, for I started the (facility at BSU), it is not like somebody handed me the money. I found a way –prior to that I have always had large research groups and lots of funding, so basically I am an entrepreneur anyway so why not try it with a company that I have started. I think successful faculty, almost by definition of their position, are entrepreneurs.

Common to both sets is the belief that time is in short supply and role balance is critical for success. Maintaining a clear distinction between the two spheres is acknowledged as the best way to balance the role demands of each sphere. Advocating a clear separation between "your act as a small business operator and your act as a professor", Prof Haubert noted that there is dissonance between the professorial set and the entrepreneurial set. Faculty members need to be educated with regard to the nuances of the technology transfer process and this is an important element of success in tech transfer.

The stage of the faculty life cycle has a clear impact on the timing of technology transfer activities. According to both TTO's, tenured faculty tend to commercialize their research while tenure-track faculty are more concerned with publishing. At MPU, there are some instances of assistant professors doing startups, because faculty are allowed to incubate in their labs. However, untenured faculty are not provided with leave of absence in either university. Earlier on in their careers, faculty tend to publish rather than patent and the motivation to do so was described by Prof. Keely;

> We had other ideas which we should have patented, but we did not, other people went ahead and patented it, but we had priority in terms of papers for it. It is because at that time I was really interested in getting the science out first..(initially) getting a reputation as a technical person is more important than a patent.

Dr. Irons at BSU added that the promotion and tenure process did not focus heavily on the creation of patents;

> I would say for the most part it is our more senior faculty members, faculty members who certainly have achieved tenure and who may already be full professors, it seems like at that point they have the flexibility to participate in this. So we recognize that in the P&T process participating in tech transfer invention disclosures, patenting is not valued very much, it is the last item on the last page or something like that. I am not sure whereas in other institutions it may be weighted more heavily.

Prior socialization also tends to make an impact on motivation to commercialize; a key administrator attributed an assistant professor's interest in commercialization even when the culture does not motivate him to do so to the university from which he graduated which has a strong commercialization record. This analysis can be corroborated by another finding: two of the three faculty members who have founded companies in this study have graduated from universities that have strong commercialization track records.

Realizing the time spent on patenting has to yield value, most faculty members go through an opportunity cost analysis when they decide to patent or publish. Value to the community at large as well as monetary return plays an important role in this decision. Prof Brinks noted;

> My attitude towards patents is very pragmatic. I believe, again like I said before, they are not worth writing if they are not going to make money, serious money. Having said that, I have a bunch of patents where I have made $2 so far, so hope springs eternal. However, I think many of our faculty members are under the false impression that getting a patent is good for their careers. I would have to say it is a sacrifice, because in the 10 or 12 patents that I have been associated with personally, I have spent much more time than I would ever spend on a good journal paper, archival international journal paper, that's sort of the way it comes down. If you don't have the monetary value for your patent, you are better off writing

> the paper and attaining notoriety, if not money. We have to educate our faculty to say that just because you have wonderful ideas, specifically because you have wonderful ideas, you shouldn't think of a patent immediately because if you cannot translate that into dollars and cents for the university and the inventors, you are much better off just writing a good series of papers, a series of journal papers.

For some, time spent on commercialization equals time spent away from publishing and the sole assistant professor in this study saw his role more as that of mentoring his students and eventually moving on to commercializing ideas. Commenting that role balance means fighting the fires that need fighting, Prof. Haubert noted the time spent on this endeavor.

> Anytime I start one (a new company), it takes a big chunk out of me, so I am not looking for this activity. But on the other hand I see a good opportunity and I do have the time then I will do it. Its kind of a zero sum game for me right now, I would be an idiot to get involved in accompany right now (because I just do not have the time right now)

All the faculty members who had started spin-offs saw their roles as entrepreneurs benefiting their role as a researcher/teacher and commented on the synergy between the two roles. In one instance, the spinout firm donated their product to the inventor faculty member's lab in return for understanding the usage pattern. Both the company and the lab benefited through this exchange. In another instance, students who had worked with the inventor professor ended up as the employees of the new startup. In most instances, the day-to-day running of the company was left to the management team. In some instances the professor continued as CEO but had a team to in charge of daily operations.

Prior experience in commercialization impacts success of the entrepreneurial effort. Faculty members who have gone through the learning curve know when and what kind of funds to access and have the ability to leverage resources. Inexperienced entrepreneurs spend a lot of time and effort on understanding the requirements and constraints of different types of federal grant monies which may be appealing but can constrain access to private sector monies.

Not all faculty members can make an easy transition to entrepreneurship. There are several routes through which professors can see their technologies commercialized and they have several options which do not necessarily have them playing the main role in the company, they can feature as Chief Technology Officers (CTO's), or as scientific advisors. Peer interaction matters, as do the training tools that the university provides to acquaint faculty members with the intricacies of starting a business. According to Hardy;

> One of the most common things, and this does not fit to a T, is that most (faculty) are grossly ill-equipped to start a company …What is dangerous is some of them think that their skillset from academia is directly transferable into business and we are now at the point where more and more recognize that, either through stories they have heard or self education tools we have given them. I think they want to see their technology get commercialized but we have not given them the option 2, 3 and 4 to do a startup. You know option 2 being you don't have to start it yourself, you can match it with somebody and you can be the CTO for a period of time to do some translation of the technology to the company but at some point you are just a stockholder, you can sit on the scientific advisory, sit on the board. …

Time spent with the faculty member on understanding the technology is essential for the Technology Licensing Officer, and a key part of the transfer process. However, the TTO recognizing that there are several burdens on faculty time does limit its contact with the faculty member to strictly what is necessary. Dr. Irons commented;

> I think there may be an misunderstanding by some Deans or department heads that every invention disclosure results in a startup company or every faculty member may be tempted to leave the university and that's rarely the case really. We certainly try to consume as little time of the faculty member as possible, we know that faculty members are pulled in several different directions. Yes, if you submit an invention disclosure we do have

> to meet with you we do have to have discussions, if we decide to apply for a patent application, the faculty member is usually the lead and working with the patent attorney to prepare the patent application it will involve certain phone discussions, it will involve providing data, it will involve reviewing drafts of patent applications and so on. But we try to make that easy, we have selected law firms that understand the faculty are very busy and we try to pick the most user friendly patent law firms to make that process as painless as possible.

Faculty inventors are essential throughout the transfer process. In most instances, licensing a patent depends heavily on the contacts and industry knowledge that a faculty member possesses. This path is invariably the first course of action for the TTO because it offers the path of least resistance. The chances of success rise exponentially when faculty members can see a clear fit for their technology and also know the companies who would be interested in the invention.

Researchers working in the applied sciences have closer contacts with industry than those in the pure sciences. This affects faculty disposition towards submitting invention disclosures. Certain faculty members are driven to work with industry because they want to see their concepts engineered and developed into products. Some faculty “do not want to even play the game” and are not disposed to working with industry because they believe that such work will constrain their research.

At MPU, faculty have to be tenured to take a leave of absence. Assistant professors are interested in startups and they are not able to take a leave of absence but they can still start up their company and incubate in their labs. Assistant professors are also under pressure to publish, and patenting thus becomes a secondary activity. Sequencing their publications is a necessity that most inventor faculty members are cognizant of and they seek the help of the TTO in understanding the time frames involved. As Patricia noted;

> We do not discourage our faculty from disclosing at all. But we do try to get to them first. ….. One of the main reasons we patent is to protect their right to operate in their own field. So we only need to patent in the US because they are here in the US. So even if they publish we have an year to patent only in the US, so we don't tell them not to publish.

According to Patricia, they see more entrepreneurial faculty at MPU than is the norm. Several of them start off the process by indicating that they will never start a company, but once they find that they can mesh it with their other roles and that MPU allows them to incubate in their labs, commercialization becomes a viable option. In some instances, they move to the corporate world. The impetus for faculty members to commercialize is not so much the money, but the speed at which they can commercialize their invention. They want to see their technology developed and they realize that sometimes their academic priorities keep pulling them away from this focus. During the process of tech transfer faculty realize that if they want their technology to help people, then they have to make it happen.

6.4.6.1 Key Findings/Working propositions

For some faculty, commercialization is clearly part of the professorial role. These faculty are boundary spanners who are comfortable in both professorial and commercial spheres; they consider their roles as entrepreneurs as extension of their professorial role. Role balance and separation of both spheres is important for most professors. Publishing is more important for assistant professors than patenting. Prior socialization to commercialization behaviors impacts the decision to commercialize. Some professors see clear synergies in both roles and once the new company is formed, professors are mostly involved in a scientific role. It is only at times of high involvement that they undertake a leave of absence from the university. Experienced faculty entrepreneurs avoid funding traps. Not all funding opportunities are suitable but they do not recognize the presence of options available to them. Faculty contacts are integral to the licensing process. For some professors the ability to patent affords the opportunity to train their students, providing an additional facet to their education. Most of the initial jobs in the start up companies are held by ex-students. Some professors have the power to resist either Venture Capital or other external pressures to move the company to other locations, although they classify this as a constant struggle. For most professors, the role balance is to ‘fight the fires that need fighting’. There appears to be a significant decoupling of intent and behavior, with opinions on commercialization changing during the faculty lifecycle.

Proposition 9: Two groups of faculty exist: those who see commercialization as part of their academic roles and those who see it outside the periphery. For those who envision it as part of their roles, there are visible synergies between both roles affecting their teaching roles positively as well. Boundary spanners make for the most successful faculty entrepreneurs.

Proposition 10: There is loose coupling of intent and behavior indicating that external stimuli can change role perceptions.

6.4.7 Theme: Motivation to patent and commercialize

Faculty members had diverse motivations for patenting and commercializing their research. For some, patenting led to the ability to protect and be able to use their own work. For others, patenting was providing value to member companies of a center. Most faculty patented or commercialized due to some external impetus. In some instances a colleague motivated them to patent or in the case of company formation, industry members enthused by the professor's research provided the impetus for commercialization. Commenting on the decision to patent Prof. Valcourt noted;

> To be truthful about this, it was basically my interaction with my colleague …. who used to work in industry ..he was always looking to write a patent and I was sort of the opposite, I did not want to do that and he said look we have to do this here, here and here and I sort of went along with that. My students like it actually because they were often joint students with him. And they would have already have experienced the patents and they would go out to industry where they would have to do it in their research. So it was important that I had interaction with other people (in the Center). (Name of colleague) and I decided that we had to not just be able to get a patent but that it should be used. You can get a patent that will never be used, that was not our intent actually.

Organizational barriers such as TTO decision to not go ahead with a patent unless licensees can be found tend to discourage faculty from the patenting process. However a certain set of conditions such as contact with industry and the motivation to spend time on patenting and commercializing tend to be a mitigating factor. In several instances it was noted that the motivation to commercialize was based on industry input. Industry members who were aware of the faculty member's research either through publications/personal contact noted commercialization potential and provided a support network for the faculty member.

Faculty make the decision to patent based on the value provided in terms of use as well as monetary value. The patenting-for-value model for nanotech inventions in particular, was noted by Prof Brinks;

> For bulk materials, we are talking of ceramic iomers or small sintered medical devices or ball bearings, we are not going to protect that, the processing and the way we go about making our nanoparticulates because I don't think there will be value. But, however for the nano-medical applications, that we protect, because I think there is great value there. Great value also means there is greater risk.

The patenting- to-protect model was a more defensive maneuver adopted by faculty and was elaborated by Prof Rine;

> It was like I said, this fellow told me about the discovery he had in his lab and how his ability to use his own work was reduced because somebody else filed the patent on his work, and that's pretty good impetus. But again I believe very strongly that taxpayers of this country support much of our research and I think they deserve a benefit from that, meaning commercialization of something. If you don't patent your invention the problem is that every company can go after it meaning no company will ever do it, because there's no advantage anybody has.

At BSU and MPU, two nanotech patents that have seen wide use have arisen out of centers and are provided royalty free to members. Work conducted at centers leads to patents that may not have tremendous value for the university but are very important for the member companies who are part of these centers.

The creation of startups in the academy was considered an anti-intellectual exercise but that lost its stigma during the dot.com boom. One of the faculty members who is the founder of several spinoff firms commented on the various reasons that he had opted out of certain companies and continued his association with others. In one case, the venture capital firm who had funded the company sought to move it to a different state. The faculty member's identification with the primary academic role prevented him from making that move. Another company which sought SBIR grants to move the technology closer to commercialization exerted too much time pressures on the faculty member's time leading to a decision to opt out.

In Prof. Stokes' view the primary impetus for commercialization is the existence of a good invention. In recounting his own impetus for starting a spinoff, he noted that the prime mover was an outside collaborator who was excited about possible commercial opportunities arising from his research. For academic researchers, working with industry scientists provides an important understanding of a different scientific culture.

6.4.7.1 Key Findings/Working Propositions

Faculty patent for two key reasons: one is that they believe it provides value to the institution, to themselves, and to society in general. The second reason is a defensive move to make sure that they are protecting their right to practice in their own fields. The impetus for patenting is due to external impetus from industrial partners or due to peers who have had prior experiences with patenting. Organizational policies are sometimes perceived as barriers, but strong motivators such as intrinsic belief and external support can be a mitigating factor. When patenting for value, faculty do recognize that some patents are high worth/high value patents and these inventions are protected due to their expected impact and returns.

Proposition 10: Motivation to patent and commercialize is due to peer experiences with patenting or due to impetus from industry. Social capital in terms of *external contacts with industry matters, as does reputational power in the form of publications, which makes industry value their research.*

Proposition 11: Faculty patent because they believe the invention provides value or because of a defensive posture of not being able to practice in their own field of use. Patents which are considered to be of high value in monetary terms are treated differently than routine patents

6.4.8 Venture Capital

The venture community has invested $434.3 million in nanotech companies in 2005, up from $196.4 million in 2004(Forman, 2006). Technology Licensing Officers at both BSU and MPU noted that angel investors provide a significant amount of seed financing for academic spinoffs. Angel investors are high networth individuals who provide capital for business startups. According to Patricia, the VC community around MPU is very active but they have lent to traditional industries like manufacturing process industries. The venture community tend not to make seed investments and these monies are essential for a university-startup to move from proof of concept to a working prototype. Foundations and several non-profit and economic development agencies make seed stage investments. Entrepreneurs can access several different “pots of money” according to Hardy:

> There’s traditionally what is known as family and friends money, so naturally there’s the entrepreneurs money, then there’s family and friends, when you start a company, you start at home and then you bump into angel money which are normally high networth individuals that have a networth of more than $1 million, excluding their primary residence or who have made more than 200,000 dollars a year for the past two or three

> years. The angel investment in this country dwarfs and I mean really dwarfs institutional venture capital. Most people think VC funds are really the engine, it is small compared to angel investors, who are putting moneys….The real issue is when you look at the business opportunity, what's the market size. VC Companies are really not looking at small markets, they don't want a 2 million, 3 million or 5 million in sales a year. An angel investor would look longer, they will stay in the deal a little longer, they can make some money. VCs want out in three to five years. They want to step on their money and make 5x, 10x.

6.4.8.1 Key Findings

Angel investment appear be more important than VC investments for early stage companies. No estimates can be made for angel investments in nanotech companies however, the VC investment in nanotech was up 121% from that in 2004. Academic entrepreneurs have several sources of monies available for creating spinoff firms, which can be accessed based on market size and potential.

6.4.9 Theme: Federal funding

Nanotechnology has seen an influx of monies through the NNI to the research community from several different agencies. The different cultures of the funding agencies tend to affect the way research is conducted and organized. Commenting on the different cultures between funding agencies, Dr. Parks noted,

> The overriding difference from the university's point of view between doing research in this field or that field is the culture of the funding agency. The culture of NIH and the culture of NSF and DARPA are very different, just fundamentally different. At NIH your goal is to get that Ro1 grant, you also want the program project grant, but you are at the top of this pyramid of all sorts of people who are working for you and its much more an individual star with a whole bunch of people working for that

> star. And at NSF and DARPA the funding is much more about collaboration with peers and you very rarely see that in biomedical research, it is much more hierarchical. If you see the medical schools you will see that they are much more hierarchical as compared to engineering schools. In going and getting funding what you will find is that a lot of times funding from companies who wants to commercialize a product flows more freely to schools in engineering and other fields just because the team approach is much more consistent with how research is done in companies, … the way people behave in medical schools as compared to non-medical schools is very different.

Relabeling of research to align it with current governmental interests is a buffering strategy adopted by faculty members. The whole cycle of getting funding also has to do with public interest and getting legislators interested. Dr. Parks added that there is ongoing search “for the next big thing”. The scientific community is always trying to capture the imagination of people in Congress because research has a long time horizon and results may not show up in products for several years. The use of terms such as nanotechnology helps generate public interest. However, research which is labeled as nanotech today may have existed several years ago under different labels.

According to Dr. Alloway, federal, state and industry funds provide different benefits to the academic value chain;

> I think we are trying to do the following, which is to look at federal R&D monies as monies for breakthroughs for invention, the most fundamental science and engineering science. Then we have industrial monies which come in and leverage off those federal monies and fundamentally seek to license and grow our intellectual capital in a way that’s advantageous to an existing business or company. What I see in between are in fact state monies that come to us in specific areas such as nanotechnology which allow us to do translational research from the mind to the market, if you will, fill that gap and hopefully create economic development by spinning off companies and creating new ventures.

There are differences between the expectations of federally funded research and that of industry-funded research. Prof Brinks noted that federal funding often is precompetitive and has a long lag time before results can have practical significance. In contrast, industrial research must have an immediate overt impact on the way a company does business if it has to be judged successful. The metric for success for federal grant is a good series of journal papers. Combining both these sources of fund helps researchers do a combination of basic science and applied research which is beneficial.

Increased collaboration in research is being fostered by funding agencies. Commenting on the influence of federal agencies in promoting collaborative work, Hardy noted;

> It's moving that direction. The people that can influence that the most are at the federal level. If they specced it in there, and that's what they are doing now and you know people follow the money, which is great, so the silos are dissolving more because it's a requirement of the play.

The hype surrounding a new technology is not a new phenomenon. Nanotechnology has been preceded by several other technology waves some of which did well and others where expectations were outdone by actual results, for e.g., superconductivity.

In nanotechnology, federal funding has had the biggest impact, with NSF in the lead. State investments in nanotechnology are based on promoting economic development. Noting that nanotechnology is an expensive area of research, Prof. Keely cited the DOD as a more appropriate place for him to send grant proposals because his work requires large investments;

> My work is very expensive- the area is extremely expensive. Just to give you an idea of how expensive it is-just to do an experiment in my lab costs about $500 a day. That is just the cost of the experiment, it is not the overhead that the university is going to charge on anything that I use, very simple my students need liquid nitrogen –they need two of those that is $400 and the university has an overhead that is 50% on supplies so you

> take half of that and add that. Now if I actually go ahead and make a device, I have to actually pay a fee to the clean room and that adds up. And this is atypical of what most professors do, in other words it doesn't cost that much for other professors.

Prof. Valcourt commenting on the overall diminution of "pure" research noted that academic labs are becoming research centers for industry and the federal government is encouraging more application based research.

Interviewees at the tech transfer office also commented on the duplication of infrastructure at the state level. Interest in promoting any new technology, for e.g., nanotechnology invariably means the creation of new programs. Across the state, there are several organizations which provide support to economic development activities. Organizations such as small business development centers, local development districts that run financing programs for businesses, local economic development organizations like the Chamber of Business and Industry all have their own infrastructure. Although the goals are the same, mass duplication of effort and infrastructure prevents the optimal leveraging of resources.

6.4.9.1 Key Findings/Working Propositions

Cultures at NIH and NSF are fundamentally different and affect the organization of research. Federal, state and industry funds have different value to the academic knowledge creation process and can be leveraged for optimal impact. The expectations and metrics of success for federally funded research are different from that of industry funded research. There is a mass duplication of facilities that are aimed at enabling tech transfer at the local and state level which creates redundancy in the process.

Proposition 12: The culture of the funding agency affects the organization and transfer of knowledge. Because nanotechnology is not rooted in a single discipline, it may mean that the transfer models in nanotechnology in the physical sciences are different from those in the life sciences.

This chapter has detailed the key findings from the interviews and the eight discrete themes that emerged from data. Differences and similarities between the two universities have been illustrated with examples. Working propositions grounded in study findings provide insight into the knowledge creation and technology transfer process in nanotechnology. The next chapter will detail the impact of these findings on the research questions.

Chapter 7

Discussion and Conclusions

The main objective of this study is to analyze knowledge creation and technology transfer in nanotechnology at research universities in the US. The previous chapters have discussed the importance of this study, the conceptual framework and research questions that frame this study, the methods used and the findings. This chapter discusses the findings in relation to each research question, and the implications of findings to policy and practice. Furthermore, it depicts the two paths through which academic nanoscale technologies are reaching the marketplace, the limitations of the study and future work.

7.1 Stratification of nanotechnology inputs and outputs

The first question that focused this study was:

1. To what extent is nanotech research and technological output in terms of funding, publications, and patents concentrated or disperse across research universities in the US? Does the pattern bear resemblance to that noted in biotechnology?

The analysis of ‘nano’ funding, patents, and publications across research universities shows that there are definite concentrations of activity. In the eleven-year period from 1994-2004, nanotech funding, patents, and publications have shown an impressive increase. The analysis of the data gathered in the study lead to three distinct conclusions. First, funding, patents and publications in nanotechnology are concentrated at a few universities indicating that regional innovation in nanotechnology could be skewed. A few universities are responsible for most of the publications, patents, and attract the most funding. The top twenty-five universities, in each ranking, account for more than 60% of the funding and publications and about 50% of the patents.

Second, the general pattern seems to favor the trend that universities that have high research expenditures overall and a strong patenting record also continue to do well at nanotech funding and patenting. However, some universities perform better with respect to nanotechnology funding, patents and publications when compared with their overall performance across other disciplines. Universities such as Cornell and Northwestern perform better on nanotech funding than their overall research expenditures ranking would warrant. UT-Austin and U Penn are better at nanotech patenting than their overall patenting performance rank as computed through AUTM data.

Third, the analysis shows that the public or private nature of the institution also plays a role in success. Although the volume of ‘nano’ publications, patents and funding is higher for public universities as a whole, on average, private universities are better at attracting funding and patenting and about the same on publications. The stable performers across all three dimensions are MIT, Cornell and Stanford.

The concentration of patterns in nanoscale funding, publications and patenting has important implications for regional patterns of innovation. Although the analysis of ‘nano’ funding, patents, and publications in this study was limited only to research universities, a comparison with the biotech industry highlights some interesting similarities. Cortright and Mayer (2002) find that the biotech industry is highly concentrated within nine metropolitan areas, with Boston and San Francisco being the top two areas. These nine areas account for more than 3/5ths of all NIH spending on research and about 2/3rds of all biotech patents. More than 3/4ths of all biotech firms with 100 or more employees that were founded in the 1990's are in one of the nine areas. An interesting point of note is that both San Francisco and Boston have three of the 20 top ranked medical institutions in the country. NIH funding levels can be thought of as a measure of research capacity. Funding is spread across research programs, but it goes disproportionately to areas with well established research infrastructures creating concentration of research.

Although this study did not focus on nanotech funding, patents and publications at the regional or Metropolitan Statistical Area (MSA) level, it is reasonable to conclude that the concentration of output noted at the university level will have an impact on the regional growth of nanotechnology.

7.2 Interdisciplinarity

The second research question that framed this analysis was:

2. How does interdisciplinarity, inherent in fields such as nanotechnology, affect the academic knowledge creation and transfer process? What structural dimensions does it take?

The study of nanoscale phenomena is inherently interdisciplinary; there is no unique research home for nanotech. Creating a device at the nanoscale, for example, requires the interfacing of differing expertise. Interdisciplinarity affects the process and structuring of the entire academic value chain in nanotechnology. It affects how knowledge is created and technologies are transferred.

The interfacing of disciplines creates opportunities and challenges in nanotech. Opportunities arise because new combinations of research arising from interdisciplinary expertise, lead to interesting discoveries which would otherwise not be conceivable. The challenges arise because interdisciplinarity, although valued, is not always rewarded within the academy. Limitations are imposed by disciplinary boundaries because researchers are trained within disciplinary paradigms. Faculty members need to share a common vision across disciplinary boundaries. It is also difficult to socialize graduate students who are studying at the nanoscale within a disciplinary structure, which poses barriers when they enter the academic job market.

Furthermore, interdisciplinarity poses issues to the structuring of the Technology Transfer Office. The TTO’s current structuring of work is deficient because nanotech spans several fields of expertise. The Technology Licensing Officers are generally versed in specific disciplinary technologies, and the interdisciplinary nature of nanoscale research poses challenges to the understanding and evaluation of technology. The application domain in nanotech is not well bounded, adding another layer of complexity. With regard to their overall patent portfolio, licensing officers at MPU estimate that about half of its patents arise from interdisciplinary research, and BSU notes a significant rise in interdisciplinary patent disclosures. Facilitation of interdisciplinarity, at all levels, from knowledge creation to tech transfer thus becomes a key issue for universities.

The knowledge creation process in nanotech is faced with several important issues. Nanotech is faced simultaneously with science and engineering problems. The science problem is that existing theories break down at the nanoscale and obstruct the march of normal science. New theories which fit phenomena at the nanoscale are continually being constructed. One of the engineering problems is to do with scalability of operations. This has a direct impact on how technologies are transferred; currently the technologies that are being licensed are those that have immediate acceptance to existing product lines. The technologies that need further development are placed in spin-offs.

Universities foster interdisciplinarity through the structuring of centers and institutes. At both MPU and BSU, new nanotech centers have been created to focus research agendas. Additionally, the movement to matrix structures helps place centers at the interstices between departments. Interdisciplinarity is also fostered through the competition for large scale federal grants which necessitate the involvement of large teams. Centers and institutes focusing specifically on nanotechnology do bring faculty with differing expertise together, but faculty buy-in is extremely important for the facilitation of interdisciplinarity. Culture plays a strong role in determining success in facilitating interdisciplinarity. At both universities, the collegial culture appears to play a strong role in fostering interdisciplinarity. Organic collaborations appear to be more successful than ones that are forced by organizations. The creation of centers and institutes are important, but not enough to promote interdisciplinary work. They provide administrative relief, but promoting synergy between team members remains a difficult exercise. The grand challenge in nanotech, as envisioned by the NNI, is not about using nanoscale science to make things smaller, but creating products that were not conceivable within disciplinary boundaries. The ability to share a common vision across disciplines is a necessary condition to successfully meet this challenge. Organizations can facilitate it through the creation of centers and institutes, but it is the institutional culture that sustains interdisciplinarity.

7.3 University Policies, Structure and Strategies

The third question of significance to this study was:

3. How do university policies, structure, and strategies influence knowledge creation, transfer and commercialization in nanotechnology?

This study revealed that university policies, culture, and strategies have a significant influence on knowledge creation, transfer, and commercialization in nanotechnology. University policies related to technology transfer and commercialization, across both the institutions under study, were isomorphic to a large extent. This isomorphism appears to be largely due to the interaction of normative and mimetic forces. To recall the arguments put forth by DiMaggio and Powell (1983), mimetic isomorphism in an organizational set occurs when organizations begin to look to other organizations that they deem to be successful. The people interviewed at each tech transfer office were candid about their limitations, and benchmarking with successful institutions was used as a standard operating procedure to effect beneficial change. Success in tech transfer, as judged by different metrics, is limited to a few universities which are widely scrutinized with regard to policies and other practices.

Normative isomorphic forces are also present due to the rise of the technology transfer function as a profession. The evolution of the tech transfer field at universities appears to be responsible for the growing similarities and decreased variation in policies. The only striking difference in policies across both universities was the revenue sharing policy at the private university. MPU has more liberal revenue sharing policies for their inventing faculty as compared to BSU. Most other policies were similar in design, but perceived differently on campus due to their prior success in tech transfer.

At the structural level, Lawrence and Lorsch (1967), the architects of contingency theory, believe that each organizational subunit should be structured so as to meet the demands of the environment to which it relates. The organization of the technology transfer offices is a case in point. At both institutions in this study, the offices were set apart geographically on campus, away from the central administration of the university. They were configured to be more hierarchical, more accessible to industry and with the built-in ability to approach external groups such as venture capitalists. However, this hierarchical and field-specific structuring of the tech transfer office creates issues when it comes to nanotech. The interdisciplinarity inherent in evaluating and marketing nanotechnologies makes it necessary for licensing officers to adopt interdisciplinary approaches in their work as well. The small size of the tech transfer office does alleviate some of these concerns because licensing officers can reach out to their colleagues. However, there is no one specific research home for these technologies, necessitating duplication of efforts at the marketing and licensing level.

This study also showed that the process of tech transfer and commercialization is affected significantly by the organizational structuring of work. The two self identified nanotech blockbuster patents at both universities emerged through industry-university centers and have found wide adoption in industry. However, the use of these patents was a condition of membership and therefore brought in no revenues to the universities. Based on this finding, there appears to be some evidence that suggests the path dependant nature of technology transfer. The organizational structuring of knowledge creation has the potential to affect the manner in which technology reaches the marketplace.

It is clear that universities based on their research dominance in certain areas are adopting nanotechnology into their strategic initiatives, and making it a focus area of interest. At BSU, for example, material science is a strong research area which lends itself readily to the area of nanomaterials, and this research expertise is being harnessed for showcasing their growing strengths in nanomaterials. The two universities in this study had fundamentally different strategic approaches towards the fostering of nanotech research. At BSU, the growth of nanotech research was part of its strategic plan, whereas for MPU, nanotech was only one of the promising new research areas of focus. However, certain common strategies to foster the growth of nanotechnology on campus included the hiring of ‘star’ professors with widely acknowledged research portfolios in nanoscale science. Placing ‘star’ faculty members at the helm of newly formed nanotech centers and institutes was also a common strategy across both universities. With regard to nanotechnology commercialization efforts in particular, both tech transfer offices indicated their presence at nanotechnology forums across the country to showcase their research strengths and growing patent portfolios.

The wide dispersion of nanotech across research areas also meant that facilities and instrumentation was spread across several labs at both universities. This problem was more apparent at BSU and rationalization efforts were under way to leverage the investments in these facilities. The tying together of these disparate facilities in nanotech across campus has resulted in a single network accessible to users at BSU. The potential to have duplication of costly nanoscale instrumentation on campus is a complicating factor in the organization of work at the nanoscale.

7.4 Organizational Culture

The fourth research question that focused this study was:

4. What effect does organizational culture have on the creation and transfer of knowledge at the nanoscale?

Organizational culture, which is easily perceived but hard to define, is a mediating influence on organizational goal-oriented activity. At MPU, faculty perceive research commercialization as a task valued by the university, whereas at BSU, most faculty interviewed feel that it is still placed at the periphery. At MPU, the perceptions are fueled by past successes and an interdisciplinary environment which is facilitated at the grassroots. At MPU, there is quicker diffusion of innovative strategy due to its smaller size as compared to BSU.

Another significant aspect at both universities was the culture prevalent at the tech transfer offices. MPU clearly had a local orientation to tech transfer due to its location and institutional history. The same factors played an important role in BSU’s global orientation to tech transfer. Additionally, the lack of a marketing culture at BSU across the university appears to have hampered the wide dispersion of technologies.

An additional cultural aspect affecting the creation and transfer of knowledge is related to the organization of research in the sciences and the culture of the funding agencies. The hierarchical structure noticed in the organization of research in the life sciences, and the more distributed structure prevalent in the physical sciences impacts the manner in which knowledge is created. This finding is important because nanotechnology is spread across several disciplines. The organization and transfer of nanotechnology in the physical sciences may be different from that of nanotechnology in the life sciences. This statement cannot be validated given that the interviewees in this study were physical scientists and engineers. However, this inference appears to be consistent with the wide disparity in the organization of work in these two spheres.

Additionally, the combination of physical and life sciences in nanobiotechnology has the ability to change the culture in physical science patenting. In this study, a physical scientist described the value of his invention with application in the life sciences, as having ‘tremendous value’, and explained the need to treat that invention differently from other inventions which may not accrue monetary value. The perceived value of technology in nanobiotech has the ability to change the ‘relational’ approach to patenting that physical scientists share, as described by Powell and Owen Smith (1998), to the more ‘proprietary’ approach that they attribute to life scientists.

7.5 Faculty Roles

The fifth and final question of importance to this study was:

5. What are faculty attitudes towards public science and proprietary for-profit science? How do faculty blend the role demands of public and private science?

Faculty across both institutions belonged to one of two groups of thought; those who believe firmly that tech transfer and research commercialization are part of their academic role, and others who believe that research commercialization is a peripheral role and takes away from their main focus. The normal routes of knowledge transfer, i.e, participation in industry-university centers and the role of patenting were valued by all faculty. Patenting was carried out due to one of two reasons; either the faculty member expected the invention to be of significant value, or patenting was a defensive gesture undertaken to prevent any future field-of-use issues. However, the creation of spin-offs was considered as the defining action that set them apart from their academic peers.

An interesting finding in this study was that all who are successful at their public science roles do not commercialize their research, but all who commercialize, i.e, are involved with a spin-off are successful at their public science roles. At BSU, the three faculty members who had commercialized their research hold 15% of the nanopublications identified from 1994-2004. Although citation measures may be more appropriate to judge the quality of these publications, it is apparent that these entrepreneurial faculty are productive in their public science roles. Faculty life cycle appears to play a key role in the decision to commercialize. All the faculty members in this study who have started companies were mid-to-late career professionals at the rank of Associate or Full Professor. The power vested through their public science credentials was leveraged to maximize their entrepreneurial efforts. Academic scientists who commercialize their research appear to successfully manage both the conflicting role demands of public and commercial science.

At MPU, commercialization activities are deeply entrenched, and creation of spin-offs in nanotech are following familiar routes. At BSU, in comparison, there is the presence of a network which values commercialization activities and is trying to move this function towards the center. This finding became apparent while interviewing faculty members researching at the nanoscale at BSU. References were made to other peer researchers in the university and to administrators who were trying to infuse cultural change at BSU. This ‘dominant coalition’ includes faculty members and key administrators who recognize that the culture at BSU has not valued research commercialization, and are seeking to change the status quo. In a manner, certain groups at BSU appear to be engaging in ‘sensemaking’ as postulated by Weick (1969). The process of organizing relates to a set of behaviors that have been learned collectively through the processes of “enactment, selection and retention”. In this manner faculty at BSU appear to be making sense of tech transfer activities collectively and moving the tech transfer process slowly from the periphery to the center.

This study found that faculty intentions and actions with regard to entrepreneurial behavior can be loosely coupled. Although entrepreneurial behavior may be prevalent among certain groups, a system wide effort to effect change is slow even with all relevant policies in place, due to loose coupling within the system. There are myriad power bases in a university setting and individual actors, i.e., faculty, have considerable control over their own domains. It appears that there is tighter coupling between members of a network, rather than as a whole organization. In effect, within-group variance tends to be smaller than between-group variance in terms of behavior.

7.6 Paths to the marketplace

Based on the findings in this case study, there appear to be two paths through which nanoscale academic technologies are transmitted to the marketplace. The two paths differ in the level of involvement, at each level of analysis, and also in their risk-reward scenario. The first path depicted in Figure **7.1** is a clear case of technologies being 'pulled' into the marketplace. These are first generation nanotechnologies such as coatings and sensors which have ready market acceptance. In such instances, the markets are well known, the application domain is well bounded and the lag time between the invention and industry wide-diffusion is shorter than in Path B. The reason for these shorter lag times is due to the organizing conditions of knowledge creation. Research generally conducted in industry-university centers, is on areas that are often industry defined. Technological roadblocks faced by industry are a common reference point of research. The use of patents created through the center is a privilege of membership for industry members. Often times, the patents are provided free of licensing fees to industry members at the highest level of membership. This leads to ready acceptance of such technologies because they provide solutions to existing problems faced by industry. Both the university and the faculty members involved in this exchange are faced with a low-risk/reward scenario. This interchange falls more under the realm of traditional knowledge transfer. At the environmental level, industry is highly involved in the problem definition and solution, whereas faculty and organizational involvement is moderate. For faculty, this is only a slight extension of their public science roles and does not involve any additional extrinsic rewards, although faculty consulting remains a possibility. This path represents a ‘business as usual’ model and represents one way in which nanoscale technologies are reaching the marketplace

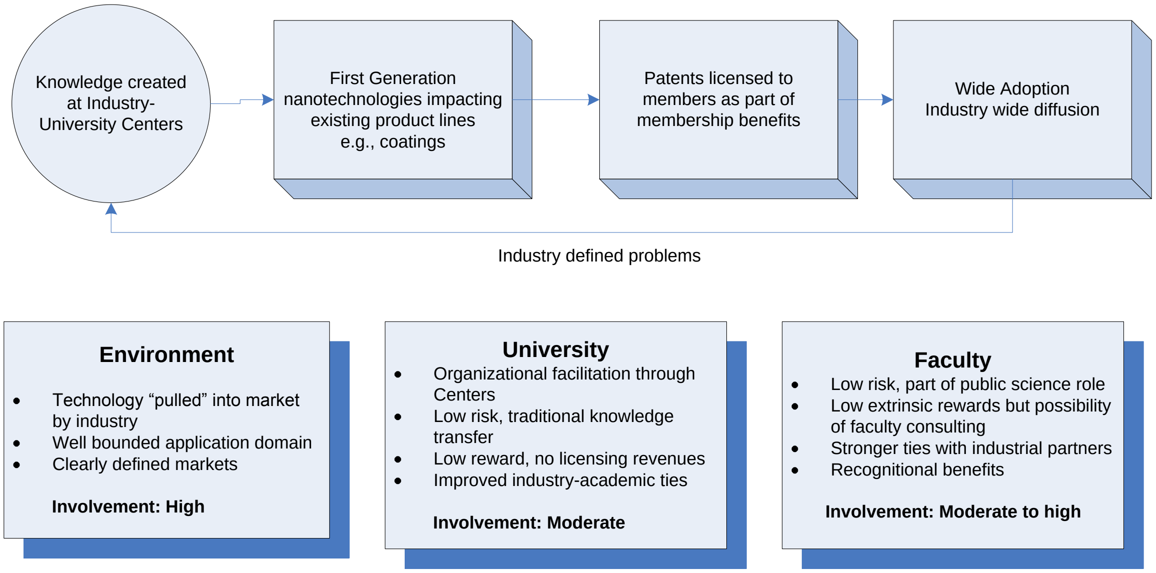

Figure **7.1**: Path A: ‘Problems finding solutions’

The second path to the marketplace is charted in Figure **7.2** . These are instances of technology being pushed into the marketplace, and are generally second generation nanoscale technologies, with high expected value and impact. These technologies are solutions seeking problems, because the application domain for these technologies is not well bounded, and the market segments are not clearly known. These technologies are mostly the result of faculty-driven research agendas and are only partly driven by industry concerns. If these technologies have moderate applicability to existing product lines, they are licensed to small companies who seek to further the invention and gain competitive advantage, with the hope of being acquired by a larger firm. Alternatively, they are licensed to large multinationals that are able to develop the invention in-house and tailor it to existing or near-term product lines. If there is no direct connection between the technology and existing product lines but there is high expected value the technologies are housed in faculty spin-off companies. The housing of these technologies with the inventor holding the tacit knowledge enables one of two things: first it allows the technology to be developed further and targeted towards a certain market and second it allows time for the technology to be scaled up. Faculty involvement in such instances is high, with a higher risk-reward scenario as compared to the first path. This scenario involves a leveraging of their public science roles and the consolidation of their power bases within and outside their organizations. University involvement is moderate to high based on their level of participation in the company. At the environmental level, industry is involved at the moderate to high level, based on their interest in the technologies and the ability to perceive its future potential.

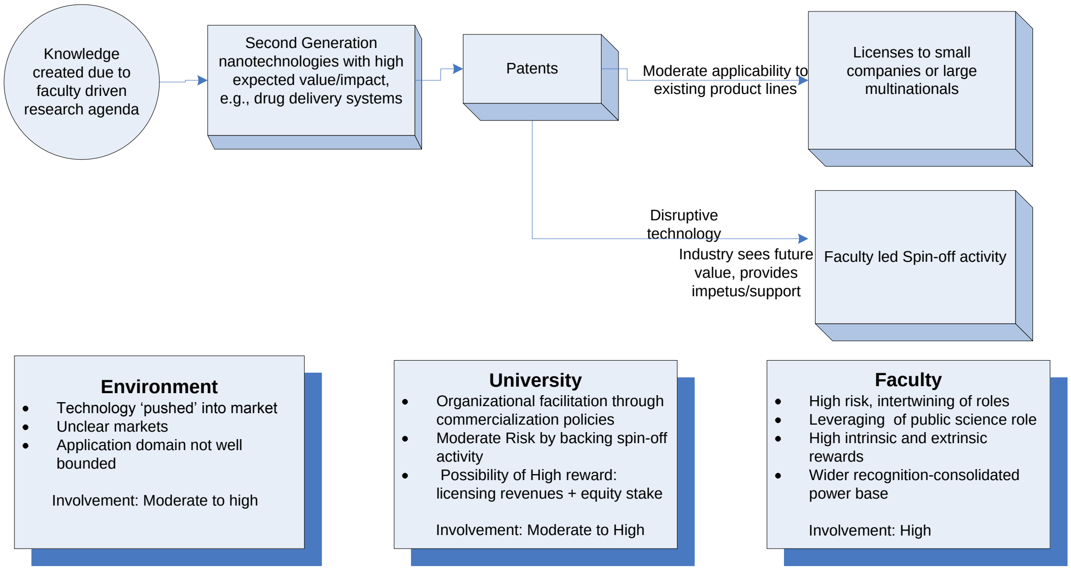

Figure **7.2**: Path B: 'Solutions Seeking Problems'

The two paths depicted here show considerable variation in their focus and the level of involvement at the environmental, organizational and individual level. The concepts of power allow in sketching a theory for faculty involved in tech transfer. Because they are the owners of tacit knowledge which is not substitutable, they become powerful entities with regard to those who seek these solutions, i.e. industry. The organization also stands to benefit through licensing agreements which bring revenue to the university. Because these boundary spanning faculty members gain resources/prestige, they consolidate their power bases within the university and are in a position to shape organizational policy. As expected, tacit knowledge invests the faculty member with a power base and protection from competition because generally there are no substitutes which can be accessed by an outside entity seeking to further the invention. Organizational, i.e., university survival does not rest on commercialization and therefore it is not a central task. However the faculty member's invention may be a necessary technology for an industrial segment, which increases the power of the faculty member in that relationship. One can hypothesize that if universities are not supportive, this whole interchange can be placed outside organizational purview in the form of faculty consulting agreements. Power is thus an important construct in analyzing knowledge creation and transfer.

7.7 Implications to Policy and Practice

This study raises important implications for policy and practice in higher education. The most important policy implication relates to the need for fostering interdisciplinarity in the academy. At the organizational level this implies the structures that facilitate interdisciplinary work and the institutionalization of rewards that are attached to such work. It is clear from the case studies that the interdisciplinarity inherent in nanotechnology affects the whole academic value chain from the training of students to the evaluation of technology at the tech transfer office. Organizational policies have to address the structuring and rewarding of interdisciplinary work. In addition, it is imperative to actively promote an organizational culture which supports such activity. The convergence of nanotech, biotech, infotech and cognitive sciences are expected to advance the frontiers of science and benefit mankind in incalculable ways in the first few decades of the 21st century (NSF, 2002). As technologies converge, disciplinary boundaries have to be increasingly permeable and the academy has to be more focused in terms of shaping faculty work and creating interdisciplinary curricula to prepare the next generation of workers. Faculty hiring policies in the age of interdisciplinarity have to be creative and look beyond disciplinary specifications.

Research, teaching and service are the three core activities on which faculty work is evaluated at research universities. Commercialization of academic research through the creation of spinoffs is becoming an important activity, which in most instances positively impacts the three core roles. Study findings indicate that entrepreneurial faculty members do not discount their public science roles. Instead, the entrepreneurial faculty in this study were prolific publishers and synergies between the roles were harnessed for maximum benefit. The debate in the academy is fast shifting from whether entrepreneurial academic science is detrimental to the current focus on the best ways to align it with more traditional academic roles. Spinoffs in nanotech need to be fostered because bottom-up nanotech research may yield disruptive technologies which need to be nurtured and organizational policy needs to facilitate such entrepreneurial activity. Tech transfer offices generally do not track the public science artifacts, i.e, publications authored by inventing faculty while evaluating inventions and this may be another area of practice that can be improved upon. Tracking of the publications and citations to these publications indicates the impact of faculty research and may indicate the potential and channels of commercial adoption of technology. This study found that leadership at the central administration and departmental level plays an important role in sending clear signals regarding the value of entrepreneurial work across the community. Faculty life cycle has an impact on entrepreneurial behavior and promotion and tenure policies need to value entrepreneurial activity and therefore actively change the manner in which newer faculty approach commercialization.

This study found that a few research universities hold a significant number of patents and publications in nanotechnology. These universities are positioned to lead regional innovation efforts in nanotechnology. State economic development policies have an important role to play in this effort and organizational strategy to leverage monies and effort can play a significant role in unlocking the potential of academic research at the nanoscale. Alignment and rationalization of instrumentation and facilities is important not just at the university but regional level as well to prevent duplication of costly instrumentation.

7.8 Limitations and Future work

The chief limitation of this study is that life scientists practicing at the nanoscale were not part of this study. Both the universities which make up the cases for this study, had research dominance in the physical sciences. Selection of faculty members at the nanoscale thus consisted predominantly of physical scientists and engineers. The life scientists that were identified as working at the nanoscale and approached to participate in this study either declined or did nor respond to the call for participation. This limitation prevents the characterization of a holistic model of nanotechnology research and commercialization.

An additional limitation is that the database of universities is structured with the use of the search string ‘nano*’. While this search strategy is reasonable, on further examination and validation of results with tech transfer professionals, it appears that a more targeted keyword based strategy would result in refined results and aid in the creation of input-output models. The data on nanofunding is restricted to NSF grants and the addition of grants from DOD, DOE and other mission agencies may change the composition of the nanofunding university ranking. At an operational level, this study raises interesting issues for institutional researchers. It is challenging to come up with quantifiable metrics to understand interdisciplinary fields of study. For example, analysis of the research universities in this dataset by size was not possible because it was difficult to isolate the number of faculty members practicing at the nanoscale without additional administrative input from each university. As more interdisciplinary fields emerge, the ability to measure key metrics through secondary data sources becomes increasingly limited.

A third limitation of this study is to do with generalizability of research results. Although the findings cannot be generalized to other university settings, the two path models can be tested in other case conditions.

Future work could include a testing of these paths in the life sciences, resulting in a more complete picture of nanotechnology research and commercialization. An interesting question that remains at the conclusion of this study is whether knowledge creation and transfer in nanotechnology in the life sciences follows a similar path to that noted in the physical sciences. Nanotechnology is not housed in one discipline and transfer paths may not be similar across the different cultures of life and physical science. Future work could also emphasize a deeper quantitative analysis of nanotechnology outputs, including spin-off activity at research universities. This would aid in the creation of decision support tools, based on these quantitative models, which would aid organizational decision making. In this particular work, the emphasis was on the interaction of environmental, organizational and individual level variables on knowledge creation and transfer and could serve as the starting point for tracing regional innovation activities in nanotechnology.

7.9 Conclusion

In conclusion, the dialog with faculty members practicing at the nanoscale makes it clear that the public and commercial realms of science are closely intertwined in nanotechnology, and it is proving to be a fertile ground for the creation of academic spin-offs. Nanoscale science has the potential to severely disrupt existing technologies, and create new markets thus changing the production landscape. The processes of knowledge creation and transfer are closely linked, and need to be understood for the organizational facilitation of these processes. In each organization, there is a general systemic understanding of tasks at the center and tasks at the periphery, and tech transfer has often been placed at the periphery in the academy. These forces are changing due to environmental pressures, and the shifting dynamics of power related with commercialization activities. The intertwining of public and commercial science, are consolidating power bases among faculty whose reputational prestige already grants them power in the academy. Power accrues to the inventing scientist due to tacit knowledge, and reputational prestige wrought by public science credentials such as publications. Tech transfer is not a central organizational goal but if commercialization becomes part of the value structure shared by the dominant coalition, the process and power bases move it to the center. Although mimetic and normative isomorphic pressures are moving universities to similar policies, their tech transfer outputs need not be similar.

Change in any organization can be initiated through the skilful use of power bases and this may be happening serendipitously in universities because they are loosely coupled organizations. Organizations can influence knowledge creation and tech transfer only to a certain extent, because the power of rewards or coercion on faculty members is increasingly limited as they go higher in the faculty life cycle. Professors, who commercialize their research are boundary spanners and according to Scott (1998), power accrues to people who are boundary spanners because they are the mediating influence with resources.

The basic tenets and organizing conditions of public science which deals with open knowledge, and commercial science which deals with patenting and commercialization are different. The increasing intertwining of these two realms as is apparent in nanotechnology has important implications as discussed in this section for the organization of knowledge creation and transfer at research universities. Two opposite forces are prevalent in the academy; those that seek change and those that seek to maintain system stability and the challenge is to successfully manage the conflict between the two forces.

Bibliography

Allen, D. N. & Norling, F. (1991). Exploring Perceived Threats in Faculty Commercialization of Research. In A.M. Brett, D.V. Gibson & R.W. Smilor (eds.). *University Spin-off Companies: Economic Development, Faculty Entrepreneurs, and Technology Transfer.* Rowman & Littlefield Publishers, Inc.

Audretsch, D.B. (1995). *Innovation and industry evolution.* Cambridge, MA: MIT press.

Audretsch, D.B., & Feldman, M.P. (1996). R&D spillovers and the geography of innovation and production. *American Economic Review, 86(3),* 630-640.

AUTM (2004). *AUTM Licensing Survey : FY 2004.* Association of University Technology Managers. Norwalk, CT.

Baldridge, J. V. (1971). *Power and Conflict in the University*. NY: John Wiley.

Baldridge, J.V, Curtis, D.V., Ecker, G., & Riley, G. (1977). *Governing Academic Organizations*, McCutchan Publishing.

Bercovitz, J., & Feldman M., (2006). Entrepreneurial universities and technology transfer: A conceptual framework for understanding knowledge-based economic development. *Journal of Technology Transfer, 31*, 175-188.

Bercovitz, J., Feldman, M., Feller I. & Burton, R. (2001). Organizational structure as a determinant of academic patent and licensing behavior: An exploratory study of Duke, Johns Hopkins, and Pennsylvania state universities. *Journal of Technology Transfer, 26:*21-35

BHEF (2001). *Working together, creating knowledge*. Business-Higher Education Forum.

Blumenthal D., Causino N., Campbell E. & Louis K.S. (1996). Relationships between academic institutions and Industry in the Life sciences-An industry survey. *Journal of Medicine, 33,* 368-374.

Boulding, K.E. (1956). General Systems Theory: The Skeleton of Science. *Management Science, 2*, 197-208.

Bradshaw, P., & Boonstra, J. (2004). Power dynamics in organizational change: A multiperspective approach. *Organizational change and learning*. 279-300, John Wiley.

Brett, A.B., Gibson, D. V., & Smilor, R. W. (1991). *University Spin-off Companies: Economic Development, Faculty Entrepreneurs, and Technology Transfer* Rowman & Littlefield Publishers.

Brouwer, M. (2005). Entrepreneurship and university Licensing. *Journal of technology transfer, 30,* 263-270

Buckely, W. (1967). *Sociology and Modern systems theory*. Englewood Cliffs, NJ: Prentice Hall.

Cameron, K.S. (1989). Organizational adaptation and Higher education. *Journal of Higher Education, 55*, April/May.

Cantlon, J.E, and Koenig, H. E. (1991). Global Economic Competitiveness and the Land Grant university. In A.M. Brett, D.V. Gibson & R.W. Smilor (eds.). *University Spin-off Companies: Economic Development, Faculty Entrepreneurs, and Technology Transfer.* Rowman & Littlefield Publishers, Inc.

Carnegie Classification. (2000). *Carnegie Classification of Institutes of Higher Education, 2000 edition*, 5th revision, 2004

Clark, B.R. (1995). *Places of Inquiry: Research and Advanced education in Modern Universities.* Los Angeles: University of California Press.

Cohen, M.D. & March, J.G., (1974). *Leadership and Ambiguity: The American College President*. McGraw Hill, New York.

Cohen, W.M., Florida, R., Randazzese, L., & Walsh J. (1998). Industry and the academy: Uneasy partners in the cause of technological advance. In R.G. Noll (ed.)

Challenges to research universities, Brookings Institution Press, Washington, D.C.

Cortright J. & Mayer H. (2002). *Signs of life: The growth of biotechnology centers in the U.S.* The Brookings Institution Center on Urban and Metropolitian policy.

Cyert, R.M. & March, J.G. (1963). *A behavioral theory of the firm*. Englewood Cliffs, NJ, Prentice Hall

Daft R.L. & Noe, R.A. (2001). *Organizational behavior*. Harcourt College Publishers, 1st edition.

David, P.A, Mowery, D.C. & Steinmuller, W.E. (1994). Analyzing the economic payoffs from basic research. In D.C. Mowery (ed.). *Science and technology policy in Interdependent economies*, 57-78, Kluwer: Boston

Diamond, A. M. (1984). An economic model of the life-cycle Research productivity of Scientists, *Scientometric, 6 (3),* 189-96.

DiGregorio, D. & Shane, S., (2003). Why do some universities generate more start-ups than others?, *Research Policy, 32 (2),* 209-27.

DiMaggio, P.J. & Powell, W. W. (1983). The Iron Cage revisited: Institutional Isomorphism and Collective rationality in organizational fields. *American Sociological Review, 48,* 147-60.

Eisenhardt, K.M. (1989). Building theories from case study research. Academy of Management Review, 14(4), 532-550.

Emerson, R.M., (1962). Power Dependence Relations. *American Sociological Review, 27,* 31-40.

Etzknowitz, H. & Leydesdorff, L. (1997). *Universities and the Global knowledge economy*. Herndon, VA: Pinter

Etzkowitz, H., Schuler E., & Gulbrandsen M. (2000). The evolution of the entrepreneurial university. In Jacob, M. & T. Hellstorm (eds.) *The future of knowledge production in the academy*, 40-60. The Society of Research into Higher Education.

Fairweather, J. S. (1993). Academic values and faculty rewards. The *Review of Higher Education, 17 (1),* pp. 43-68, 1993.

Feldman, M.P., Feller, I., Bercovitz, J.E.L. & Burton, R.M., (2001). Understanding evolving University-Industry relationships. In M.P. Feldman & A.N. Link (eds.) *Innovation policy in the knowledge-based economy*, 171-188, Kluwer, MA

Feldman, M. P. & Massard, N. (2002). Location, Location, Location. In Feldman M.P., and Massard, N (eds.) *Institutions and Systems in the geography of Innovation,*.1-20, Kluwer, MA.

Feldman, M.P., Feller, I., Bercovitz, J.E.L., & Burton, R.M. (2002a). University Technology Transfer and the System of Innovation. In M. P. Feldman & Massard, N (eds.) *Institutions and Systems in the geography of Innovation*, 55-77, Kluwer, MA.

Feldman, M., Feller, I., Bercovitz, J. & Burton, R. (2002b). Equity and the Technology Transfer strategies of American research Universities. *Management Science, 48(1),* 105-121.

Feldman, M. P., Link A.N., & Siegel, D.S. (2002c). *The economics of Science and Technology, An overview of Initiatives to foster innovation, entrepreneurship and economic growth.* Springer.

Feller, I. (1990). Universities as Engines of R&D based economic growth: They think they can. *Research Policy, 19,* 335-348

Feller, I. (1997). Technology Transfer from Universities. In J.C. Smart (ed.) *Higher Education: Handbook of Theory and Research*, Vol. XII, 1-42.

Finkelstein, S. (1992). Power in top management teams: Dimension, measurement and validation, *The Academy of Management Journal*, 35, 3

Forman, D. (2006). Nano's all dressed up with nowhere to go, Small Times, Retrieved March 29, 2006 from http://www.smalltimes.com/articles/article_display.cfm?Article_ID=251963&p=109

French, J. R.P., & Raven, B. (1959). Bases of social power, In D.P. Cartwright (ed.). *Studies in Social Power*. 150-167, University of Michigan, Ann Arbor

Geiger, R. L. (1990). Organized Research Units – Their Role in the Development of University Research. *Journal of Higher Education*, 61(1), 1-19.

Geiger, R.L. (2004). Knowledge and Money: Research Universities and the paradox of the marketplace, Stanford University Press

Geiger, R.L., Hallacher, P., Harper B., Prabhu, R., & Sa, C, (2005). Nanotechnology and the States, Public Policy, University research and economic development in Pennsylvania, a report to the National Science Foundation, Grant #0403783

Gibbons, M. & Gummett, P. (1984). *Science, Technology and Society Today.* Manchester University Press.

Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P. & Trow, M., (1994). *The New Production of Knowledge*. Sage Publications.

Gibson, D. V. & Smilor, R. W., 1991. The Role of the Research University in Creating and Sustaining the U.S. Technopolis, in , A.B., Gibson, D. V., and Smilor, R. W (eds.) *University Spin-off Companies: Economic Development, Faculty Entrepreneurs, and Technology Transfer.* Rowman & Littlefield Publishers, Inc.

Hackman, J. D. (1985). Power and Centrality in the allocation of resources in colleges and universities. *Administrative Science Quarterly* 30 (1).

Haksson, A.G. (1998). *The commercialization of university research discoveries: Are university technology transfer offices stimulating the process?* Ph.D. Dissertation, MIT.

Hall, P. (1997). The university and the city. *GeoJournal 41.4:* 301-309, Kluwer Academic Publishers, Netherlands.

Henderson, R., Jaffe, A.B. & Trajtenberg, M. (1995). *Universities as a Source of Commercial Technology: A Detailed Analysis of University Patenting 1965-1988,* NBER, Inc.

Henrekson, M. & Rosenberg N. (2001). Designing efficient Institutions for Science-based entrepreneurship: Lessons from the US and Sweden. *Journal of Technology Transfer, 26,* 207-231

Huang Z., Chen, H., Chen Z.K. & Roco M. (2004). International development in 2003: Country, Institution and Technology Field analysis based on USPTO patent database. *Journal of Nanoparticle Research, 6:*325-354

Jacob, A. (2000). Mode 2 in context: The contract researcher, the university and the knowledge society" In Jacob, M. and T. Hellstorm (eds.). *Thefuture of knowledge production in the academy,* The Society of Research into Higher Education.

Jacobi, P.T. (2001). *A comparison of faculty perceptions of university technology transfer by level of institutional success in the technology transfer process*. Ph. D. Dissertation, Louisiana State University and Agricultural and Mechanical College.

Jaffe A., Tratjenberg M. & Hederson R. (1993). Geographic localization of knowledge spillovers as evidenced by patent citations, *Quarterly Journal of Economics*

Jensen, R. & Thursby, M. (1998). *Proofs and Prototypes for Sale: The Tale of University Licensing*, NBER Inc.

Johansson, M., Jacob, M. & Hellstrom, T. (2005) The strength of strong ties: University spin-offs and the significance of historical relations, *Journal of technology transfer*, *30*, 271-286

Johnson, L.G. (1984). *The high-technology connection: academic/industrial cooperation for economic growth*, ASHE-ERIC Higher Education Research Reports.

Kuhn, T. (1996). *The structure of Scientific Revolutions*, 3rd edition, University of Chicago Press

Kuhns, B.A. (1999) *Technology transfer Performance: The impact of entrepreneurial responses to institutional and commercial pressures in the United States universities.* Ph.D. Dissertation, University of Houston.

Lattuca L.R. (2001). *Creating Interdisciplinarity: Interdisciplinary Research and Teaching among College and University faculty*, Vanderbilt University Press.

Lawrence, P.R. & Lorsch, J.W. (1967). *Organization and Environment: Managing Differentiation and Integration*, Harvard, Cambridge, MA.

Levin, S.G. & Stephan P.E. (1991). Research productivity over the life cycle: Evidence for Academic Scientists. *American Economic Review*, *81(1)*, 114-132

Lowe, R. (2002). Invention, Innovation and Entrepreneurship: The commercialization of University Research by Inventor-Founded Firms. Ph.D. Disseratation, University of California, Berkeley.

March, J.G. & Olsen, J.P. (1976). *Ambiguity and Choice in Organizations*. Bergen, Norway: Universitetsforlaget

Matkin, G. (1990). *Technology Transfer and the University.* Macmillan Publishing Company.

McSherry, C. (2001). *Who owns academic work?,* Harvard University Press, Cambridge, MA.

Mintzberg, H. (1979). *The Structuring of Organizations*, Prentice Hall Inc.

Mowery D.C. (1994). *Science and Technology Policy in Interdependent Economies*, Kluwer, MA

Mowery, D. C., & Rosenberg, N. (1998). *Paths of Innovation, technological change in 20th century America*. Cambridge University Press

Mowery, D.C., & Ziedonis A.A. (2001). *The geographic reach of market and non-market channels of technology transfer: Comparing citations and licenses of university patents*, NBER, Working paper 8568

National Science Board. (2006). *Science and Engineering Indicators 2006*. Arlington, VA: National Science Foundation (volume 1, NSB 06-01; volume 2, NSB 06-01A).

Nelson, S.D. (1981). *Knowledge Creation: An overview*. In Rich, R.F., (ed), The Knowledge Cycle, Sage Publications, CA

Neumann, Y. & Finaly-Neumann E. (1990) The Reward-Support Framework and faculty commitment to their university, Research in Higher Education, 31(1), 75-97,

NSF (2002). *Converging Technologies for Improving Human performance, Nanotechnology, Biotechnology, Information technology and Cognitive Science*. Roco, C.M., and Bainbridge W.S., (eds.). NSF/DOC Sponsored report, Arlington, VA.

NSF (2003). *Nanotechnology: Societal Implications-Maximizing Benefit for Humanity*, Roco, C.M., and Bainbridge W.S., (eds.), Arlington, VA.

NSF (2006). *Academic Research and Development Expenditures: Fiscal Year 200.*, NSF 06-323, Division of Science Resource Statistics, Ronda Britt, Project officer., Arlington, VA.

NSTC (2002). *National Nanotechnology Initiative: The initiative and its implementation plan.* National Science and technology Council, Committee on Technology, Washington D.C

Owen-Smith, J. & Powell W. (2001). To patent or not: Faculty Decisions and Institutional success at Technology transfer, *Journal of Technology Transfer, 26,* 99-114.

Owen-Smith, J. (2000). *Public Science, Private Science: The Causes and Consequences of Patenting by Research One Universities.* Ph.D. Dissertation, University of Arizona.

Paisley, W.J. (1968). Information needs and uses, *Annual Review of information Science and Technology, 3,* 1-30.

Pfeffer ,J. & Salancik, G. R. (1974). Organizational decision making as a political Process: The case of a university budget. *Administrative Science Quarterly,* 19(2), 135-151

Powell, W. & Owen-Smith J. (1998). Universities and the market for intellectual property in the life sciences. *Journal of Policy Analysis and Management*, *17, 2*, 253-77.

Powell, W. W., Koput, K. W., & Smith-Doerr L. (1996) Interorganizational Collobaration and the locus of innovation: Networks of learning in biotechnology. *Administrative Science Quarterly*, *41,* 116-145.

Powers, J.B. (2000). *Academic entrepreneurship in higher education: Institutional effects on performance of university technology transfer*, Ph.D. Dissertation, Indiana University.

Rhoades, G. & Slaughter, S. (1991). Professors, Administrators and Patents: The negotiation of technology transfer. *Sociology of Education, 64, 2*, 65-77.

Rich, R.F. (1981). *The Knowledge cycle.* Sage Publications, CA.

Rip, A. (2000) Fashions, Lock-ins and the heterogeneity of knowledge production" In Jacob, M. and T. Hellstorm (eds.). *The future of knowledge production in the academy*, pp. 28-39, The Society of Research into Higher Education.

Rosenberg, N. & Nelson, R. R. (1994). American universities and technical advances in industry. *Research Policy*, 23, 323-348.

Salancik, G.R., & Pfeffer, J. (1974). The bases and use of power in organizational decision making: The case of a university. *Administrative Science Quarterly*, 19, 4, 453-473.

Scott, W.R. (1998). Organizations: Rational, Natural and Open Systems, 4th ed, Prentice Hall, New Jersey.

Shane, S. (2004). *Academic Entrepreneurship: University Spinoffs and Wealth Creation*, Edward Elgar Publishing Inc., MA

Slaughter, S. & Leslie, L.L., (1997). *Academic capitalism*, The Johns Hopkins University Press.

Slaughter, S. & Rhoades G. (2004). *Academic capitalism and the new economy, Markets, State and Higher Education*, The Johns Hopkins University Press.

Stephan, P & Levin, S. (1996). Property rights and entrepreneurship in Science, *Small Business Economics, 8*, 177-88

Strasler, S. M. (1998). Faculty views and attitudes about technology transfer, Ph.D. Dissertation, University of Michigan.

Thompson, J.D. (1967). *Organizations in Action*, McGraw-Hill, NY

Weick, K. E. (1976). Educational institutions as loosely coupled systems. *Administrative Science Quarterly*, 26(1).

Weick, K.E., (1969). *The Social Psychology of Organizing*, Addison- Wesley Reading, MA.

Yin, R.K. (2003). *Case Study Research: Design and Methods*, 3rd edition, Sage Publications.

Ziedonis, A.A. (2001). *The commercialization of university technology: Implications for firm strategy and public policy*. Ph.D. Dissertation, UC Berkeley.

Ziman, J. (1996). Postacademic Science: constructing knowledge with networks and norms. *Science Studies, 9 (1),* 67-80

Zucker, L. G., Darby, M. R., & Armstrong, J. S. (2001). *Commercializing Knowledge: University Science, Knowledge Capture, and Firm Performance in Biotechnology,* NBER, Inc.

Zucker, L. G., & Darby, M. R. (2005). *Socio-economic Impact of Nanoscale science: Initial results and Nanobank.* NBER, Working paper 11181

Appendix A

List of Research universities included in the database

Public Universities

Arizona State University
Clemson University
Colorado State University
Florida State University
Georgia Tech
Indiana University
Iowa State University
Kansas State University
Louisiana State University
Michigan State University
Mississippi State University
New Mexico State University
North Carolina State University
Ohio State University
Ohio University
Oklahoma State University
Oregon State University
Pennsylvania State Univ
Purdue University
Rutgers University New Brunswick
SUNY at Buffalo
SUNY at Stony Brook
Temple University
Texas A&M
Texas Tech University
University of Alabama Birmingham
University of Arizona
University of Arkansas
UC-Berkeley
UC-Davis
UC-Irvine
UCLA
UC-Riverside
UC-San Diego
UC-Santa Barbara
UC-Santa Cruz
University of Cincinnati
University of Colorado at Boulder
University of Connecticut
University of Delaware
University of Florida
University of Georgia
University of Houston
University of Idaho
U Illinois at Urbana-Champaign
University of Iowa
University of Kansas
University of Kentucky
University of Louisville
University of Maryland College Park
University of Massachusetts Amherst
University of Michigan Ann Arbor
University of Minnesota-Twin Cities
University of Missouri-Columbia
University of Nebraska-Lincoln
University of New Mexico
UNC Chapel Hill
University of Oklahoma Norman
University of Oregon Eugene
University of Pittsburgh
University of Rhode Island
University of South Carolina Columbia
University of South Florida
University of Tennessee Knoxville
University of Texas at Austin
University of Utah
University of Vermont
University of Virginia Main Campus
University of Washington
University of Wisconsin-Madison
Utah State University
Virginia Commonwealth University
Virginia Polytechnic
Washington State University
Wayne State University
West Virgina University

Private Universities
Boston University
Brown University
California Institute of Technology
Carnegie-Mellon University
Case Western Reserve University
Columbia University
Cornell University - Endowed
Duke University
Emory University
George Washington University
Georgetown University
Harvard University
Howard University
Johns Hopkins University
Lehigh University
MIT
New York University
Northeastern University
Northwestern University
Princeton University
Rensselaer Polytechnic Institute
Stanford University
Syracuse University
Tufts University
Tulane University
University of Chicago
University of Miami
University of Notre Dame
University of Pennsylvania
University of Rochester
University of Southern California
Vanderbilt University
Washington University
William Marsh Rice University
Yale University

Appendix B

List of Tier1, Tier 2 and Tier 3 Universities -‘Nanofunding’

Tier 1 (1 std dev above the mean)
Cornell University
MIT
UW-Madison
Stanford
Northwestern
U Illinois at UC
Harvard
UC Berkeley
UCLA
Penn State Univ

Tier 2 (Between the mean and 1 std dev)
U Maryland College Park
University of Pennsylvania
Caltech
Princeton
University of Texas at Austin
UC-Santa Barbara
University of Minnesota
University of Kentucky
Johns Hopkins University
Rice
Arizona State University
U Michigan Ann Arbor
Brown University
Columbia University
Carnegie-Mellon University
University of Florida
Georgia Tech
UC-Davis
North Carolina State
University of North Carolina
University of Chicago
U Nebraska-Lincoln
Ohio State University
University of Washington
Oklahoma State University
University of Virginia

Tier 3(Below the mean)

University of New Mexico
University of California-San Diego
Duke University
Rensselaer Polytechnic Institute
University of Massachusetts Amherst
Washington University
Purdue University
Michigan State University
University of Utah
University of Notre Dame
SUNY at Stony Brook
University of Idaho
University of Southern California
University of Arkansas
University of California-Irvine
University of Delaware
Iowa State University
University of South Carolina Columbia
SUNY at Buffalo
Rutgers University New Brunswick
University of Rochester
Lehigh University
University of Tennessee Knoxville
University of Oregon Eugene
University of Pittsburgh
University of Arizona
University of Oklahoma Norman
Colorado State University
University of Colorado at Boulder
Vanderbilt University
Florida State University
Virginia Polytechnic
Texas A&M Research Foundation
Boston University
Yale University
University of South Florida
New York University
University of Vermont
University of Connecticut
University of Cincinnati
Mississippi State University
Clemson University
Louisiana State University
Wayne State University
Case Western Reserve University
Indiana University
University of California-Riverside
Kansas State University
Texas Tech University
West Virginia University
Washington State University
Ohio University
University of Missouri-Columbia
Northeastern University
Oregon State University
University of Houston
Tufts University
Virginia Commonwealth University
Tulane University
University of California-Santa Cruz
University of Alabama Birmingham
University of Louisville
University of Rhode Island
Georgetown University
University of Kansas
University of Georgia
Syracuse University
University of Iowa
University of Miami
Emory University
George Washington University
Howard University
New Mexico State University
Utah State University
Temple University

Appendix C

List of Tier1, Tier 2 and Tier 3 Universities - AUTM Research Expenditures

Tier 1
Johns Hopkins University
MIT
UIllinois UC/Chicago
University of Washington
U Michigan Ann Arbor
U Wisconsin-Madison
University of Pennsylvania
Stanford University
SUNY
Harvard University
Pennsylvania State Univ
U Colorado at Boulder
University of Minnesota

Tier 2
Cornell
Texas A&M
University of Pittsburgh
Washington University
Duke
University of Arizona
North Carolina State
Columbia
University of Florida
University of Southern California
Caltech
Ohio State University
Georgia Tech
University of Texas at Austin
University of Alabama at Birmingham
Purdue University
University of Maryland College Park
Northwestern
Michigan State
Indiana University
University of Georgia
University of Iowa
U of North Carolina Chapel Hill
University of Massachusetts
Emory

Tier 3

University of Utah
University of Missouri-Columbia
Vanderbilt University
Boston University
University of Virginia
University of Chicago
University of Miami
Virginia Polytechnic
Rutgers University,
Case Western Reserve University
Iowa State University
University of South Florida
Wayne State University
New York University
University of Kansas
University of Tennessee Knoxville
University of Rochester
Carnegie-Mellon University
Colorado State University
Florida State University
Mississippi State University
University of New Mexico
University of Nebraska-Lincoln
Oregon State University
Clemson University
University of Connecticut
Washington State University
Utah State University
University of Kentucky
Georgetown University
University of Cincinnati
Princeton University
Brown University
Tufts University
Temple University
U South Carolina at Columbia
Tulane University
University of Oklahoma
Virginia Commonwealth University
Oklahoma State University
University of Louisville
University of Vermont
Texas Tech University
University of Delaware
University of Arkansas
Arizona State University
New Mexico State University
University of Oregon Eugene
Kansas State University
University of Idaho
University of Houston
University of Rhode Island
Louisiana State University
University of Notre Dame
William Marsh Rice University
Rensselaer Polytechnic Institute
Northeastern University
Ohio University

Appendix D

List of Tier1, Tier 2 and Tier 3 Universities - Nanopublications

Tier 1 (1 std dev above the mean)
University of California-Berkeley
MIT
U Illinois at Urbana-Champaign
Penn State Univ
Georgia Tech
Northwestern University
Harvard University
UC-Santa Barbara
Cornell University - Endowed
U Michigan Ann Arbor
California Institute of Technology
North Carolina State University
University of Texas at Austin
University of Minnesota
Stanford University

Tier 2(Between the mean and 1 std dev)
University of California-Los Angeles
University of Wisconsin-Madison
Arizona State University
William Marsh Rice University
University of Florida
Rensselaer Polytechnic Institute
University of Washington
Johns Hopkins University
Ohio State
University of California-Davis
Purdue University
University of Pennsylvania
University of California-San Diego
UNC-Chapel Hill
University of Delaware
Princeton University
University of Kentucky
University of Maryland College Park
Carnegie-Mellon University
University of Notre Dame
University of Tennessee Knoxville
Iowa State University
University of California-Irvine
Texas A&M Research Foundation
University of Southern California
SUNY at Stony Brook
University of Connecticut
Michigan State University
University of Nebraska-Lincoln
University of Virginia Main Campus

Tier 3(Below the mean)

University of Pittsburgh
Clemson University
University of Rochester
Washington University
Duke University
Columbia University
Vanderbilt University
U Massachusetts Amherst
Yale University
University of Utah
University of Arizona
University of Colorado at Boulder
University of New Mexico
University of Cincinnati
University of Chicago
U South Carolina Columbia
Case Western Reserve University
University of California-Riverside
University of Houston
Kansas State University
Florida State University
SUNY at Buffalo
Louisiana State University
Brown University
Washington State University
Colorado State University
Virginia Commonwealth U
Oklahoma State University
Indiana University
University of Georgia
U Alabama at Birmingham
New York University
Boston University
Wayne State University
Lehigh University
UC-Santa Cruz
Tulane University
New Mexico State University
Emory University
University of Arkansas
Georgetown University
Northeastern University
University of Idaho
University of Iowa
University of South Florida
Tufts University
University of Miami
Oregon State University
Texas Tech University
University of Missouri-Columbia
University of Oregon Eugene
George Washington University
University of Louisville
Temple University
University of Oklahoma Norman
West Virginia University
University of Kansas
University of Rhode Island
Ohio University
Howard University
Virginia Polytechnic
Syracuse University
Utah State University
Rutgers New Brunswick
Mississippi State University
University of Vermont

Appendix E

List of Tier1, Tier 2 and Tier 3 Universities - Nanopatents

Tier 1(1 Std dev above the mean)
MIT
University of Texas at Austin
Caltech
Johns Hopkins University
UMichigan Ann Arbor
Cornell University
Stanford University
UW-Madison
University of Pennsylvania

Tier 2 (Between the mean and 1 std dev)
Harvard University
University of Minnesota-Twin Cities
U North Carolina at Chapel Hill
University of Utah
North Carolina State University
Pennsylvania State Univ
University of Washington
Northwestern University
Brown University
Duke University
University of Chicago
University of Pittsburgh
Yale University
Michigan State University
U of Illinois at Urbana-Champaign
Columbia University
Georgia Tech
University of Southern California
Princeton University
Iowa State University
University of Florida
University of Iowa
Texas A&M Research Foundation
Washington University

Tier 3(Below the mean)

University of South Florida
New York University
University of Nebraska-Lincoln
University of Kentucky
Boston University
Ohio State University
U Massachusetts Amherst
University of Virginia
Vanderbilt University
Case Western Reserve
Louisiana State University
Carnegie-Mellon University
William Marsh Rice University
U Colorado at Boulder
University of Rochester
U Tennessee Knoxville
Northeastern University
Virginia Commonwealth
Virginia Polytechnic
University of Connecticut
University of New Mexico
Wayne State University
Colorado State University
U Alabama at Birmingham
University of Houston
Purdue University
Rutgers University
University of Arkansas
University of Cincinnati
U Maryland College Park
University of Oregon Eugene
SUNY at Stony Brook
U Oklahoma Norman
RPI
U Missouri-Columbia
Emory University
University of Arizona
U South Carolina Columbia
Georgetown University
University of Delaware
University of Georgia
Kansas State University
Ohio University
Tulane University
University of Idaho
Washington State University
Indiana University
Clemson University
Utah State University
New Mexico State University
Oklahoma State University
Temple University
Texas Tech University
University of Kansas
University of Miami
Florida State University
University of Vermont
Oregon State University
Syracuse University
Tufts University
SUNY at Buffalo
University of Louisville
Lehigh University
Mississippi State University
West Virginia University
George Washington University
University of Notre Dame

Appendix F

List of Tier1, Tier 2 and Tier 3 Universities-AUTM patents

Tier 1
MIT
Caltech
Stanford University
Johns Hopkins
U Wisconsin-Madison
Cornell University
U Michigan Ann Arbor
Pennsylvania State Univ
University of Florida
Columbia University
Washington University

Tier 2
Harvard
SUNY
Duke
University of Chicago
University of Pennsylvania
University of Washington
University of Minnesota
Michigan State
North Carolina State
Georgia Tech
UIllinois UC/Chicago
U Alabama at Birmingham
University of Utah
University of Iowa
Rutgers University
UNC Chapel Hill
Texas A&M
University of Pittsburgh
University of Georgia
Iowa State
U Southern California
U Tennessee Knoxville
Emory
Carnegie-Mellon
Northwestern

Tier 3 (below the mean)

University of Kentucky
Purdue
Virginia Polytechnic Institute
New York
Vanderbilt
Indiana
UT Austin
Princeton
Ohio State University
Case Western Reserve
University of Massachusetts
U Colorado at Boulder
University of Rochester
U Maryland College Park
Brown
University of Virginia
University of New Mexico
Boston University
University of South Florida
University of Oklahoma
U Nebraska-Lincoln
Washington State University
Arizona State University
University of Cincinnati
University of Connecticut
Florida State University
Wayne State University
Tufts University
U Missouri-Columbia
University of Arkansas
Georgetown University
Louisiana State University
Virginia Commonwealth U
Texas Tech University
Colorado State University
Rensselaer Polytechnic Institute
University of Arizona
Temple University
Kansas State University
Clemson University
William Marsh Rice University
Mississippi State
Tulane University
University of Kansas
University of South Carolina
Northeastern University
University of Delaware
University of Vermont

VITA

Radhika Prabhu

Education

Ph.D., Higher Education
Penn State University, PA, May 2007

Graduate Certificate in Institutional Research
Penn State University, PA, December 2003

Master of Management Studies (MBA program)
Specialization in Marketing Management, *University of Bombay, India, May 1993*

Post Graduate Diploma in Mass Communication and Journalism
University of Bombay, India, May 1990

Bachelor of Commerce
University of Bombay, India, May 1989

Academic Work Experience

Graduate Research Assistant, *Center for the Study of Higher Education, Penn State University, 2000-2005*

Papers and Presentations

Cabrera, A. F., Deil-Amen, R., Prabhu, R., Terenzini, P. T., Lee, C., Frankling, R. E. (2006). Increasing the college preparedness of at-risk students. *Journal of Latinos and Education*, *5*(0), 79-97.

Prabhu, R., (October 2004) *Emerging Knowledge Creation and Technology Transfer Patterns in Nanotechnology*, presented at Emerging Issues in Technology Transfer, Technology Transfer Society (T2S) 26th Annual Conference, Albany, NY.

Cabrera, A. F., Prabhu, R., Deil-Amen, R., Terenzini, P., T., Lee, C., & Franklin Jr, R., E. (November, 2003). *Increasing the college preparedness of at-risk students.* Association for the Study of Higher Education (ASHE) Annual Conference, Oregon, OR.

Colbeck, C., Geertz-Gonzalez R., Prabhu, R., and Bjorklund, S.A., (June 2000), *One step Ahead of the Alligator: Balancing Teaching With Other Faculty Responsibilities*, From theory to Practice: An Anniversary Symposium, Penn State University, University Park, PA.

Prabhu, R., and Beltran Y., (March 2000) *Role of Information Technology in Higher education in India and the United States*, Comparative and International Education Society Conference, San Antonio, TX.

Awards and Honors

Recipient of the *Conrad Frank Jr. Graduate Fellowship*, College of Education, 2002-03
Recipient of the *Doris M. Niebel Scholarship in Education*, 2001-02