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ADVANCES IN THE STUDY OF ENTREPRENEURSHIP, INNOVATION AND ECONOMIC GROWTH
VOLUME 16

UNIVERSITY ENTREPRENEURSHIP AND TECHNOLOGY TRANSFER:

PROCESS, DESIGN, AND INTELLECTUAL PROPERTY

GARY D. LIBECAP
Editor

UNIVERSITY ENTREPRENEURSHIP AND TECHNOLOGY TRANSFER: PROCESS, DESIGN, AND INTELLECTUAL PROPERTY

ADVANCES IN THE STUDY OF ENTREPRENEURSHIP, INNOVATION AND ECONOMIC GROWTH

Series Editor: Gary D. Libecap

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EDITED BY

GARY D. LIBECAP
The University of Arizona, USA

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INTRODUCTION

American universities, indeed, universities throughout the world, are facing increased demand to share the knowledge developed within their campuses. Historically, students pass knowledge to the greater society. But since at least the 1960s, the university's research role has dramatically increased, with more and more resources devoted to basic and applied research in the physical and biological sciences, engineering, humanities, social sciences, and management fields. Not all of this research can be transmitted through the graduation of students. Research on basic scientific and life processes and engineering also eventually results in applications in new products and processes. Given the large investment in university research, society naturally seeks greater returns through patents, licensing, and new business starts. Local and state governments, especially, look to universities for job creation and economic growth through greater knowledge transfer.

In addition to these external demands, administrators and faculty within universities grow more interested in the potential from knowledge transfer. They believe students have better chances for employment with experience in commercialization; they believe that revenues from royalties and other licensing revenue can augment declining government support of their academic programs; they believe that the academic reputation of their institutions can be enhanced with greater success in knowledge transfer; and finally, they believe that all levels of government will be more supportive of the institution if it reveals a clear interest and success in knowledge transfer.

But internal demand does not come only from administrators and faculty. Students want greater emphasis on the practical application of their university-based knowledge. They want greater training in commercialization, knowledge that is applicable to real-world problems and hence will be demanded by employers. Finally, they have intellectual demands to see how university ideas might be modified to meet economic and social needs.

In the face of growing external and internal demands for knowledge transfer, universities have responded by investing in augmented technology transfer or licensing offices, adding courses and programs in commercialization, and perhaps most importantly, broadening administrative and academic support for knowledge transfer. The emphasis is no longer solely on the ivory tower. The bioscience and engineering fields, in particular, express interest in knowledge transfer, and more specifically, technology transfer, because of the perceived opportunities for patenting and licensing revenues.

Entrepreneurship programs and curricula across colleges and universities worldwide predates the new interest in knowledge transfer. Entrepreneurship classes that emphasize the process of business plan development and new launch of business ideas have become some of the most popular in the academy. Regional, national, and international business plan competitions allow student teams to practice their presentations, to defend them against the critical review of judges, and to obtain exposure among angel investors and venture capitalists. Entrepreneurship programs have grown beyond business school, which was their traditional home, to engineering, life sciences, agriculture, medical, and humanities programs. Indeed, as entrepreneurship enrollments have grown, there has been a natural interest in knowledge transfer. New university ideas with potential commercial application are especially attractive to student teams as the basis for their business plans and possible launches. There is greater interaction between entrepreneurship faculty, students, and those in science and engineering. University licensing and technology transfer offices are becoming more involved in entrepreneurship activities.

Given all of this progress, it seemed appropriate to gather academics involved in entrepreneurship education, officers of technology transfer programs, and those who study the process and problems of university-based knowledge transfer, to discuss what synergies exist and how entrepreneurship and technology transfer might be promoted more effectively. Using a grant from the Ewing Marion Kauffman Foundation of Kansas City, the Karl Eller Center at the University of Arizona commissioned 10 papers to examine the topics of technology transfer, intellectual property, and entrepreneurship program development. The papers were presented at the White Stallion Ranch, northwest of Tucson, January 20–23, 2005. Participants are listed at the end of the Introduction, along with the conference program.

The first paper, Chapter 1 of this volume, by Donald S. Siegel and Phillip H. Phan, Rensselaer Polytechnic Institute, "Analyzing the Effectiveness of University Technology Transfer: Implications for Entrepreneurship Education," begins by highlighting some of the major technologies developed from university laboratories that resulted in the creation of new industries. These include the 1940s development of the electronic calculator at the University of Pennsylvania that led to the computer industry, the 1960s launch of fiber optics at MIT that stimulated telecommunications, the 1970s investigations in DNA at Stanford and UC Berkeley that provided the basis for the biotechnology industry, the 1980s supercomputing at the University of Illinois that advanced the Internet, and the sequencing of DNA/the Human Genome at Cal Tech and Johns Hopkins that advanced pharmacogenomics. These are examples of major hits for technology transfer, but Siegel and Phan are concerned with the process underlying more routine technology transfer. They identify the principal agents and institutions for technology transfer as university scientists, industry scientists who interact with them, industry–university research centers, university technology transfer offices, science parks, incubators, firms that interact with universities, and venture capital firms. They identify indicators of technology transfer output/performance as invention disclosures, patents, licensing agreements, licensing revenue, research productivity of both industry and university scientists, startup formation, the survival of startups, and employment growth. Summarized, these metrics illustrate patterns in technology transfer. Siegel and Phan provide some key stylized facts: patents are not that important for certain technologies/industries, many scientists do not disclose inventions, faculty involvement is critical, universities rely on outside lawyers to negotiate with firms, technology transfer office staff add significant value to the transfer process, no strong evidence supports returns to scale, private universities are somewhat more productive, and incentives in the royalty distribution formula and organizational structure matter in encouraging faculty in technology transfer. They also present some impediments to technology transfer, such as information and cultural barriers between universities and firms, especially small firms; insufficient rewards for faculty in technology transfer; high staff turnover in technology transfer offices; and, of import to the conference, the education component, for both faculty and students, in the process of entrepreneurship and business plan development. Siegel and Phan conclude their chapter with suggestions for promoting university technology transfer to include, among other things, the development of interdisciplinary entrepreneurship programs that attend to technologies.

Chapter 2, by David Mowery, University of California, Berkeley, “The Bayh–Dole Act and High-Technology Entrepreneurship in U.S. Universities: Chicken, Egg, or Something Else?” provides a rich historical background on U.S. universities and innovation. Mowery notes that the university share of basic research in the United States has grown from 33% in 1953 to 60% in 1999. Universities often are associated with the growth of regional high-tech clusters populated by entrepreneurial firms and driven by new innovations. American universities influence industrial innovation through the training of scientists and engineers; publishing research; consulting with the private sector; interacting informally and in conferences with industry researchers; obtaining patents and licenses for university inventions; and establishing new firms led by faculty, graduates, and other researchers. Since the 1970s patents from university research has grown, particularly in biomedical fields. Mowery provides long-term data on the share of university patents among all domestic assigned patents, and the record reveals an upswing after 1975, with more or less continuous growth since that time. Also, since 1978, drug/medical patents have outpaced those in chemicals, electrical/electronic, and mechanical. With this information, Mowery asks if the Bayh-Dole Act of 1980, which gave universities greater authority over licensing terms from federally funded research, was a major source of this observed growth? He conjectures that the Bayh–Dole Act was more likely the effect, rather than the cause, of increased patenting. Universities such as Purdue, Stanford, MIT, Harvard, and Columbia lobbied for greater flexibility and consistency in federal policy just as their research and patenting activities were rising. Mowery turns to the question of how university IPR policy has affected entrepreneurial firms. He notes that there has been little empirical research in this area, but summarizes some available data. In 2002, 14–16% of university licensees were faculty founded startups, and 50–54% of licensees were small, less than 500 employees – these firms were not established to commercialize the specific invention. Patents may play a relatively secondary role in commercialization in non-biomedical fields. To illustrate the relationship between university patenting and licensing policies and entrepreneurial firms, Mowery provides five case studies, some of which were founded as vehicles for technology development and acquisition by other firms rather than technology commercialization. There was substantial variation in the level and nature of inventor involvement in commercialization. In three of the cases, the firms began work on similar technologies without licenses. These examples show the two-way flow of knowledge between the university and industry, and the importance of personnel movement between the two as part of knowledge transfer. The cases reveal little evidence that patenting/licensing activities were associated with delays in publication of academic research advances. Mowery also examines university IPR polices. He points out that universities have unrealistic expectations regarding the level of licensing revenues. Between 1999 and 2003, the entire University of California system had net institutional revenues of only $15 million a year out of an annual budget of nearly $3 billion. He addresses issues of how the management of IPR policies can facilitate licensing and entrepreneurial growth.

Chapter 3, “The Knowledge Spillover Theory of Entrepreneurship and Technological Diffusion,” by David Audretsch, Max Keilbach, and Erik Lehmann of the Max Planck Institute for Research on Entrepreneurship, Growth, and Public Policy, and Indiana University, provides more detailed empirical evidence on knowledge spillover using German data. Audretsch, Keilbach, and Lehmann begin by asking, what is entrepreneurship? The definitions they provide emphasize creating new products, processes, services, and organizations through the process of opportunity discovery. With this as background, the authors explore how knowledge is spilled over from research centers to the broader society to provide the basis for endogenous growth. They outline an endogenous growth model with knowledge externalities. They hypothesize that entrepreneurship will be greater in the presence of higher investments in new knowledge, and that entrepreneurship will be spatially located within close proximity to knowledge sources. Audretsch, Keilbach, and Lehmann estimate the model to test the hypotheses using German data across local political jurisdictions. They examine the determinants of startups by population and economic growth across the regions. They find that entrepreneurship as reflected in startups is positively influenced by investments in knowledge, all else being equal, and that entrepreneurship in turn is an important factor in economic growth. The chapter closes with a discussion of policy implications that may arise if supporting a spillover of knowledge.

Chapter 4 is the first of three on intellectual property issues associated with university-based research and commercialization. Katherine J. Strandburg, DePaul College of Law, writes “Curiosity-Driven Research and University Technology Transfer.”

In this chapter, Strandburg asks two questions – will university patenting promote commercialization of basic research spin-offs, and does university patenting threaten traditional scientific norms and basic research? She is concerned that greater emphasis on commercialization and increased licensing revenues might distort the traditional university focus on curiosity-driven research as compared to commercially driven research. Strandburg argues that basic research is socially valuable and worth protecting and promoting in developing university technology transfer policies. She notes that markets will fail to provide the socially optimal demand structure and that universities, using government funding, are important sources of basic research. She describes a model of basic academic research, whereby curiosity determines the research selected by scientists, and the peer review process disciplines for quality. She argues that basic scientists are self-selected by a taste for research, and are thus less likely to be interested in short-term commercial goals. Among this group of scientists exist norms that include communalism, universalism, disinterestedness, skepticism, invention, and independence. After elaborating on each of these norms, Strandburg asks if increased university emphasis on patenting/tech transfer will pose a threat. Among her concerns are whether industry funding and royalties will influence the kinds of research undertaken. She describes some predictions of her academic research model, including a lack of patenting. She also outlines some university practices that can be adopted to protect basic research, including experimental use exemptions in potential patent infringements.

Chapter 5, "The Irrationality of Speculative Gene Patents," by David E. Adelman, James E. Rogers College of Law at the University of Arizona, continues examination of university IP policies. Adelman notes that biotech is the center of fears about proliferating patenting by universities and the private sector. The concern is that aggressive patenting is undermining the scientific norms, as outlined by Strandburg, and creating a patent "anti-commons." He describes a pronounced surge in the patent of research tools that were previously more freely available in the public domain, and a significant rise in defensive patenting, particularly in the genomic sciences. Adelman argues that speculative biotech patenting, particularly of genetic probes, putative drug targets, and uncharacterized genetic sequences, is irrational. To develop his argument, he outlines the features of biomedical science and R&D: there is a complexity of disease processes with numerous genes involved and a combination of genetic and environmental causes; there are large uncertainties with weak causal associations between specific genes, and most diseases and random processes often play a significant role. With a proliferation of drug targets and genetic data, the challenge is to use research tools to discover viable products at a time when the drug pipeline has actually declined for almost a decade. R&D in biotech is shaped by high costs and uncertainties of discovery versus the low cost and ease of copying. Biological complexity mitigates the potential for patents to create broad monopolistic power. Genomic methods have generated a large number of research tools. As a result, Adelman concludes that there are so many biotech, problem-specific research tools and such high levels of uncertainties of payoff that patenting makes little sense. The current state of biotech research and development represents the worst conditions for strategic patenting – the number of potential patents is large and the value highly uncertain. The complexity of human biology creates a further disincentive for speculative patenting. The redundancy and intricacy of biological processes will enable scientists to circumvent existing problem-specific patents.

Enforcement of problem-specific research tools will be prohibitively costly. In the absence of an infringing product or sale, infringing uses will be very difficult to identify and the low value of speculative patents will eliminate the incentive to invest in patent enforcement. Accordingly, Adelman argues for a tempered university patent policy in biotech.

Chapter 6, "Commercializing University Research Systems in Economic Perspective: A View from the Demand Side," by Brett M. Frischmann, Loyola University Law School, is the last of the three chapters on university IP trends and technology transfer. Frischmann argues that the issues surrounding commercialization of university research are quite similar to those surrounding the commercialization of other mixed infrastructure, such as the Internet. As with Strandburg, Frischmann is concerned about the impact of technology transfer and emphasis on greater royalties on the traditional basic science environment. Universities have to decide how to allocate infrastructure investment that may be directed toward application and not basic research. He notes that universities may execute a variety of different strategies for promoting entrepreneurship, each coinciding with different degrees of participation in the commercialization process. Universities can be entrepreneurs, support entrepreneurs, and/or educate entrepreneurs. The basic point, according to Frischmann, is that universities need not be commercial entrepreneurs in order to teach entrepreneurship or provide students with entrepreneurial opportunities and experience. Indeed, an active, entrepreneurial university may offer hands-on, practical training in entrepreneurship for students in the fields of business and science and technology. Successful commercialization of university research requires close collaboration among participants in the university science and technology research system and with faculty, students, and administrators. An interdisciplinary entrepreneurship program provides an excellent environment for commercializing research and educating entrepreneurs. Universities may also opt to be less entrepreneurial while still being involved in the commercialization process. They may leave the post-patent efforts to licensees or spin-off companies, external investors and entrepreneurs. The need to coordinate the efforts of scientists, technologists, innovators, investors and entrepreneurs still provides ample opportunities for entrepreneurship training. Finally, entrepreneurship need not involve commercial enterprise. Universities that decide not to make commercialization a priority and instead aim to sustain their science and technology research systems as mixed infrastructure may still advance entrepreneurship education through open source, community-based enterprise projects and internships with local businesses.

Chapter 7 is the first of four chapters on the links between tech transfer and university entrepreneurship. “Pros and Cons of Faculty Participation in Licensing,” is by Jerry G. Thursby, Emory University, and Marie C. Thursby, Georgia Institute of Technology. The Thursbys begin by stating the importance of university research for industrial innovation. Although university licensing has increased dramatically, there remains a debate over faculty involvement as allowed by the Bayh-Dole Act. Proponents of licensing argue that its incentives underwrite the development needed for many technologies that are being commercialized, while critics argue that publication alone is sufficient for transfer and that licensing diverts faculty from more basic research. The Thursbys try to bring some needed empirical evidence to the debate. According to their industry survey, disclosures tend to be concentrated in science, engineering and medicine. Only 40% of disclosures lead to licenses, and less than half of these ever generate income because so many are very early in development. Indeed, the top 5 income generating licenses bring in 76% of total university licensing incomes. Because of the embryonic nature of university inventions their licenses had a higher failure rate than non-university technologies. About half of the failures were due to the technology. Fifty-two percent of university inventions were for new product development and only 9% for process improvement. The survey found little use of patenting to block entry by rivals, again probably because of the early stage of university technologies. Using a large survey data set of 3,342 faculty at 6 major universities over up to 17 years, the authors find that faculty involvement may be quite limited. Over 64% of faculty never disclosed discoveries and about 15% disclosed only once. Involvement in licensing appears to have had little impact on the nature of research with the ratio of basic research publications to all publications roughly constant over time. To raise faculty awareness there must be improved understanding of applications of their research through commercialization. There also must be greater interaction between faculty and those involved in commercialization, including technology transfer office personnel, angel investors, and officers of firms. The authors describe the advantages of faculty involvement in licensing, which include potentially greater disclosures and royalty income, and they outline the disadvantages which include possible compromises of traditional research agendas. The authors provide evidence to shed light on these controversial issues. They also examine the factors that encourage or discourage faculty involvement. In conclusion they find little diversion of faculty research agendas. The increase in licensing lies less with changes in faculty research and more with changes in the interests of the university central administrations.

Chapter 8, "Introducing Technology Entrepreneurship to Graduate Education: An Integrative Approach," by Marie Thursby, Georgia Tech, describes the very successful program underway at Georgia Tech and Emory. She argues that successful technology commercialization requires the integration of scientific and engineering expertise with knowledge of management, law, economics, and public policy. Accordingly, the entrepreneurship program centers around student teams that investigate the commercialization of their business plan research. The targeted students include PhDs in science and engineering, management and economics, and MBA and law students. Five factors are included in PhD training – managing R&D for business growth, balancing long-term and short-term R&D, integrating R&D and business strategy, making innovation happen, and assessing productivity. For MBA and law students, the emphasis is improved understanding of the technologies. These program objectives are addressed in the Technological Innovation: Generating Economic Results (TI:GER) program. The interdisciplinary program outlined in the chapter includes classes, research, theses, clinics and internships. Professor Thursby provides outlines of the courses offered, their sequences, and integration across the student groups. Research objectives also are described.

Chapter 9, "An Integrated Model of University Technology Commercialization and Entrepreneurship Education," by Arthur A. Boni and S. Thomas Emerson, Carnegie Mellon University, outlines a similar program linking entrepreneurship and technology transfer. The authors describe university sources of technology, processors of technology, and the institutional structure and community through which technology transfer occurs. They then describe the external community involved, including angel investors, VCs, legal and accounting firms, incubators, trade organizations, and state and local governments. With this background, Boni and Emerson describe the importance of aligning the constituencies to integrate university resources and to interface with external groups to better transfer knowledge. Their entrepreneurship program is at the center of this effort. It involves a business school and tech transfer office alliance to identify faculty and technologies, to address IP problems, and to locate appropriate commercial partners. The business school educates and supports entrepreneurs at the MBA level, undergraduate and non-MBA levels. There is interlinkage with technologists on campus in business plan development. For national exposure, the university supports various business plans competitions. Boni and Emerson conclude with case examples of recent successful launches based on university technology.

Chapter 10, "Organizational Modularity and Intra-University Relationships between Entrepreneurship Education and Technology Transfer," by Andrew Nelson and Thomas Byers, Stanford University, describes Stanford's technology licensing and entrepreneurship education interface through the engineering school. Nelson and Byers summarize the growth in patent filings, licenses, and royalty income at Stanford. They also outline the growth in entrepreneurship education and how these two are linked. Given the decentralized nature of Stanford, networks are critical, and the authors describe the networks that have developed to promote technology transfer and entrepreneurship.

At the conclusion of this chapter's conference presentation a number of issues were discussed by the group regarding the interface between entrepreneurship and knowledge transfer. Key objectives were to place entrepreneurship and knowledge transfer within the university's teaching, research, and outreach missions – and this seem natural to do. The group also emphasized the notion of knowledge transfer. Potentially valuable products, processes, and services can come from other parts of campus beyond the life sciences and engineering programs. The integration of interdisciplinary programs is important and faculty and administration involvement is essential in building interfaces with the external community for successful knowledge transfer.

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Analyzing the Effectiveness of University Technology Transfer: Implications for Entrepreneurship Education

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The Bayh-Dole Act and High-Technology Entrepreneurship in U.S. Universities: Chicken, Egg, or Something Else?

David C. Mowery, Haas School of Business, U.C. Berkeley

The Knowledge Spillover Theory of Entrepreneurship and Technological Diffusion

David B. Audretsch. Max Keilbach, and Erik Lehmann, Max Planck Institute for Research on Entrepreneurship, Growth and Public Policy, Indiana University

SESSION 2: INTELLECTUAL PROPERTY

Session Background Papers:

Curiosity-Driven Research and University Technology Transfer

Katherine J. Strandburg, DePaul University College of Law

The Irrationality of Speculative Gene Patents

David E. Adelman, James E. Rodgers, College of Law, The University of Arizona

Commercializing University Research Systems in Economic Perspective: A View from the Demand Side

Brett M. Frischmann, School of Law, Loyola University

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Pros and Cons of Faculty Participation in Licensing

Jerry G. Thursby, Department of Economics, Emory University and Marie C. Thursby, National Bureau of Economic Research & College of Management, Georgia Institute of Technology

Organizational Modularity and Intra-University Relationships between Entrepreneurship Education and Technology Transfer

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An Integrated Model of University Technology Commercialization and Entrepreneurship Education

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Introducing Technology Entrepreneurship to Graduate Education: An Integrative Approach

Marie C. Thursby, National Bureau of Economic Research & College of Management, Georgia Institute of Technology

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ANALYZING THE EFFECTIVENESS OF UNIVERSITY TECHNOLOGY TRANSFER: IMPLICATIONS FOR ENTREPRENEURSHIP EDUCATION

Donald S. Siegel and Phillip H. Phan

ABSTRACT

We review and synthesize the burgeoning literature on institutions and agents engaged in the commercialization of university-based intellectual property. These studies indicate that institutional incentives and organizational practices play an important role in enhancing the effectiveness of technology transfer. We conclude that university technology transfer should be considered from a strategic perspective. Institutions that choose to stress the entrepreneurial dimension of technology transfer need to address skill deficiencies in technology transfer offices, reward systems that are inconsistent with enhanced entrepreneurial activity, and education/training for faculty members, post-docs, and graduate students relating to interactions with entrepreneurs. Business schools at these universities can play a major role in addressing these skill and educational deficiencies through the delivery of targeted programs to technology licensing officers and members of the campus community wishing to launch startup firms.

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1. INTRODUCTION

Universities are increasingly being viewed by policymakers as engines of economic growth via the commercialization of intellectual property through technology transfer. Indeed, recent qualitative studies suggest that many research universities have adopted formal mission statements expressing enthusiastic support for technology transfer (Markman, Phan, Balkin, & Gianiodis, 2005) and commercialization. The primary commercial mechanisms for technology transfer are licensing agreements, research joint ventures, and university-based startups. Such activities can also lead to financial gains for the university and other non-pecuniary benefits. As a result, many research institutions are searching for ways to maximize the output and "effectiveness" of technology transfer.

Unfortunately, formal management of an intellectual property portfolio is a relatively new phenomenon for many universities. This has led to considerable uncertainty among administrators regarding optimal organizational practices relating to inventor incentives, technology transfer "pricing," legal issues, strategic objectives, and measurement and monitoring mechanisms. We contend that the effectiveness of technology transfer is ultimately determined by the competencies of university scientists, entrepreneurs, technology transfer officers, and other university administrators and their incentives to engage in entrepreneurial activities. The purpose of this chapter is to explore the implications of recent research on university technology transfer for entrepreneurial education. We assume that university administrators are interested in enhancing their effectiveness in this arena, which appears to be the case at many universities.

The rise in the rate of technology commercialization at universities has also attracted considerable attention in the academic literature. While most authors have analyzed university patenting and licensing, some researchers have also assessed the entrepreneurial dimensions of university technology transfer. Many authors have examined the institutions that have emerged to facilitate commercialization, such as university technology transfer offices (TTOs), industry–university cooperative research centers (IUCRCs), science parks, and incubators. Other chapters focus more directly on *agents* involved in technology commercialization, such as academic scientists. Specifically, several authors examine the determinants and outcomes of faculty involvement in university technology transfer, such as their propensity to patent, disclose inventions, coauthor with industry scientists, and form university-based startups. These empirical chapters build on the theoretical analysis of Jensen and Thursby (2001), who demonstrate that inventor involvement in university technology transfer potentially attenuates the deleterious effects of informational asymmetries that naturally arise in technological diffusion from universities to firms.

In this chapter we review the burgeoning literature on institutions and agents engaged in the commercialization of university-based intellectual property. These studies indicate that institutional incentives and organizational practices play an important role in enhancing the effectiveness of technology transfer. The evidence presented in these chapters also clearly demonstrates the considerable heterogeneity in stakeholder objectives, perceptions, and outcomes relating to this activity.

While the degree of variation across institutions makes it somewhat difficult to generalize, we believe that university administrators should consider technology transfer from a strategic perspective. A strategic approach to technology transfer implies that such initiatives should be driven by long-term goals, provided with sufficient resources to achieve these objectives, and monitored for performance. Institutions that choose to stress the entrepreneurial dimension of technology transfer need to address the following issues:

- Competency and skill deficiencies in many TTOs.
- Reward systems that are inconsistent with greater entrepreneurial activity.
- Education/training for faculty members, post-docs, and graduate students in the specifics of the entrepreneurial process, the role of entrepreneurs, and how to interact with the business/entrepreneurial community.

Business schools at these institutions can play a major role in addressing these skill and knowledge deficiencies through the delivery of targeted educational programs for technology licensing officers and members of the campus community wishing to launch startup firms (Wright, Lockett, Tiratsoo, Alferoff, & Mosey, 2004; Lockett & Wright, 2004).

The remainder of this chapter is organized as follows: in the following section, we analyze the objectives and cultures of the three key stakeholders in university technology transfer: academic scientists, university research administrators, and firms/entrepreneurs. This discussion underscores the complex, boundary-spanning role assumed by the TTO in facilitating technology commercialization. Section 3 presents an extensive review of the literature on university licensing and patenting. The next section explores the literature on an institution that was designed to stimulate and support entrepreneurial activities in the technology transfer process: the science park. Section 5 reviews studies of startup formation at universities. Section 6 presents lessons learned and recommendations relating to entrepreneurial education.

2. OBJECTIVES, MOTIVES, AND CULTURES OF UNIVERSITY TECHNOLOGY TRANSFER STAKEHOLDERS

Following Siegel, Waldman, and Link (2003a), we conjecture that the key stakeholders in university technology transfer are academic scientists, technology licensing officers and other university research administrators, and firm-based managers and entrepreneurs who commercialize university-based technologies. In our process model of technology transfer, the technology licensing office assumes the role of a boundary spanner, filling what Burt (1992) terms a "structural hole" to mediate the flow of resource and information within the network of technology transfer stakeholders (see Fig. 1). In this framework, academic scientists discover new knowledge when conducting funded research projects and, thus, act as suppliers of innovations. Their invention disclosures to the university constitute the critical input in the technology transfer process.

Note that the Bayh-Dole Act, the landmark legislation governing university technology transfer, stipulates that faculty members working on a federal research grant are required to disclose their inventions to the TTO. However, field studies (Siegel et al., 2003a; Siegel, Westhead, & Wright, 2003b) and survey research (Thursby, Jensen, & Thursby, 2001) indicate

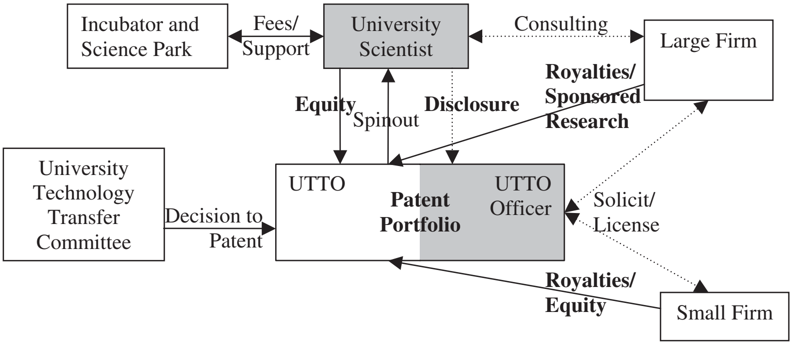

Fig. 1. A Process Model of University Technology Transfer. Shaded Areas are Potential Entrepreneurial Actors, Bold Represent Resource Flows.

that many faculty members are not disclosing inventions to the TTO. A failure to disclose inventions highlights the importance of licensing officers in the TTO simply eliciting more disclosures.

If the faculty member decides to file an invention disclosure with the TTO, the university administration, in consultation with a faculty committee, must decide whether to patent the invention. At this juncture, the TTO attempts to evaluate the commercial potential of the invention. Given the high cost of filing and protecting patents, some institutions are reluctant to file for a patent if there is little interest expressed by industry in the technology. Sometimes firms or entrepreneurs have already expressed sufficient interest in the new technology to warrant filing a patent.

If a patent is granted, the university typically attempts to "market" the invention by contacting firms that can potentially license the technology or entrepreneurs who are capable of launching a startup firm based on the technology. This step highlights the importance of the technology licensing officer's personal networks and their knowledge of potential users of the technology. Faculty members may also become directly involved in the licensing agreement as technical consultants or as entrepreneurs in a university spin-out. Indeed, Jensen and Thursby (2001) outline a theoretical model, suggesting that faculty involvement in the commercialization of a licensed university-based technology increases the likelihood that such an effort will be successful. Licensing agreements entail either upfront royalties, royalties at a later date, or equity in a startup firm launched to commercialize the technology.

Within the context of our model (Fig. 1), it is useful to reflect on the incentives and cultures of the three key stakeholders in university technology transfer: academic scientists, the TTO and university administrators, and firm/entrepreneurs. Academic scientists, especially those who are untenured, seek the rapid dissemination of their ideas and breakthroughs. This propagation of new knowledge is manifested along several dimensions, including publications in the most selective scholarly journals, presentations at leading conferences, and research grants. The end result of such activity is peer recognition through citations and stronger connections to the key social networks in academia. Such notoriety is the hallmark of a successful career in academia. Faculty members may also seek pecuniary rewards, which can be pocketed or plowed back into their research to pay for laboratory equipment, graduate students, and post docs.

The TTO and other research administrators are also charged with the responsibility of protecting the university's intellectual property portfolio. At the same time, they attempt to generate revenue from this portfolio and, therefore, actively seek to market university-based technologies to companies and entrepreneurs. This process takes place within the culture of a university, which may present competing interests related to the democratization of ideas, considerations of internal equity, bureaucratic procedures, and community interests. Some university administrators at public institutions may also understand that the Bayh-Dole Act embodied a desire to promote a more rapid rate of technological diffusion. Thus, these officials may be willing to extend the use of the university's technologies at a relatively low cost to firms.

Companies and entrepreneurs are motivated by a desire to commercialize university-based technologies for financial gain. They wish to secure exclusive rights to such technologies, since it is critical to maintain proprietary control over technology resources that may constitute a source of competitive advantage. Firms and entrepreneurs also place a strong emphasis on speed, in the sense that they often wish to commercialize the technology as soon as possible so as to establish a "first-mover" advantage. These agents operate in an entrepreneurial culture.

The stark disparities in the motives, perspectives, and cultures of the three key players in this process underscore the potential importance of organizational factors and institutional policies in effective university management of intellectual property. Thus it is not surprising that studies of the relative performance of university technology transfer have explored the importance of institutional and managerial practices. In the following section of the chapter, we review these papers.

3. REVIEW OF EMPIRICAL STUDIES ON THE EFFECTIVENESS OF UNIVERSITY LICENSING AND PATENTING

Table 1 presents a review of empirical studies on the effectiveness of university technology transfer licensing. Many papers have focused on the role of the TTO. Some studies have been based on qualitative analysis of agents involved in these transfers. Such qualitative research has played a critical role in informing more accurate empirical analyses. This point was stressed in Siegel et al. (2003a), which was based on a combination of econometric analysis and field-based interviews. The authors derived three key stylized facts from their qualitative research. The first is that many academic scientists do not disclose their inventions as required by the Bayh-Dole Act.

The authors also found that patents were not important for certain technologies and industries, such as computer software. This result implies that *invention disclosures*, not *patents*, are the critical input in university technology transfer. Their third finding was that many universities outsource legal services related to technology transfer, i.e. they use external lawyers to negotiate licensing agreements with firms. The final result is that universities appear to have multiple strategic objectives or perceived "outputs" for technology transfer: licensing and the formation of startup companies.

As shown on Table 1, several authors have attempted to assess the productivity of TTOs, using data on university technology transfer "outputs" and "inputs" (e.g. Siegel et al., 2003a; Thursby & Thursby, 2002; Friedman & Silberman, 2003). These papers highlight two key issues that arise in the context of production analysis, the first is whether to employ non-parametric methods or parametric estimation procedures.

The most popular non-parametric estimation technique is data envelopment analysis (DEA). DEA is essentially a linear-program, which can be expressed as follows:

$$\max h_k = \frac{\sum_{r=1} u_{rk} \bar{\mathbf{Y}}_{rk}}{\sum_{i=1} v_{ik} \, \bar{\mathbf{X}}_{ik}} \tag{1}$$

subject to

$$\frac{\sum_{r=1}^{s} u_{rk} \bar{\mathbf{Y}}_{rj}}{\sum_{i=1}^{m} v_{ik} \bar{\mathbf{X}}_{ij} < 1} \quad j = 1, \ldots, n, \quad u_{rk} > 0;\ v_{ik} > 0 \tag{2}$$

where h denotes efficiency, $\bar{\mathbf{Y}}$ is the vector of outputs, $\bar{\mathbf{X}}$ the vector of inputs, i the inputs (m inputs), r the outputs (s outputs), and n the number of k decision-making units (DMUs), or the unit of observation in a DEA study.

The unit of observation in a DEA study is referred to as the decision-making unit (DMU). In a DEA study, it is assumed that DMUs attempt to maximize efficiency. The input-oriented DEA algorithm yields an efficiency "score," bounded between 0 and 1, for each DMU by choosing weights (u_r and v_i) that maximize the ratio of a linear combination of the unit's outputs to a linear combination of its inputs (see Eq. (2)). DEA fits a piecewise linear surface to rest on top of the observations, which is called the "efficient frontier." The efficiency of each DMU is measured relative to all other DMUs, with the constraint that all DMUs lie on or below the efficient frontier. DEA also identifies best practice DMUs, or those that are on the frontier. All other DMUs are viewed as being inefficient relative to the frontier DMUs.

Table 1. Empirical Studies of University Technology Licensing and Patenting.

Author(s)	Data Sets	Methodology	Key Results
Siegel et al. (2003)	AUTM, NSF, and U.S. census data, interviews	TFP of university licensing – stochastic frontier analysis and field interviews	TTOs exhibit constant returns to scale with respect to the number of licensing; increasing returns to scale with respect to licensing revenue; organizational and environmental factors have considerable explanatory power
Link and Siegel (2003)	AUTM, NSF, and U.S. census data, interviews	TFP of university licensing – stochastic frontier analysis	Land grant universities are more efficient in technology transfer; higher royalty shares for faculty members are associated with greater licensing income
Friedman and Silberman (2002)	AUTM, NSF, NRC, Milken institute "Tech-Pole" data	Regression analysis-systems equations estimation	Higher royalty shares for faculty members are associated with greater licensing income
Lach and Schankerman (2004)	AUTM, NSF, and NRC	Regression analysis	Higher royalty shares for faculty members are associated with greater licensing income
Rogers, Yin and Hoffmann (2000)	AUTM, NSF, and NRC	Correlation analysis of composite tech transfer score	Positive correlation between faculty quality, age of TTO, and number of TTO staff and higher levels of performance in technology transfer
Thursby et al. (2001)	AUTM, authors' survey	Descriptive analysis of authors' survey/regression analysis	Inventions tend to be disclosed at an early stage of development; Elasticities of licenses and royalties with respect to invention disclosures are both less than one; faculty members are increasingly likely to disclose inventions.
Foltz, Bradford and Kim (2000)	AUTM, NSF	Linear regression	Faculty quality, Federal Research Funding, and number of TTO staff have a positive impact on university patenting

Bercovitz, Feldman, Feller, and Burton (2001)	AUTM and case studies, interviews	Qualitative and quantitative analysis	Analysis of different organization structures for technology transfer at Duke, Johns Hopkins, and Penn State; differences in structure may be related to technology transfer performance
Thursby and Kemp (2002)	AUTM	Data envelopment analysis and logit regressions on efficiency scores	Faculty quality and number of TTO staff has a positive impact on various technology transfer outputs; private universities appear to be more efficient than public universities; universities with medical schools less efficient
Thursby and Thursby (2002)	AUTM and authors' own survey	Data envelopment analysis	Growth in university licensing and patenting can be attributed to an increase in the willingness of professors to patent and license, as well as outsourcing of R&D by firms; not to a shift toward more applied research
Chapple, Lockett, Siegel, and Wright (2005)	U.K.-NUBS/UNICO survey-ONS	Data envelopment analysis and stochastic frontier analysis	U.K. TTOs exhibit decreasing returns to scale and low levels of absolute efficiency; organizational and environmental factors have considerable explanatory power
Carlsson and Fridh (2002)	AUTM	Linear regression	Research expenditure, invention disclosures, and age of TTO have a positive impact on university patenting and licensing

In contrast, stochastic frontier estimation (SFE) is a parametric method developed independently by Aigner, Lovell, and Schmidt (1977) and Meeusen and Van den Broeck (1977). SFE generates a production (or cost) frontier with a stochastic error term consisting of two components: a conventional random error ("white noise") and a term that represents deviations from the frontier, or relative inefficiency.

SFE is based on the assumption that the production function can be characterized as:

$$y_i = \mathbf{X}_i \beta + \varepsilon_i \tag{3}$$

where the subscript i refers to the ith university, y represents licensing output, $\bar{\mathbf{X}}$ denotes a vector of inputs, β is the unknown parameter vector, and ε is an error term that consists of two components, $\varepsilon_i = (V_i - U_i)$, where U_i is a non-negative error term representing technical inefficiency, or failure to produce maximal output given the set of inputs used, and V_i is a symmetric error term that accounts for random effects. Thus, we can rewrite Eq. (3) as:

$$y_i = \bar{\mathbf{X}}_i \beta + V_i - U_i \tag{4}$$

Following Aigner et al. (1977), it is typical to assume that the U_i and V_i have the following distributions:

$$V_i \sim \text{i.i.d. } N(0, \sigma_v^2)$$
$$U_i \sim \text{i.i.d. } N^+(0, \sigma_u^2), \quad U_i \geqslant 0$$

That is, the inefficiency term, U_i, is assumed to have a half-normal distribution: i.e. universities are either "on the frontier" or below it.[1]

SFE and DEA each have advantages and disadvantages. The use of DEA obviates the need to make these assumptions regarding the functional form of the production function and the nature of the "error" term in the equation (since there is no "error" term). Another advantage is that it allows for multiple outputs in the production function. A major weakness of DEA is that it is deterministic and, thus, does not distinguish between technical inefficiency and noise. A key benefit of SFE is that it allows hypothesis testing and the construction of confidence intervals. A drawback is the need to assume a functional form for the production function and for the distribution of the technical efficiency term.

The use of SFE raises the second key issue in the context of production analysis: the choice of a functional form for the production function. Most parametric studies of technology transfer efficiency have been based on the Cobb–Douglas specification. Link and Siegel (2003) use a flexible functional form, the Translog, which imposes fewer restrictions on elasticities of substitution than the Cobb–Douglas specification. This can be specified as follows:

$$\ln y_i = \sum_{k=1}^{K} \beta_k \ln \bar{\mathbf{X}}_{ki} + \frac{1}{2} \sum_{k=1}^{K} \sum_{l=1}^{K} \gamma_{kl} \ln \bar{\mathbf{X}}_{ki} \ln \bar{\mathbf{X}}_{li} \quad i = 1, 2, \ldots, N \qquad (5)$$

where y and $\bar{\mathbf{X}}$ again denote the technology transfer output and a vector of K technology transfer inputs, respectively, and i refers to the ith university.

Thursby and Thursby (2002) employ DEA methods to assess whether the growth in licensing and patenting by universities can be attributed to an increase in the willingness of professors to patent, without a concomitant, fundamental change in the type of research they conduct. The alternative hypothesis is that the growth in technology commercialization at universities reflects a shift away from basic research toward a more applied research. The authors find support for the former hypothesis. More specifically, they conclude that the rise in university technology transfer is the result of a greater willingness on the part of university researchers to patent their inventions, as well as an increase in outsourcing of R&D by firms via licensing.

Siegel et al. (2003a) use SFE to pose a different research question: why are some universities more effective at transferring technologies than comparable institutions? Specifically, they attempt to assess and "explain" the relative productivity of 113 U.S. university TTOs. Contrary to conventional economic models, they found that variation in relative TTO performance cannot be completely explained by environmental and institutional factors. The implication of this finding is that organizational practices are likely to be an important determinant of relative performance.

The authors supplemented their econometric analysis with qualitative evidence, derived from 55 structured, in-person interviews of 100 university technology transfer stakeholders (i.e. academic and industry scientists, university technology managers, and corporate managers and entrepreneurs) at five research universities in Arizona and North Carolina. The field research allowed them to identify intellectual property policies and organizational practices that can potentially enhance technology transfer performance.

The econometric results indicate that a production function model provides a good fit. Based on estimates of their "marginal product," it appears that technology licensing officers add significant value to the commercialization process. The findings also imply that spending more on lawyers reduces the number of licensing agreements but increases licensing revenue. Licensing revenue is subject to increasing returns, while licensing agreements are characterized by constant returns to scale. An implication of increasing returns for licensing revenue is that a university wishing to maximize revenue should spend more on lawyers. Perhaps this would enable university licensing officers to devote more time to eliciting additional invention disclosures and less time to negotiating with firms.

The qualitative analysis identified three key impediments to effective university technology transfer. The first was informational and cultural barriers between universities and firms, especially for small firms. Another impediment was insufficient rewards for faculty involvement in university technology transfer. This includes both pecuniary and non-pecuniary rewards, such as credit toward tenure and promotion. Some respondents even suggested that involvement in technology transfer might be detrimental to their careers. Finally, there appear to be problems with staffing and compensation practices in the TTO. One such problem is a high rate of turnover among licensing officers, which is detrimental toward the establishment of long-term relationships with firms and entrepreneurs. Other concerns are insufficient business and marketing experience in the TTO and the possible need for incentive compensation.

In a subsequent paper, Link and Siegel (2003) find that a particular organizational practice can potentially enhance technology licensing: the “royalty distribution formula,” which stipulates the fraction of revenue from a licensing transaction that is allocated to a faculty member who develops the new technology. Using data on 113 U.S. TTOs, the authors find that universities allocating a higher percentage of royalty payments to faculty members tend to be more efficient in technology transfer activities (closer to the “frontier,” in the parlance of SFE). Organizational incentives for university technology transfer appear to be important. This finding was independently confirmed in Friedman and Silberman (2003) and Lach and Schankerman (2003), using slightly different methods and data.

Other authors have explored the role of organizational incentives in university technology transfer. Jensen, Thursby, and Thursby (2003) model the process of faculty disclosure and university licensing through a TTO as a game, in which the principal is the university administration and the faculty and TTO are agents who maximize expected utility. The authors treat the TTO as a dual agent, i.e. an agent of both the faculty and the university. Faculty members must decide whether to disclose the invention to the TTO and at what stage, i.e. whether to disclose at the most embryonic stage or wait until it is a lab-scale prototype. The university administration influences the incentives of the TTO and faculty members by establishing university-wide policies for the shares of licensing income and/or sponsored research. If an invention is disclosed, the TTO decides whether to search for a firm to license the technology and then negotiates the terms of the licensing agreement with the licensee. Quality is incorporated in their model as a determinant of the probability of successful commercialization. According to the authors, the TTO engages in a "balancing act," in the sense that it can influence the rate of invention disclosures, must evaluate the inventions once they are disclosed, and negotiate licensing agreements with firms as the agent of the administration.

The Jensen et al. (2003) theoretical analysis generates some interesting empirical predictions. For instance, in equilibrium, the probability that a university scientist discloses an invention and the stage at which he or she discloses the invention is related to the pecuniary reward from licensing, as well as faculty quality. The authors test the empirical implications of the dual agency model based on an extensive survey of the objectives, characteristics, and outcomes of licensing activity at 62 U.S. universities.[2] Their survey results provide empirical support for the hypothesis that the TTO is a dual agent. They also find that faculty quality is positively associated with the rate of invention disclosure at the earliest stage and negatively associated with the share of licensing income allocated to inventors.

Bercovitz et al. (2001) examine what could be a critical implementation issue in university management of technology transfer: the *organizational structure* of the TTO and its relationship to the overall university research administration. Based on the theoretical work of Alfred Chandler and Oliver Williamson, they analyze the performance implications of four organizational forms: the functional or unitary form (U-Form), the multidivisional (M-form), the holding company (H-form), and the matrix form (MX-form). The authors note that these structures have different implications for the ability of a university to coordinate activity, facilitate internal and external information flows, and align incentives in a manner that is consistent with its strategic goals with respect to technology transfer.

To test these assertions, they examine TTOs at Duke, Johns Hopkins, and Penn State and find evidence of alternative organizational forms at these three institutions. They attempt to link these differences in structure to variation in technology transfer performance along three dimensions: transaction output, the ability to coordinate licensing and sponsored research activities, and incentive alignment capability. While further research is needed to make conclusive statements regarding organizational structure and performance, their findings imply that organizational form does matter.

In sum, the extant literature on TTOs suggests that the key impediments to effective university technology transfer tend to be organizational in nature (Siegel et al., 2003a; Siegel, Waldman, Atwater, & Link, 2004). These include problems with differences in organizational cultures between universities and (small) firms, incentive structures, including both pecuniary and non-pecuniary rewards, such as credit toward tenure and promotion, and staffing and compensation practices of the TTO itself.

4. REVIEW OF STUDIES ON THE EFFECTIVENESS OF SCIENCE PARKS

In recent years there has been a substantial increase in investment in science parks and other property-based institutions that facilitate technology transfer. Many universities have established science parks and incubators in order to foster the creation of startup firms based on university-owned (or licensed) technologies. Public universities (and some private universities) also view these institutions as a means of fostering regional economic development (Table 2).

Science parks have become an international phenomenon. The Association of University Research Parks (AURP) reports that there are 123 university-based science parks in the U.S. (Link & Link, 2003). The U.K. Science Park Association (UKSPA) reports that there were 32 science parks in 1989 and 46 in 1999 (Siegel et al., 2003b). According to Lindelof and Loftsen (2003), there are 23 science parks in Sweden. Asia is also a major player. Japan leads the list with 111; China has over 100; Hong Kong and South Korea each report two parks; and Macau, Malaysia, Singapore, Taiwan, and Thailand have one each. India established 13 parks in late-1980s, but with the exception of Bangalore, India's Silicon Valley, all have failed.

This increased level of activity has stimulated an important academic debate concerning whether such property-based initiatives enhance the performance of corporations, universities, and economic regions. More practically, it has also led to an interest among policymakers and industry leaders in identifying best practices. Unfortunately, few academic studies address such issues. This can be attributed to the somewhat embryonic nature of science parks and the fact that most science parks are public–private partnerships, indicating that multiple stakeholders (e.g. community groups, regional, and state governments) have enormous influence over their missions and operational procedures. Thus, developing theories to characterize the

Table 2. Recent Empirical Studies of Science Parks in the U.S., U.K., and Sweden.

Author(s)	Country of Analysis	Data/Methodology	Proxies for Performance	Key Results
Westhead and Storey (1994)	United Kingdom	Longitudinal dataset containing information on the characteristics and performance of firms located on and off science parks in the United Kingdom	Survival	No difference in the survival rates of firms located on university science parks and similar firms not located on university science parks
Westhead, Storey, and Cowling (1995)	United Kingdom	Longitudinal dataset containing information on the characteristics and performance of firms located on and off science parks in the United Kingdom/multivariate logistic regression analysis.	Survival	Sponsored science park environments did not significantly increase the probability of firm survival
Westhead and Storey (1995)	United Kingdom	Longitudinal dataset containing information on the characteristics and performance of firms located on and off science parks in the United Kingdom	Survival	Science park firms with a link to the university have a higher survival rate than science park firms without such a link
Westhead, and Cowling (1995)	United Kingdom	Longitudinal dataset containing information on the characteristics and performance of firms located on and off science parks in the United Kingdom	Employment growth	No difference in employment growth rates of firms located on university science parks and similar firms not located on university science parks
Siegel et al. (2003b)	United Kingdom	Longitudinal dataset containing information on the	Research productivity	Science park firms are more efficient than non-science park firms in

Table 2. (*Continued*)

Author(s)	Country of Analysis	Data/Methodology	Proxies for Performance	Key Results
		characteristics and performance of firms located on and off science parks in the United Kingdom/Estimation of R&D production function		research (i.e. generating new products and services and patents)
Link and Link (2003)	United States	Association of university related research parks (AURRP) survey; survey of park directors	Employment and tenant growth on all research parks	Real estate parks are the fastest growing type of park, but their growth is not related to being close to a university
Link and Scott (2003)	United States	Association of university related research parks (AURRP) survey; authors' survey of university provosts/hazard function regression analysis/Ordered probit equation estimation	Employment growth/Six dimensions of the academic mission of the university	Proximity to a university and the availability of venture capital have a positive impact on growth; science park enables universities to generate more publications and patents, more easily place graduates, and hire pre-eminent scholars
Link and Scott (2004)	United States	Association of university related research parks (AURRP) survey; authors' survey of university provosts	Percentage of university research park tenants that are university-based startups	There is a positive association between the percentage of university-based startups and the age of the park, the quality of the research environment at the university, proximity to the university, and whether the parks have a biotech focus

Lindelof and Loftsen (2003)	Sweden	Longitudinal dataset containing information on the characteristics and performance of firms located on and off science parks in Sweden	Two dimensions of R&D output: counts of patents and new products/ self-reported data on strategic motivations	Insignificant differences between science park and non-science park firms, along two dimensions of R&D output: counts of patents and new products. However, science parks place a stronger emphasis on innovative ability, sales and employment growth, market orientation, and profitability than non-science park firms
Lindelof and Loftsen (2004)	Sweden	Longitudinal dataset containing information on the characteristics and performance of firms located on and off science parks in Sweden	Measures of R&D output, sales and employment growth	Insignificant differences in R&D output between science park and non-science park firms; however science park firms with stronger links and networks to universities have higher levels of R&D output and growth than comparable non-science park firms
Ferguson and Olofsson (2004)	Sweden	Longitudinal dataset containing information on the characteristics and performance of firms located on and off science parks in Sweden	Survival, sales and employment growth	Science park firms have a higher survival rate than non-science park firms; however, there is no difference in sales and employment growth

precise nature of their business models and managerial practices can be somewhat complex.

Link and Scott (2003) examine the evolution and growth of U.S. science parks and their influence on academic missions of universities, employing econometric methods and qualitative analysis. They use two data sources: a dataset constructed by the Association of University Related Research Parks (AURRP) containing a directory of science parks and limited information on their characteristics, and their own qualitative survey of provosts at 88 major research universities. The provosts were asked several questions about the impact of the university's involvement with science parks on various aspects of the academic mission of the university.

Their results suggest that the existence of a formal relationship with a science park enables a university to generate more scholarly publications and patents and also allows them to more easily place Ph.D. students and hire preeminent scholars. They also found that there appears to be a direct relationship between the proximity of the science park to the university and the probability that the academic curriculum will shift from basic toward applied research.

In a subsequent study (Link & Scott, 2004), the authors analyze the determinants of the formation of university spin-off companies within the university's research park and report that university spin-off companies constitute a greater proportion of the companies in older parks and in those parks with richer university research environments. The authors also find that university spin-off companies comprise a larger proportion of firms in parks that are located closer to their university and in parks that have a biotechnology focus.

The best available evidence on the effects of science parks is from the United Kingdom. Several studies were based on longitudinal data consisting of performance indicators for firms located on science parks and a control group of firms not located on science parks (Monck, Porter, Quintas, Storey, & Wynarczyk, 1988; Westhead & Storey, 1994; Westhead et al., 1995). The authors found no difference between the closure rates of firms located on science parks and similar firms not located on science parks (32% versus 33%), implying that sponsored science park environments did not significantly increase the probability of business survival or enhance job creation.

With respect to the importance of the university, Westhead and Storey (1995) found a higher survival rate among science park firms with a university link (72%) than firms without such a link (53%). Westhead (1997), examining differences in R&D "outputs" (i.e. counts of patents, copyrights, and new products or services) and "inputs" (i.e. percentage of scientists and engineers in total employment, the level and intensity of R&D expenditure, and information on the thrust and nature of the research undertaken by the firm) of firms located on science parks and similar firms located off science parks, found no significant differences between science park and off-park firms.

However, Siegel et al. (2003b) found that science park firms have higher research *productivity* than comparable non-science park firms, in terms of generating new products and services and patents, but not copyrights. These findings are relatively insensitive to the specification of the econometric model and controls for the possibility of an endogeneity bias. This preliminary evidence suggests that university science parks could constitute an important spillover mechanism since they appear to enhance the research productivity of firms.

There have also been several evaluation studies of Swedish science parks. Lindelof and Löftsen (2003, 2004) conducted a "matched pairs" analysis of 134 on-park and 139 off-park Swedish firms using techniques similar to those employed by Westhead and Storey (1994). The authors report that there are insignificant differences between science park and non-science park firms in terms of patenting and new products. However, they find that companies located on science parks appear to have different strategic motivations than comparable off-park companies. More specifically, they seem to place a stronger emphasis on innovative ability, sales and employment growth, market orientation, and profitability. Lindelof and Löftsen (2004) also found that the absolute level of interaction between the university and companies located on science parks is low, but that science park firms were more likely to have a relationship with the university than non-science park firms. Considered together with other evidence presented in Ferguson and Olofsson (2004), their results imply that science park firms interacting with nearby universities will achieve higher levels of R&D output than comparable non-science park firms.

In sum, the empirical research on these institutions suggests the importance of a university link in enhancing the performance of firms located on science parks. In part, this is because many science parks were created to incubate the spinouts created from university-based technology. What has been less clear is the exact nature of this link that contributes to the differences between park and off-park firms. Speculation has ranged from explanations of knowledge spillovers to the proximity of the requisite competencies to staff these firms. Nonetheless, given the technological nature of such firms, we conjecture that there may be an important role for the technology transfer process in the success of the university-related science parks and their business tenants. This brings us to the next section of our chapter, which is the empirical work related to university-based spinouts.

5. REVIEW OF STUDIES OF STARTUP FORMATION AT UNIVERSITIES

Although the dominant form of commercialization has traditionally been licensing, there is a rapidly growing population of university-based entrepreneurial startup firms. According to the Association of University Technology Managers (AUTM, 2004), the number of startup firms at U.S. universities rose from 35 in 1980 to 374 in 2003. This rise in startup activity has attracted considerable attention in the academic literature. Some of these studies use the university as the unit of analysis, while others focus on individual entrepreneurs (Table 3).

Studies using the university as the unit of analysis typically focus on the role of university policies in stimulating entrepreneurial activity. Roberts and Malone (1996) conjecture that Stanford generated fewer startups than comparable institutions in the early 1990s because the institution refused to sign exclusive licenses to inventor–founders.

Degroof and Roberts (2004) examine the importance of university policies relating to startups in regions where environmental factors (e.g. technology transfer and infrastructure for entrepreneurship) are not particularly conducive to entrepreneurial activity. The authors derive a taxonomy of four types of startup policies: an absence of startup policies, minimal selectivity/support, intermediate selectivity/support, and comprehensive selectivity/support. Consistent with Roberts and Malone (1996), they find that comprehensive selectivity/support is the optimal policy for generating startups that can exploit venture with high growth potential. However, such a policy is an ideal that may not be feasible, given resource constraints. The authors conclude that while spinout policies do matter in the sense that they affect the growth potential of ventures, it may be more desirable to formulate such policies at a higher level of aggregation than the university.

Di Gregorio and Shane (2003) directly assess the determinants of startup formation using AUTM data from 101 universities and 530 startups. Based on estimates of count regressions of the number of university-based startups, they conclude that the two key determinants of startups are faculty quality and the ability of the university and inventor(s) to assume equity in a startup in lieu of licensing royalty fees. Interestingly, the availability of

Table 3. Studies of the Antecedents and Consequences of Startup Formation at Universities.

Author(s)	Unit of Analysis	Data/Methodology	Key Results
Di Gregorio and Shane (2003)	University-based startups	AUTM survey/Count regressions of the determinants of the number of startups	Two key determinants of startup formation: faculty quality and the ability of the university and inventor(s) to take equity in a startup, in lieu of licensing royalty fees; a royalty distribution formula that is more favorable to faculty members reduces startup formation
O'Shea, Allen, and Chevalier (2004)	University-based startups	AUTM survey/Count regressions of the determinants of the number of startups	A university's previous success in technology transfer is a key determinant of its rate of startup formation
Franklin, Wright, and Lockett (2001)	TTOs and university-based startups	Authors' quantitative survey of U.K. TTOs	Universities that wish to launch successful technology transfer startups should employ a combination of academic and surrogate entrepreneurship
Lockett, Wright, and Franklin (2003)	TTOs and university-based startups	Authors' quantitative and qualitative surveys of U.K. TTOs	Universities that generate the most startups have clear, well-defined spinout strategies, strong expertise in entrepreneurship, and vast social networks
Lockett and Wright (2004)	TTOs and university-based startups	Authors' quantitative survey of U.K. TTOs/Count regressions of the determinants of the number of startups	A university's rate of startup formation is positively associated with its expenditure on intellectual property protection, the business development capabilities of TTOs, and the extent to which its royalty distribution formula favors faculty members
Nerkar and Shane (2003)	University-based startups	Longitudinal data from MIT startups/Hazard function analysis	"Radicalness" of the new technology and patent scope increase the probability of survival more in fragmented industries than in concentrated sectors ⇒ Effectiveness of technology strategies of new firms appears to depend on industry conditions

Table 3. *(Continued)*

Author(s)	Unit of Analysis	Data/Methodology	Key Results
Meseri and Maital (2001)	TTOs and university-based startups	Authors' qualitative survey of Israeli TTOs	Criteria used by Israeli TTOs to appraise entrepreneurial startups are similar to those employed by venture capitalists
Markman, Phan, Balkin, and Gianiodis (2004a)	TTOs and university-based startups	AUTM survey, Authors' survey/Linear regression analysis	Equity licensing and startup formation are positively correlated with TTO wages; uncorrelated or even negatively correlated with royalty payments to faculty members
Markman, Phan, Balkin, and Gianiodis (2004b)	TTOs and university-based startups	AUTM survey, Authors' survey/Linear regression analysis	There are three key determinants of time – to market (Speed): TTO resources, competency in identifying licensees, and participation of faculty-inventors in the licensing process
Markman et al. (2005)	TTOs and university startups	AUTM survey, Authors' survey/Linear regression analysis	The most attractive combinations of technology stage and licensing strategy for new venture creation–early stage technology and licensing for equity–are least likely to favored by the university (due to risk aversion and a focus on short-run revenue maximization)
Audretsch (2000)	Entrepreneurs in the life sciences	101 Founders of 52 biotech firms/Hazard function regression analysis	University entrepreneurs tend to be older, more scientifically experienced
Louis, Blumenthal, Gluck, and Stoto (1989)	Faculty members in the life sciences	778 faculty members from 40 universities/ regression analysis	Key determinant of faculty-based entrepreneurship: local group norms; university policies and structures have little effect
Bercovitz and Feldman (2004)	Medical school researchers at Johns Hopkins and Duke	Determinants of the probability of filing an invention disclosure	Three factors influence the decision to disclose inventions: norms at the institutions where the researchers were trained and the disclosure behaviors of their department chairs and peers

Zucker, Darby, and Brewer (1998)	Relationships involving "star" scientists and U.S. biotech firms	Scientific papers reporting genetic-sequence discoveries, data on biotech firms from the North Carolina Biotechnology Center (1992) & Bioscan (1993)/ Count regressions	Location of star scientists predicts firm entry in biotechnology
Zucker, Darby, and Armstrong (2000)	Relationships involving "star" scientists and U.S. biotech firms	Scientific papers reporting genetic-sequence discoveries, data on biotech firms from the North Carolina Biotechnology Center (1992) & Bioscan (1993)/ Count regressions	Collaboration between star scientists and firm scientists enhances research performance of U.S. biotech firms, as measured using three proxies: number of patents granted, number of products in development, and number of products on the market
Zucker and Darby (2001)	Relationships involving "star" scientists and Japanese biotech firms	Data on Biotechnology firms and the Nikkei biotechnology directory	Collaboration between star scientists and firm scientists enhances research performance of Japanese biotech firms, as measured using three proxies: number of patents granted, number of products in development, and number of products on the market

venture capital in the region where the university is located and the commercial orientation of the university (proxied by the percentage of the university's research budget that is derived from industry) are found to have an insignificant impact on the rate of startup formation. The authors also find that a royalty distribution formula that is more favorable to faculty members reduces startup formation, a finding that is confirmed by Markman et al. (2005). Di Gregorio and Shane (2003) attribute this result to the higher opportunity cost associated with launching a new firm, relative to licensing the technology to an existing firm.

O'Shea et al. (2004) extend these findings in several ways. First, they employ a more sophisticated econometric technique employed by Blundell, Griffith, and Van Reenen (1995) on innovation counts, which accounts for unobserved heterogeneity across universities due to ''history and tradition.'' This type of ''path dependence'' would seem to be quite important in the university context. Indeed, the authors find that a university's previous success in technology transfer is a key explanatory factor of startup formation. Consistent with Di Gregorio and Shane (2003), they also find that faculty quality, commercial capability, and the extent of federal science and engineering funding are also significant determinants of higher rates of university startup formation.

Franklin et al. (2001) analyze perceptions at U.K. universities regarding entrepreneurial startups that emerge from university technology transfer. The authors distinguish between academic and surrogate (external) entrepreneurs and ''old'' and ''new'' universities in the U.K. Old universities have well-established research reputations, world-class scientists, and are typically receptive to entrepreneurial startups. New universities, on the other hand, tend to be weaker in academic research and less flexible with regard to entrepreneurial ventures. They find that the most significant barriers to the adoption of entrepreneurial-friendly policies are cultural and informational and that the universities generating the most startups (i.e. old universities) are those that have the most favorable policies regarding *surrogate* (external) entrepreneurs. The authors conclude that the best approach for universities that wish to launch successful technology transfer startups is a combination of academic and surrogate entrepreneurship. This would enable universities to simultaneously exploit the technical benefits of inventor involvement and the commercial know-how of surrogate entrepreneurs.

In a subsequent paper, Lockett et al. (2003) find that universities that generate the most startups have clear, well-defined strategies regarding the formation and management of spinouts. These schools tend to use surrogate (external) entrepreneurs, rather than academic entrepreneurs, to manage this process. It also appears as though the more successful universities have greater expertise and vast social networks that help them generate more startups. However, the role of the academic inventor was not found to differ between the more and less successful universities. Finally, equity ownership was found to be more widely distributed among the members of the spinout company in the case of the more successful universities.

Using an extended version of the same database, Lockett and Wright (2004) assess the relationship between the resources and capabilities of U.K. TTOs and the rate of startup formation at their respective universities. In doing so, the authors apply the resource-based view (RBV) of the firm to the university. RBV asserts that an organization's superior performance (in the parlance of strategic management, its "competitive advantage") is related to its internal resources and capabilities. They are able to distinguish empirically between a university's resource inputs and its routines and capabilities. Based on estimation of count regressions (Poisson and Negative Binomial), the authors conclude that there is a positively correlation between startup formation and the university's expenditure on intellectual property protection, the business development capabilities of TTOs, and the extent to which its royalty distribution formula favors faculty members. These findings imply that universities wishing to spawn numerous startups should devote greater attention to recruitment, training, and development of technology transfer officers with broad-based commercial skills. We will refer back to these results in the following section of the chapter.

Markman et al. (2005) develop a model linking university patents to new firm creation in university-based incubators, with university TTOs acting as the intermediaries. They focus on universities because such institutions are responsible for a substantial fraction of technology-oriented incubators in the U.S. While there have been some qualitative studies of university TTO licensing (e.g. Bercovitz et al., 2001; Siegel et al., 2003a; Mowery, Nelson, Sampat, & Ziedonis, 2001), they have been based on data from elite research universities only (e.g. Stanford, UC Berkeley, and MIT) or from a small sample of more representative institutions. These results may not be generalizable to the larger population of institutions that do not enjoy the same favorable environmental conditions. To build a theoretically saturated model of TTOs' entrepreneurial development strategies, the authors collected qualitative and quantitative data from virtually the entire population of university TTOs.

A surprising conclusion of Markman et al. (2005) is that the most "attractive" combinations of technology stage and licensing strategy for new venture creation, i.e. early stage technology, combined with licensing for equity, are least likely to be favored by the university and thus not likely to be used. That is because universities and TTOs are typically focused on short-term cash maximization, and extremely risk-averse with respect to financial and legal risks. Their findings are consistent with evidence presented in Siegel et al. (2004), who found that TTOs appear to do a better job of serving the needs of large firms than small, entrepreneurial companies. The results of these studies imply that universities should modify their technology transfer strategies if they are serious about promoting entrepreneurial development.

In additional studies (Markman et al., 2004a, b), the authors use the same database to assess the role of incentive systems in stimulating academic entrepreneurship and the determinants of innovation speed, or time to market. An interesting result of Markman et al. (2004a) is that there is a positive association between compensation to TTO personnel and both equity licensing and startup formation. On the other hand, royalty payments to faculty members and their departments are uncorrelated or even negatively correlated with entrepreneurial activity. This finding is consistent with Di Gregorio and Shane (2003).

In Markman et al. (2004b), the authors find that speed matters, in the sense that "faster" TTOs can commercialize technologies that are protected by patents, the greater the returns to the university and the higher the rate of startup formation. They also report that there are three key determinants of speed: TTO resources, competency in identifying licensees, and participation of faculty-inventors in the licensing process.

Nerkar and Shane (2003) analyze the entrepreneurial dimension of university technology transfer, based on an empirical analysis of 128 firms that were founded between 1980 and 1996 to commercialize inventions owned by MIT. They begin by noting that there is an extensive literature in management that suggests that new technology firms are more likely to survive if they exploit radical technologies (e.g. Tushman & Anderson, 1986) and if they possess patents with a broad scope (e.g. Merges & Nelson, 1990). The authors conjecture that the relationships between radicalness and survival and scope and survival are moderated both by the market structure or level of concentration in the firm's industry. Specifically, they assert that radicalness and patent scope increase the probability of survival more in fragmented industries than in concentrated sectors. They estimate a hazard function model using the MIT database and find empirical support for these hypotheses. Thus, the effectiveness of the technology strategies of new firms may be dependent on industry conditions.

Several studies focus on *individual* scientists and entrepreneurs in the context of university technology transfer. Audretsch (2000) examines the extent to which entrepreneurs at universities are different than other entrepreneurs. He analyzes a dataset on university life scientists in order to estimate the determinants of the probability that they will establish a new biotechnology firm. Based on a hazard function analysis, including controls for the quality of the scientist's research, measures or regional activity in biotechnology, and a dummy for the career trajectory of the scientist, the author finds that university entrepreneurs tend to be older and more scientifically experienced.

There is also evidence on the importance of norms, standards, and culture in this context. Based on a qualitative analysis of five European universities that had outstanding performance in technology transfer, Clark (1998) concluded that the existence of an entrepreneurial culture at those institutions was a critical factor in their success. Roberts (1991) finds that social norms and MIT's tacit approval of entrepreneurs were critical determinants of successful academic entrepreneurship at MIT.

Louis et al. (1989) analyze the propensity of life-science faculty to engage in various aspects of technology transfer, including commercialization. Their statistical sample consists of life scientists at the 50 research universities that received the most funding from the National Institutes of Health. The authors find that the most important determinant of involvement in technology commercialization was local group norms. They report that university policies and structures had little effect on this activity.

The unit of analysis in Bercovitz and Feldman (2004) is also the individual faculty member. They analyze the propensity of medical school researchers at Johns Hopkins and Duke to file invention disclosures, a potential precursor to technology commercialization. The authors find that three factors influence the decision to disclose inventions: norms at the institutions where the researchers were trained and the disclosure behaviors of their department chairs and peers, respectively.

The seminal papers by Lynne Zucker and Michael Darby and various collaborators explore the role of "star" scientists in the life sciences on the creation and location of new biotechnology firms in the U.S. and Japan. In Zucker et al. (2000), the authors assessed the impact of these university scientists on the research productivity of U.S. firms. Some of these scientists resigned from the university to establish a new firm or kept their faculty position, but worked very closely with industry scientists. A star scientist is defined as a researcher who has discovered over 40 genetic sequences, and affiliations with firms are defined through co-authoring between the star scientist and industry scientists. Research productivity is measured using three proxies: number of patents granted, number of products in development, and number of products on the market. They find that ties between star scientists and firm scientists have a positive effect on these three dimensions of research productivity, as well as other aspects of firm performance and rates of entry in the U.S. biotechnology industry (Zucker, Darby, & Armstrong, 1998; Zucker et al., 1998).

In Zucker and Darby (2001), the authors examine detailed data on the outcomes of collaborations between "star" university scientists and biotechnology firms in Japan. Similar patterns emerge in the sense that they find that such interactions substantially enhance the research productivity of Japanese firms, as measured by the rate of firm patenting, product innovation, and market introductions of new products. However, they also report an absence of geographically localized knowledge spillovers resulting from university technology transfer in Japan, in contrast to the U.S., where they found that such effects were strong. The authors attribute this result to the following interesting institutional difference between Japan and the U.S in university technology transfer. In the U.S., it is common for academic scientists to work with firm scientists at the firm's laboratories. In Japan, firm scientists typically work in the academic scientist's laboratory. Thus, according to the authors, it is not surprising that the local economic development impact of university technology transfer appears to be lower in Japan than in the U.S.

The research on TTOs, science parks, and startup formation summarized in Sections 3, 4, and 5 underscore the importance of identifying the interests and incentives of those who manage the technology transfer process. The extant literature also highlights the need to understand how these managers interact with key stakeholders and those who manage these stakeholders (e.g. science park and incubator managers, department chairs, and entrepreneurs) who are employed at these institutions.

In the case of the university, an internal market for the efficient allocation of resources does not exist. Therefore, decisions relating to technology transfer and new venture creation may be driven by internal bargaining, which would bring to the fore the question of incentives versus university mission. Theoretically, the relationship between TTO managers, the university administration and entrepreneurs can be modeled as a multi-level agency problem. As in the case of all agency problems, the resolution can come through more complete contracts, accurate measurement and monitoring, or the creation of a culture of trust. This again points to the importance of organizational processes and individual behaviors in providing a complete explanation for the link between TTOs and spinouts.

6. LESSONS LEARNED/RECOMMENDATIONS

A synthesis of the literature suggests that several issues must be addressed by university administrators and other policymakers (e.g. regional or state authorities) in order to enhance the effectiveness of technology transfer. First, universities should adopt a *strategic* approach to this activity. Such an approach raises a set of formulation and implementation issues.

The *formulation* of a technology transfer strategy entails a set of choices regarding institutional goals and priorities, allocation of resources to achieve these goals, technological emphasis, and modes of technology transfer. The *implementation* of a technology transfer strategy requires choices regarding information flows, organizational design/structure, human resource management practices in the TTO, and reward systems for faculty involvement in technology transfer. There are also a set of implementation issues relating to different modes of technology transfer, licensing, startups, sponsored research, and other modes that are focused more directly on stimulating economic development, such as incubators and science parks. We now consider each of these in turn, in the context of the quantitative and qualitative analyses cited in previous sections of the chapter.

Universities must be transparent, forthright, and consistent about their strategic goals and priorities for technology transfer. Such an approach will allow for more efficient matching between the TTO and its suppliers, the academic scientists. Clarity and consistency of purpose is likely to result in more productive interactions between the TTO and university scientists, since TTO officers will hit fewer "dry wells" and faculty members will find a more receptive audience for their ideas.

Establishing priorities also relates to choices regarding technological emphasis for the generation of licensing opportunities, relating to stage of development and field of emphasis. For instance, proof-of-concept technologies are likely to be more attractive than other technologies if the strategic objective is licensing for cash, since it is relatively easy to compute economic value under this scenario. Furthermore, such technologies can be codified for efficient arms-length transfer, and they are more likely than other technologies to result in a commercial product, without substantial additional research expense.

University administrators and regional policymakers must also make a strategic choice regarding field of emphasis. Opportunities for technology commercialization and the propensity of faculty members to engage in technology transfer vary substantially across fields both between and within the life sciences and physical sciences. For example, many universities have recently launched initiatives in the life sciences and biotechnology with expectations of enhanced revenue and job creation through technology transfer.

As noted earlier, the research on TTOs and licensing revenue suggests that it is difficult for universities to assess financial rates of returns on this activity. We assert that in light of this finding, universities must develop the expertise to manage their licensing portfolio as a set of options, rather than individual wagers on "winner-take-all" projects. This type of portfolio management has implications for selection, training, and development of TTO personnel and other relevant stakeholders, including faculty members.

Resource allocation decisions must also be driven by strategic choices the university makes regarding various modes of technology transfer. Recall that universities can choose among a variety of "outputs" to emphasize, including licensing, startups, sponsored research and other mechanisms of technology transfer that are focused more directly on stimulating economic and regional development, such as incubators and science parks. Licensing and sponsored research yield revenue, while equity from startups may generate a long-term payoff. Universities that stress economic development outcomes are advised to focus on startups since these companies can potentially create jobs in the local region or state. Note also that while a startup strategy entails higher risk (since the probability of failure for new companies is relatively high), it also can potentially generate high returns if the startup is taken public. However, a startup strategy entails additional resources, if the university chooses to assist the academic entrepreneur in launching and developing their startup.

A strategic approach to university technology transfer should also address *implementation* issues. These refer to the organization processes and structural choices that a university must make in order to execute its technology transfer priorities. Our literature review highlighted the importance of human resource management practices. Several qualitative studies (e.g. Siegel et al., 2004) indicate that there are deficiencies in the TTO, with respect to marketing skills and entrepreneurial experience. Unfortunately, field research (Markman et al., 2004a) has also revealed TTOs are not actively recruiting individuals with such skills and experience. Instead, representative institutions appear to be focusing on expertise in patent law and licensing or technical expertise. Training and development programs for TTO personnel are advised, along with additional administrative support for this activity, since many TTOs lack sufficient resources and competencies to identify the most commercially viable inventions.

Another conclusion that emerges from the literature review is that implementation issues intersect formulation issues at the point where resources are assigned. Given the dual agency role assumed by technology licensing officers (Jensen et al., 2003), a key resource issue is the design of incentives for TTOs to accomplish their tasks. Research has shown that career paths for university technology licensing officers are limited and often of short duration (Markman et al., 2004a), which implies that incentives should be directed toward creating immediate feedback and rewards (i.e. cash) to elicit the desired behaviors.

Qualitative studies also clearly indicate that information flows between researchers and the TTO must be improved. The first step is for the TTO, working in conjunction with university administration, to be more proactive in eliciting invention disclosures. Also, faculty members expressing an interest in forming a startup or sourcing for sponsored research opportunities, information, and even training on "how to do it" should be able to access such information from the TTO. Given that the formation of a startup involves activities and skills not typically associated with the competencies of a laboratory scientist, universities should utilize their business school faculty and staff to provide training and mentoring to the academic entrepreneur.

The end result is an expansion of the TTO's role as a boundary spanner to include managerial and "softer" business skills in order to foster additional entrepreneurial activity at the university. Successful implementation of this approach requires thinking of the technology transfer and entrepreneurial processes in tandem, which calls for a university level *curriculum* approach to an affirmative training and development program to encourage, support, and accelerate startups.

Fig. 2 illustrates the elements of a technological entrepreneurship curriculum that, while commonly encountered in business schools, can also be applied to technology transfer stakeholders (academic entrepreneur, TTO officer, incubator manager, and small firm licensee) involved in startup formation. Note that the curriculum is broad in scope, in terms of who participates in the creation and dissemination of knowledge regarding entrepreneurship, but also provides in-depth coverage. Here, the continual creation of new knowledge regarding university startups resides with the faculty researcher. Thus, incentives should be created for faculty within the university to expand their research domains to include questions related to innovation and entrepreneurship from technical and managerial perspectives. Universities should also consider establishing a formal program that allows successful faculty entrepreneurs to serve as role models and mentors

Faculty	**Institution**	**TTO Stakeholders**
Interdisciplinary theory	Incubator/Technology Park	Entrepreneurship courses
Evaluation/Policy research	Technology transfer	Technology familiarization
Practitioner research	Knowledge clusters	Internships
Academic conferences	Angel Network	Idea labs
Research workshops	Venture forum	Business plan competitions
Ph.D. program		Venture forum

Fig. 2. Example of a Complete Technological Entrepreneurship Curriculum.

for faculty, students, and post-docs who wish to engage in new venture creation. The implication of such an initiative is that the entrepreneurship curriculum must be driven from the top of the hierarchy and embedded in the institutional priorities, design principles and measurement systems of the university.

According to Fig. 2, the cadre of faculty conducting research on technology transfer and entrepreneurship (a growing number at many institutions) should also be responsible for the creation of entrepreneurship courses and training programs for TTO stakeholders. This closes the loop between knowing and doing. A standard academic curriculum is focused on knowledge acquisition. In contrast, to be immediately useful, the design principle for the training and educational programs we propose should be based on a process perspective (i.e. the new venture startup cycle) and therefore must be oriented toward overcoming problems entrepreneurs face in developing a successful commercial venture. Stakeholders can acquire knowledge in the area they most need, based on the problems they encounter in the startup stage of the venture (e.g. venture capital funding) without having to take all courses. Note that courses can be designed and taught by faculty members across divisions of the university with the appropriate experience or knowledge set. Ideally, such programs should be managed by top-level university administrators. Wake Forest and Rensselaer Polytechnic Institute have created top-level administrative positions in entrepreneurship (e.g. a Vice Provost for Entrepreneurship). Such an action highlights the importance of these initiatives within the university and also sends an important signal to other stakeholders (e.g. faculty, donors) that the university places a high value on such activities.

As Fig. 3 illustrates, the primary role of such a program is training on the "soft drivers" of business venturing. Fig. 3 identifies specific courses aimed at addressing stylized conclusions regarding entrepreneurial success from research. For example, research has shown that successful entrepreneurs have cognitive routines that allow them to recover quickly from failure, such that the fear of failure, while always present, does not represent a hindrance to the desire to launch new ventures. Research has also revealed that serial entrepreneurs are on average more successful, which suggests the importance of learning and knowledge accumulation of the "how to" aspects of new venture creation. Therefore, entrepreneurship courses designed for TTO stakeholders should focus both on the mechanics of launching a venture and the economic/strategic implications of the technologies being commercialized. Finally, for the TTO officer or entrepreneur who is not familiar with the specifics of the technology, technology survey courses, taught by faculty scientists, are recommended.

Figs. 2 and 3 suggest that the role of the institution in the implementation of a technology entrepreneurship curriculum is to create organizational structures such as a venture forum, incubator or technology park, in which technology transfer activities are given an institutional context and recognition. More importantly, field research has demonstrated that attention must be paid to organizational design issues. For example, if the university is serious about increasing the rate of startup activity, then resource allocation and monitoring decisions should be made by top university administrators. Thus, the entrepreneurship curriculum and its related educational program must be institutionally embedded throughout the university in

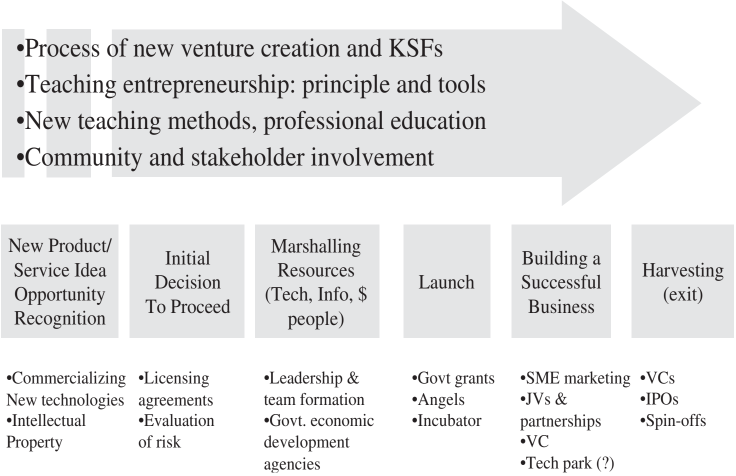

Fig. 3. A Phase-Model of a Technological Entrepreneurship Program for TTO Stakeholders.

order to maximize its impact on the effectiveness of the technology transfer process. More specifically, such initiatives cannot be primarily driven by the TTO, business or engineering school with an entrepreneurship program, or individual stakeholders. Given that the problem is multi-level in nature and involves the simultaneous actions of multiple stakeholders, it must be addressed from the highest strategic level of the university. Thus, specific boundary-spanning roles must be assigned to the TTO and business school. Such a top-down driven approach attenuates the possibility of role conflict and information gaps caused by the adhoc or organic design typically encountered in an academic environment.

Decisions regarding organizational design must be accompanied by appropriate staffing and compensation policies with respect to the TTO and other university staff directly responsible for startups, such as incubator and science park management. For example, TTOs are advised to hire staff with a broad array of skills that cover the spectrum of the new venture creation cycle (Fig. 3). Additionally, preliminary research indicates that incentives matter because TTO officers and related stakeholders act as dual agents for the university and the faculty member. Therefore, consistent with agency theory, an appropriate mechanism should be employed that aligns the interests of the agents with their principals, in order to elicit the optimal level of effort. Incentive structures fall into two categories. Pay for effort (behavior) or pay for results (productivity). Appropriate compensation systems balance the mix of both types in order to encourage the appropriate efforts, especially when team effort matters, to sustain productivity levels for the long term.

Appropriate incentives must also be designed for faculty members who constitute the source of invention disclosures – the critical input in university technology transfer. As discussed extensively, there is a natural conflict of interests generated by the traditional academic reward system, which is focused on peer-reviewed publication of (generally) primary research, and the technology transfer reward system, which is focused on revenue generation from (generally) applied research. This dilemma can only be resolved at the highest levels of the university administration because it is the direct result of top-level priorities. In a sense, the university can view the faculty member as an agent of its strategic intent. When an agent is exposed to a conflict of interest generated by the conflicting goals of the principal, only the latter can resolve it.

In conclusion, our review of the literature suggests that universities wishing to be productive in technology transfer, especially in terms of generating numerous spinouts, should adopt a strategic approach to the commercialization of their intellectual property portfolios. Such an approach begins with establishing clear priorities at the university level, combined with appropriate organization design choices focused on eliciting an ample supply of invention disclosures. It also entails changing incentives to encourage entrepreneurial behaviors and establishing a university-level process-based educational curriculum for all stakeholders engaged in technology transfer.

NOTES

1. Some authors assume a truncated normal or exponential distribution for the inefficiency disturbance (see Sena, 1999).
2. See Thursby et al. (2001) for an extensive description of this survey.

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THE BAYH-DOLE ACT AND HIGH-TECHNOLOGY ENTREPRENEURSHIP IN U.S. UNIVERSITIES: CHICKEN, EGG, OR SOMETHING ELSE?[☆]

David C. Mowery

ABSTRACT

Academic entrepreneurship (defined in this case as the involvement of university faculty and researchers in commercial development of their inventions) has been a unique characteristic of the U.S. higher education system for most of the past 100 years. This long history of interaction, as well as academic patenting and licensing, contributed to the formation of the political coalitions that led to the passage of the Bayh-Dole Act in 1980. This paper reviews the evidence on university–industry interactions and technology transfer, focusing in particular on the role of the

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Bayh-Dole Act in (allegedly) transforming this relationship. I also examine recent research that considers the Act's effects on the formation of new, knowledge-based firms that seek to exploit university inventions. This research is in its infancy, and much remains to be done if we are to better understand the relationships among high-technology entrepreneurship, the foundation of new firms, and the patenting and licensing activities of U.S. universities before and after 1980.

1. INTRODUCTION

During the 1990s, the era of the "New Economy," numerous observers (including some, who less than 10 years earlier had written off the U.S. economy as doomed to economic decline in the face of competition from such economic powerhouses as Japan) hailed the resurgent economy in the United States as an illustration of the power of high-technology entrepreneurship. The new firms that a decade earlier had been criticized by such authorities as the MIT Commission on Industrial Productivity[1] for their failure to compete successfully against large non-U.S. firms were seen as important sources of economic dynamism and employment growth. Indeed, the transformation in U.S. economic performance between the 1980s and 1990s is only slightly less remarkable than the failure of most experts in academia, government, and industry to predict it.

A central "cause" of U.S. economic resurgence in the 1990s, according to the experts who arguably had misdiagnosed the causes of U.S. economic decline during the 1980s, was university–industry research collaboration and technology transfer, especially the licensing by U.S. universities of patented inventions. Moreover, many of these accounts attributed to the increase in U.S. university patenting and licensing after 1980, as well as the broader growth in high-technology entrepreneurship within the U.S. economy during the 1990s, to changes in U.S. public policy during the 1980s, particularly the Bayh-Dole Act of 1980.[2] Implicit in many of these characterizations was the argument that university patenting and licensing were essential to growth in the economic contributions of U.S. university research.[3] Similar characterizations of the effects of the Bayh-Dole Act have been articulated by the President of the Association of American Universities,[4] the Commissioner of the U.S. Patent and Trademark Office,[5] and the *Technology Review*.[6]

Although it seems clear that the criticism of high-technology startups that was widespread during the period of pessimism over U.S. competitiveness was overstated, the recent focus on patenting and licensing as the essential ingredient in university–industry collaboration and knowledge transfer may be no less exaggerated. The emphasis on the Bayh-Dole Act as a catalyst to these interactions also seems somewhat misplaced, ignoring as it does the long history, extending to at least the earliest decades of the 20th century, of collaboration and knowledge flows between universities and industry in the United States. This chapter reviews the evidence on university–industry interactions and technology transfer, focusing in particular on the role of the Bayh-Dole Act in (allegedly) transforming this relationship. I also examine recent research that considers the Act's effects on the formation of new, knowledge-based firms that seek to exploit university inventions. This research is in its infancy, and much remains to be done, if we are to better understand the relationships among high-technology entrepreneurship, the foundation of new firms, and the patenting and licensing activities of U.S. universities before and after 1980.

2. HOW DOES ACADEMIC RESEARCH INFLUENCE INDUSTRIAL INNOVATION? A REVIEW OF RECENT STUDIES

A number of recent studies based on interviews and surveys of senior industrial managers in industries ranging from pharmaceuticals to electrical equipments have examined the influence of university research on industrial innovation. All of these studies (GUIRR, 1991; Mansfield, 1991; Levin et al., 1987; Cohen, Nelson, & Walsh, 2002) emphasize the significance of interindustry differences in the relationship between university and industrial innovation. The biomedical sector, especially biotechnology and pharmaceuticals, is unusual in that university research advances affect industrial innovation more significantly and directly in this field than is true of other sectors.

In these other technological and industrial fields, universities occasionally contributed relevant "inventions," but most commercially significant inventions came from nonacademic research. The incremental advances that were the primary focus of firms', R&D activities in these sectors were largely the domain of industrial research, problem-solving, and development. University research contributed to technological advances by enhancing knowledge of the fundamental physics and chemistry underlying manufacturing processes and product innovation, and experimental techniques (including instrumentation).

The studies by Levin et al. (1987) and Cohen et al. (2002) summarize industrial R&D managers' views on the relevance to industrial innovation of various fields of university research (Table 1 summarizes the results discussed in Levin et al., 1987). Virtually all of the fields of university research that were rated as "important" or "very important" for their innovative activities by survey respondents in both studies were related to engineering or applied sciences. These fields of U.S. university research frequently developed in close collaboration with industry. Interestingly, with the exception of chemistry, few basic sciences appear on the list of university research fields deemed by industry respondents to be relevant to their innovative activities.

The absence of fields such as physics and mathematics in Table 1, however, should not be interpreted as indicating that academic research in these fields does not contribute to technical advance in industry. Instead,

Table 1. The Relevance of University Science to Industrial Technology.

Science	No. of Industries with "Relevance" Scores		Selected Industries for which the Reported "Relevance" of University Research was Large (>6)
	⩾5	⩾6	
Biology	12	3	Animal feed, drugs, processed fruits/vegetables
Chemistry	19	3	Animal feed, meat products, drugs
Geology	0	0	None
Mathematics	5	1	Optical instruments
Physics	4	2	Optical instruments, electronics
Agricultural science	17	7	Pesticides, animal feed, fertilizers, food products
Applied math/operations research	16	2	Meat products, logging/sawmills
Computer science	34	10	Optical instruments, logging/sawmills, paper machinery
Materials science	29	8	Synthetic rubber, nonferrous metals
Medical science	7	3	Surgical/medical instruments, drugs, coffee
Metallurgy	21	6	Nonferrous metals, fabricated metal products
Chemical engineering	19	6	Canned foods, fertilizers, malt beverages
Electrical engineering	22	2	Semiconductors, scientific instruments
Mechanical engineering	28	9	Hand tools, specialized industrial machinery

Source: Previously unpublished data from the Yale Survey on Appropriability and Technological Opportunity in Industry. For a description of the survey, see Levin et al. (1987).

these results reflect the fact that the effects on industrial innovation of basic research findings in such areas as physics, mathematics, and the physical sciences are realized only after a considerable lag. Moreover, application of academic research results may require that these advances be incorporated into the applied sciences, such as chemical engineering, electrical engineering, and material sciences. The survey results summarized in Cohen et al. (2002) indicate that in most industries, university research results play a minor role in triggering new industrial R&D projects; instead, the stimuli originate with customers or from manufacturing operations. Pharmaceuticals is an exception, since university research in this field often triggers industrial R&D projects.

Cohen et al. (2002) further report that the results of "public research" performed in government laboratories and universities were used more frequently by U.S. industrial firms (on average, in 29.3% of industrial R&D projects) than prototypes emerging from these external sources of research (used in an average of 8.3% of industrial R&D projects). A similar portrait of the relative importance of different outputs of university and public-laboratory research emerges from the responses to questions about the importance to industrial R&D of various information channels (Table 2). Although pharmaceuticals is unusual in assigning considerable importance to patents and license agreements involving universities and public laboratories, respondents from this industry still rated research publications and conferences as a more important source of information. For most industries, patents and licenses involving inventions from university or

Table 2. Importance to Industrial R&D of Sources of Information on Public R&D (including university research).

Information Source	% Rating it as "Very Important" for Industrial R&D
Publications & reports	41.2
Informal interaction	35.6
Meetings & conferences	35.1
Consulting	31.8
Contract research	20.9
Recent hires	19.6
Cooperative R&D projects	17.9
Patents	17.5
Licenses	9.5
Personnel exchange	5.8

Source: Cohen et al. (2002).

public laboratories were reported to be of little importance, compared with publications, conferences, informal interaction with university researchers, and consulting.

The consistency in the findings of the Levin et al. study and the more recent survey conducted by Cohen and colleagues is striking – the "New Economy" notwithstanding, the late 1990s do not present a sharp contrast with the late 1970s. At the same time, it is important to highlight the fact that these surveys focus primarily on established firms, and the Levin study in particular is concerned almost exclusively with manufacturing – such important "service sector" industries as software (which scarcely existed at the time of the Levin survey) are excluded. Additional research on the relationship between the innovative activities of smaller firms, especially those in knowledge-intensive industries, and better coverage of innovation in the nonmanufacturing sector are needed in future research. We also lack comparably detailed information on the relationship between academic research and firms' innovative activities in other industrial economies.

Nonetheless, these studies highlight a difference in the relationship between academic research and industrial innovation in the biomedical field and those of other knowledge-intensive sectors. This work also suggests that academic research rarely produces "prototypes" of inventions for development and commercialization by industry – instead, academic research informs the methods and disciplines employed by firms in their R&D facilities. Finally, the channels rated by industrial R&D managers as most important in this complex interaction between academic and industrial innovation rarely include patents and licenses. Perhaps the most striking aspect of these survey and interview results is their limited influence on the design of recent policy initiatives to enhance the contributions of university research to industrial innovation.

3. THE BAYH-DOLE ACT AND ACADEMIC PATENTING IN THE UNITED STATES

3.1. The "Pre-Bayh-Dole" Era

The pre-1980 patenting activities of U.S. universities built on research collaborations between university and industrial researchers that spanned many channels of technology, and knowledge exchange, including publishing, training of industrial researchers, faculty consulting, and other activities. University–industry collaboration in turn was facilitated by the unusual structure of the U.S. higher education system (especially by comparison with those of other industrial economies) during the 20th century. The U.S. higher education system was significantly larger, included a very heterogeneous collection of institutions (religious and secular, public and private, large and small, etc.), lacked any centralized national administrative control, and encouraged considerable interinstitutional competition for students, faculty, resources, and prestige (see Geiger, 1986, 1993; Trow, 1979, 1991, among other discussions). In addition, the reliance by many public institutions of higher education on ''local'' (state-level) sources for political and financial support further enhanced their incentives to develop collaborative relationships with regional industrial and agricultural establishments. The structure of the U.S. higher education system thus strengthened incentives for faculty and academic administrators to collaborate in research and other activities with industry (and to do so through channels that included much more than patenting and licensing) long before the Bayh-Dole Act's passage.

The collaboration between university and industrial researchers, combined with the focus of many U.S. university researchers on scientific problems with important industrial, agricultural, or other public applications, meant that a number of U.S. universities patented faculty inventions throughout the 20th century. Nevertheless, despite the adoption by a growing number of universities of formal patent policies by the 1950s, many of these policies, especially those at medical schools, prohibited patenting of inventions, and university patenting was far less widespread than was true of the post-1980 period. Collaboration between university and industrial researchers, combined with the focus of many U.S. university researchers on problems with important industrial or agricultural applications, meant that a number of U.S. universities patented faculty inventions throughout the 20th century. Although U.S. universities were patenting patent faculty inventions as early as the 1920s, few institutions had developed formal patent policies prior to the late 1940s, and a number of these policies embodied considerable ambivalence toward patenting. Many of the universities active in patenting chose not to manage patenting and licensing themselves, in many cases because of concern over the political consequences of a visible role in profiting from faculty inventions, and in other cases because of fears that their nonprofit tax status could be jeopardized.[7]

The Research Corporation, founded in 1912 by Frederick Cottrell, a University of California faculty inventor, who wished to use the licensing revenues from his patents to support scientific research, assumed a prominent role as a manager of university patents and licensing. Even in these early decades of patenting and licensing, biomedical technologies accounted for a disproportionate share of licensing revenues for the Research Corporation, and other early university licensors, such as the Wisconsin Alumni Research Foundation. Public universities were more heavily represented in patenting than private universities during the 1925–1945 period.

World War II and the Cold War that followed transformed the structure of the U.S. national innovation system (Mowery & Rosenberg, 1998). Nowhere was this transformation more dramatic than in U.S. universities. Formerly funded largely by state governments, the U.S. Agriculture Department, and industry, academic research experienced a surge of federal funding. As the growth in university–industry research links had done during the 1920s and 1930s, increased federal funding of university research strengthened two motives for university involvement in patenting. First, the expanded scale of the academic research enterprise increased the probability that universities would produce patentable inventions. Second, many federal research sponsors required the development of a formal patent policy.

As in the pre-war period, many universities during the 1950s and 1960s "outsourced" patent management (McKusick, 1948). Data on Research Corporation Invention Administration Agreements (IAAs) reveal the dimensions of this trend: As of 1940, only three of the nation's 89 "Research Universities" (as classified by the Carnegie Commission's 1973 taxonomy) had signed IAAs with the Research Corporation. By 1950 this number had increased to 20 and by the mid-1960s nearly two-thirds of the Carnegie Commission's Research Universities were Research Corporation clients.

Well into the 1960s, many U.S. universities continued to avoid direct involvement in patent administration, and others maintained a "hands off" attitude toward patents altogether. Columbia's policy left patenting to the inventor and patent administration to the Research Corporation, stating that "it is not deemed within the sphere of the University's scholarly objectives" to hold patents, and Harvard, Chicago, Yale, and Johns Hopkins adopted similar positions. All of these universities, as well as Ohio State and Pennsylvania, discouraged or prohibited medical patents. Other universities allowed patents on biomedical inventions only if it was clear that patenting would be in the public interest.[8] This institutional ambivalence toward patenting began to change during the 1960s, although the prohibitions on medical patenting at Columbia, Harvard, Johns Hopkins, and Chicago were not dropped until the 1970s. The pace of change accelerated during the 1970s, in response to federal initiatives in R&D funding and patent policy.

The decade of the 1970s represented a watershed in U.S. University patenting and licensing. Universities expanded their patenting, especially in biomedical fields, and assumed a more prominent role in managing their patenting and licensing activities, supplanting the Research Corporation. Agreements between individual government research funding agencies and universities contributed to the growth of patenting during the 1970s. Private universities also expanded their patenting and licensing during this decade. The number of universities establishing technology transfer offices and/or hiring technology transfer officers began to grow in the 1970s. Although the Act was followed by a wave of entry by universities into management of patenting and licensing, growth in these activities was well established by the late 1970s. Indeed, as we note below, lobbying by U.S. research universities was one of the several factors behind the passage of the Bayh-Dole Act in 1980.

3.1.1. Sources of Growth in University Patenting during the 1970s

The growth of university patenting during the 1970s reflected changes in the sources of academic research funding and advances in biomedical research that were basic research results with considerable promise for profitable application in industry, a very unusual combination. In addition, of course, reductions in the rate of growth in federal funding of university research during the early 1970s heightened the interest of university faculty and administrators in the potential revenues associated with licensing these research advances. Increased academic interest in licensing revenues combined with growing dissatisfaction with the performance of the leading institutional "agent" charged with responsibility for handling many universities' patenting and licensing transactions, the Research Corporation, to produce entry by a number of universities (particularly private universities) into direct management of their patenting and licensing.

Just as would be true of the Bayh-Dole bill at the end of the 1970s, increased university interest in managing patents and licenses during the late 1960s was associated as both cause and effect with changes in federal policy toward patenting of federally funded research. Pressure from universities led federal agencies to develop new agency-specific waivers for patent rights, and this policy shift contributed to growth in university patenting during the 1970s.

In response to criticism of its management of intellectual property rights associated with publicly funded pharmaceutical research (Harbridge House, 1968a, p. II-21; GAO, 1968, p. 11), the federal Department of Health, Education and Welfare (HEW), which housed the National Institutes of

Health, in 1968 established Institutional Patent Agreements (IPAs) that gave universities with "approved technology transfer capability" the right to retain title to agency-funded patents.[9] Although exclusive licensing was allowed under the terms of the IPAs, these agreements typically required that academic institutions favor nonexclusive licenses for their inventions.

As part of the policy shift that included the development of IPAs, HEW began to act more quickly on requests from universities and other research performers for title to the intellectual property resulting from federally funded research. Between 1969 and 1974 the agency approved 90% of petitions for title and negotiated IPAs with 72 universities and nonprofit institutions (Weissman, 1989). The National Science Foundation (NSF) instituted a similar IPA program in 1973, and the Department of Defense began in the mid-1960s to allow universities with approved patent policies to retain title to inventions resulting from federally funded research.

Approximately one quarter (49/212) of the Carnegie Research and Doctoral Universities had IPAs with either HEW or NSF during the 1970s. These institutions accounted for 73% of university patenting during the 1970s, and continued to account for 55% of university patenting during the 1980s. Another 27 of these universities petitioned the government for title during the 1974–1980 period (as indicated by acknowledgements in the "government interest" section of their patents). Together, institutions that either petitioned for rights or had IPAs accounted for 92% of patents during the 1970s, and 85% of university patents during the 1980s. As we note below, many of the most active patenters in the post-Bayh-Dole era were among the leaders in patenting government-funded research during the 1970s.

During the 1970s, the institutional ambivalence that had characterized the pre-1940 debates within MIT and other leading universities over direct involvement in management of patenting subsided, for reasons that are not well understood, and a number of universities entered into or significantly expanded their direct management of patenting and licensing. Private universities, in particular, expanded their patenting and licensing rapidly during this decade – their share of university-assigned patents grew from 14% in 1960 to 45% in 1980. The number of universities establishing technology transfer offices and/or hiring technology transfer officers began to grow in the late 1960s, well before the passage of the Bayh-Dole Act. Although the Act was followed by a wave of entry by universities into management of patenting and licensing, growth in these activities was apparent by the late 1970s. Indeed, lobbying by U.S. research universities was one of the several factors behind the passage of the Bayh-Dole Act in 1980. The Act therefore is as much an effect as a cause of expanded patenting and licensing by U.S. universities during the post-1960 period.

3.2. Origins of the Bayh-Dole Act

By the 1970s, the developments described above meant that many U.S. universities were able to patent the results of federally funded research via agency-specific IPAs or similar programs at the Defense Department, as well as through case-by-case petitions. But HEW policy discussions in the late 1970s, triggered concern among many U.S. research universities that their ability to patent and license government funded inventions might be curtailed. These concerns, along with growing dissatisfaction within Congress and the industrial community over the lack of uniformity in patent rights to inventions resulting from federally funded research, provided the immediate impetus for the introduction of the bill in 1978 that eventually became the Bayh-Dole Act.

In August 1977, HEW's Office of the General Counsel expressed concern that university patents and licenses, particularly exclusive licenses, could contribute to higher healthcare costs (Eskridge, 1978). The Department ordered a review of its patent policy, including a reconsideration of whether universities' rights to negotiate exclusive licenses should be curtailed.[10] During the ensuing 12-month review by HEW of its patent policies, the agency deferred decisions on 30 petitions for patent rights and 3 requests for IPAs.

In response to HEW's review of its patent policies, "[u]niversities got upset and complained to Congress" (Broad, 1979a, p. 476). Heaton, Hill, and Windham (2000) notes that a patent attorney from Purdue University and a congressional staffer, who previously had worked at the University of Arizona, both of which sought more liberal policies toward patenting publicly funded research, respectively asked Senators Bayh and Dole to introduce a bill liberalizing and rationalizing federal policy. In September 1978, Senator Robert Dole (R-KS) held a press conference where he criticized HEW for "stonewalling" university patenting (commenting, "rarely have we witnessed a more hideous example of overmanagement by the bureaucracy") and announced his intention to introduce a bill to remedy the situation (Eskridge, 1978, p. 605). On September 13, 1978, Senators Birch Bayh (D-IN) and Dole introduced S. 414, the University and Small Business Patent Act.

The Act proposed a uniform federal patent policy that gave universities and small businesses rights to any patents resulting from government-funded research.[11] The bill lacked provisions that had been included in most IPAs, including the requirement that a participating university must have an "approved technology transfer" capability. In contrast to the language of many IPAs between universities and HEW, the bill imposed no restrictions on the negotiation by universities and other research institutions of exclusive licensing agreements.[12]

Many members of Congress had long opposed any federal grant of ownership of patents to research performers or contractors (Broad, 1979b). The Bayh-Dole bill nevertheless attracted little opposition. The bill's focus on securing patent rights for only universities and small business weakened the argument that such patent-ownership policies would favor big business.[13] The bill's introduction in the midst of debates over U.S. economic competitiveness also proved crucial to its passage. An article in *Science* discussing the debate on the Bayh-Dole bill observed that:

> The critics of such legislation, who in the past have railed about the "giveaway of public funds" have grown unusually quiet. The reason seems clear. Industrial innovation has become a buzzword in bureaucratic circles … the patent transfer people have latched onto this issue. It's about time, they say, to cut the red tape that saps the incentive to be inventive. (Broad, 1979b, p. 479)

A number of universities, including Harvard University, Stanford University, the University of California,[14] and the Massachusetts Institute of Technology, lobbied for passage of the bill, and throughout the debates representatives of these and other research universities were active in "commenting and helping to develop the final language" of the House and Senate versions of the bill (Barrett, 1980). Witnesses from active institutional patenters (including Stanford, Purdue, and Wisconsin) testified in support of the bill, as did representatives from various university associations (including the American Council on Education, the Society for University Patent Administrators, and the National Association of College and University Business Officers) and the Research Corporation. The support of these groups was supplemented by positive statements from witnesses representing small businesses and small business trade groups, like the National Small Business Association, the Small Business Legislative Council, and the American Society of Inventors. But the prominent role of research universities in lobbying for the Act highlights the extent to which the Bayh-Dole Act was a response to increased university patenting during the 1970s, rather than an exogenous "cause" of the post-1980 growth in patenting and licensing.

The Bayh-Dole Patent and Trademark Amendments Act of 1980 provided blanket permission for performers of federally funded research, to file for patents on the results of such research and to grant licenses for these patents, including exclusive licenses, to other parties. The Act facilitated university patenting and licensing in at least two ways. First, it replaced a web of IPAs that had been negotiated between individual universities and federal agencies with a uniform policy. Second, the Act's provisions expressed congressional support for the negotiation of exclusive licenses between universities and industrial firms for the results of federally funded research.

The passage of the Bayh-Dole Act was one part of a broader shift in U.S. policy toward stronger intellectual property rights.[15] Among the most important of these policy initiatives was the establishment of the Court of Appeals for the Federal Circuit (CAFC) in 1982. Established to serve as the court of final appeal for patent cases throughout the federal judiciary, the CAFC soon emerged as a strong champion of patentholder rights.[16] But even before the establishment of the CAFC, the 1980 U.S. Supreme Court decision in *Diamond v. Chakrabarty* upheld the validity of a broad patent in the new industry of biotechnology, facilitating the patenting and licensing of inventions in this sector. The origins of Bayh-Dole thus must be viewed in the context of this larger shift in U.S. policy toward intellectual property rights.

3.3. The Effects of Bayh-Dole

How did the Bayh-Dole Act affect patenting by U.S. universities? Since overall patenting in the United States grew during this period, indicators of university patenting need to be normalized by overall trends in patenting or R&D spending. Figs. 1 and 2 present two such indicators that span the period before and after the Bayh-Dole Act. Fig. 1 depicts U.S. research university patenting as a share of domestically assigned U.S. patents during 1963–1999, in order to remove the effects of increased patenting in the United States by foreign firms and inventors during the late 20th century. Universities increased their share of patenting from less than 0.3% in 1963 to nearly 4% by 1999, but the rate of growth in this share begins to accelerate before, rather than after 1980. Fig. 2 plots the ratio of aggregate university patenting at time t to aggregate academic R&D expenditures at time $t-1$, for application years 1963–1993.[17] The figure reveals an increase

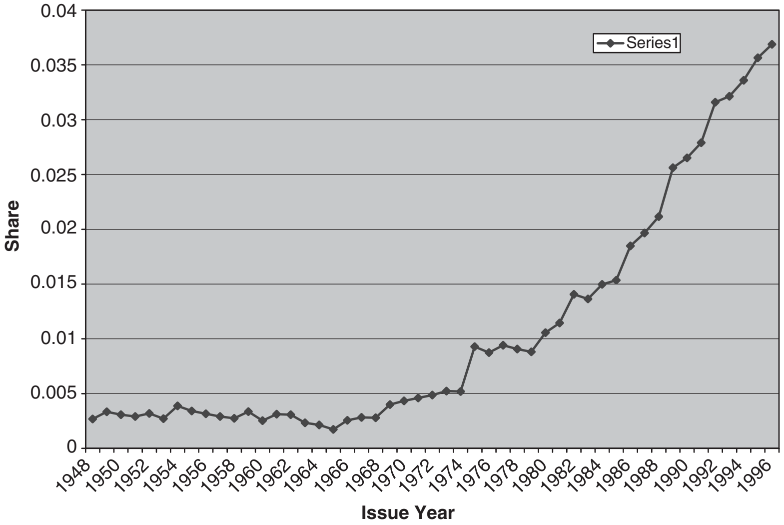

Fig. 1. University Patents as a Share of All Patents w/ Domestic Assignees, 1948–1996.

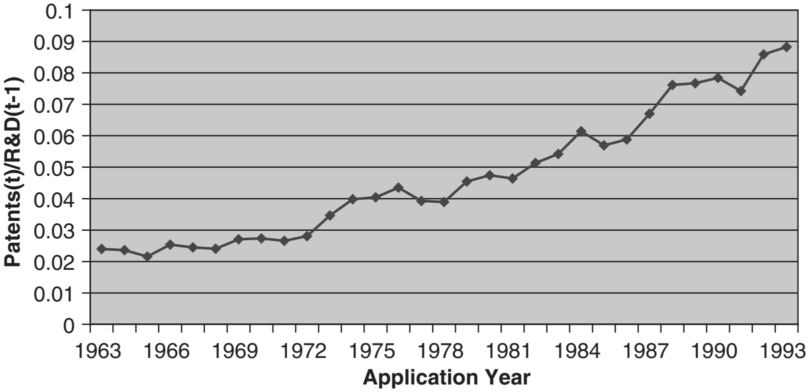

Fig. 2. University Patents Per R&D Dollar, 1963–1993.

in aggregate university "patent propensity" after 1981 (as pointed out by Henderson, Jaffe, & Trajtenberg, 1998), but this is the continuation of a trend that dates at least as far back as the early 1970s; there is no evidence of a "structural break" in trends in patent propensity after Bayh-Dole.[18]

Another issue of interest in academic patenting is the distribution among technology fields of university patents during the pre- and post-Bayh-Dole periods. Fig. 3 displays this information for U.S. research university patents during 1960–1999, and highlights the growing importance of biomedical patents in the patenting activities of the leading U.S. universities during the period. Nonbiomedical university patents increased by 90% from the 1968–1970 period to the 1978–1980 period, but biomedical university patents increased by 295%. This rapid growth in biomedical patents also reflected growth of the IPA program of the major biomedical funding agency (HEW) during the 1970s. The increased share of biomedical disciplines within overall federal academic R&D funding, the dramatic advances in biomedical science that occurred during the 1960s and 1970s, and the strong industrial interest in the results of this biomedical research, all affected the growth of university patenting during this period.

Moreover, the trends in Fig. 3, if anything, understate the extent to which biomedical inventions dominate universities' licensing income. Licensing data from the University of California 9-campus system, Stanford University, and Columbia University, cited in Mowery et al. (2004), show that biomedical patents accounted for more than 66–85% of the gross licensing revenues of these academic institutions by the mid-1990s. Another

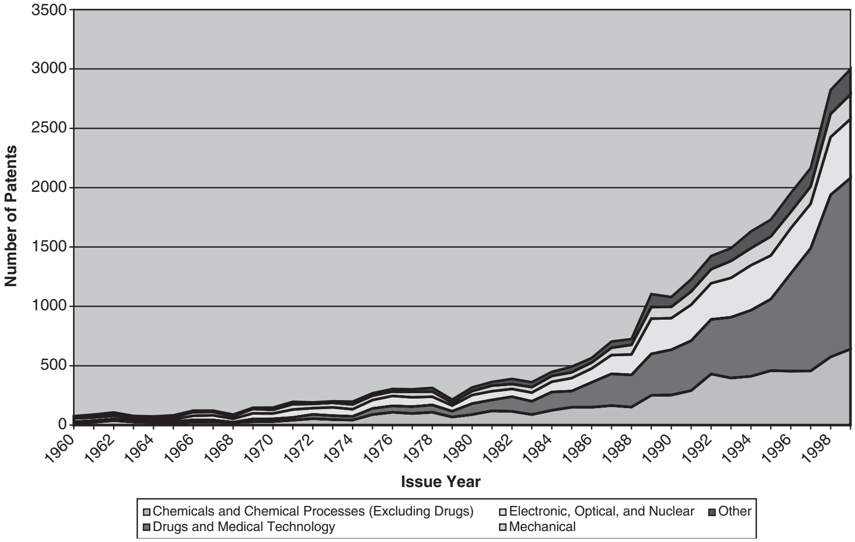

Fig. 3. Technology Field of Carnegie University Patents, 1960–1999.

important point about these institutions' licensing revenues is the small size of overall academic budgets that they represent. To cite only one example, the annual net licensing revenues of the University of California system after deduction of operating expenses and payments to inventors averaged roughly $16 million during fiscal 1999–2003, less than 0.5% of the system's annual research expenditures of nearly $3 billion. Keeping in mind that the UC system is among the U.S. academic institutions with the highest gross licensing revenues, it is obvious that the financial contributions to university operating budgets from patent licensing are trivial in most cases, and negative for a great many institutions.

Another aspect of universities' licensing activities that is directly relevant to discussions of "academic entrepreneurship" concerns the characteristics of the firms licensing university patents. Although, many of the positive evaluations of the economic effects of the Bayh-Dole Act highlight the role of small-firm startups as beneficiaries of these licensing transactions, the data compiled by the Association of University Technology Managers (AUTM, 2001, 2002) suggest that firms founded specifically to commercialize the licensed technology account for a minority of licensees. The AUTM annual reports for 2001 and 2002 indicate that 14–16% of university patent licensees in these years were startup firms founded to exploit the licensed inventions. More than one-half (50–54%) of academic licensees during this period were small (fewer than 500 employees) firms already in existence, while roughly one-third (32–33%) of licensees were large firms. The emphasis in recent academic research (DiGregorio & Shane, 2003) on the role of university "spinoffs" in the licensing activities of U.S. universities thus needs to be qualified by a recognition that such startups are much less significant in absolute numbers as licensees than large firms.

After Bayh-Dole, universities increased their involvement in management of patenting and licensing, setting up internal technology transfer offices to manage licensure of university patents. Fig. 4 shows the distribution of years of "entry" by universities into patenting and licensing, defined as the year in which the universities first devoted 0.5 FTE employees to "technology transfer activities" (AUTM, 1998). Although "entry" accelerated after Bayh-Dole, growth in this measure of university commitment to "technology transfer" predates Bayh-Dole. Longitudinal data on university licensing activities are less complete, but the available data indicate that in FY2000, U.S. universities signed more than 4000 license agreements, representing more than a doubling since FY1991 (AUTM, 2000).

Fig. 5 plots the patenting activity (number of patents, listed by year of application) by university for U.S. universities in the 1970s and 1980s. The

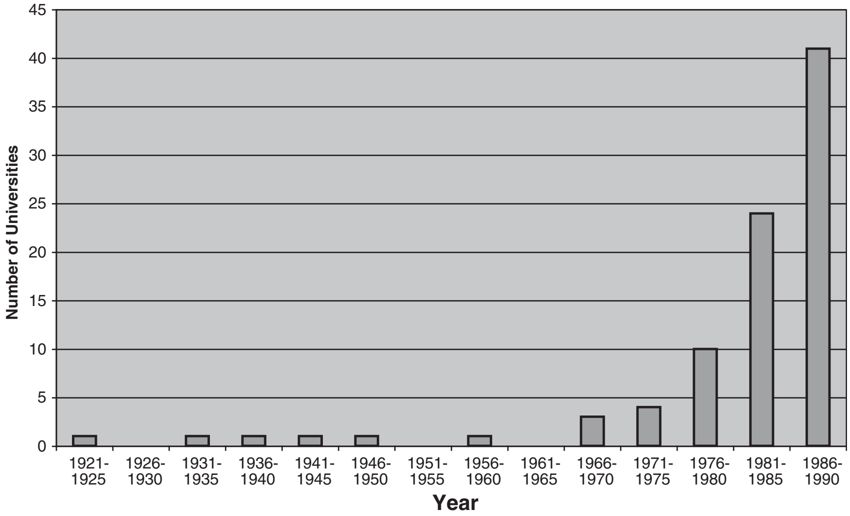

Fig. 4. Year of "Entry" into Technology Transfer Activities.

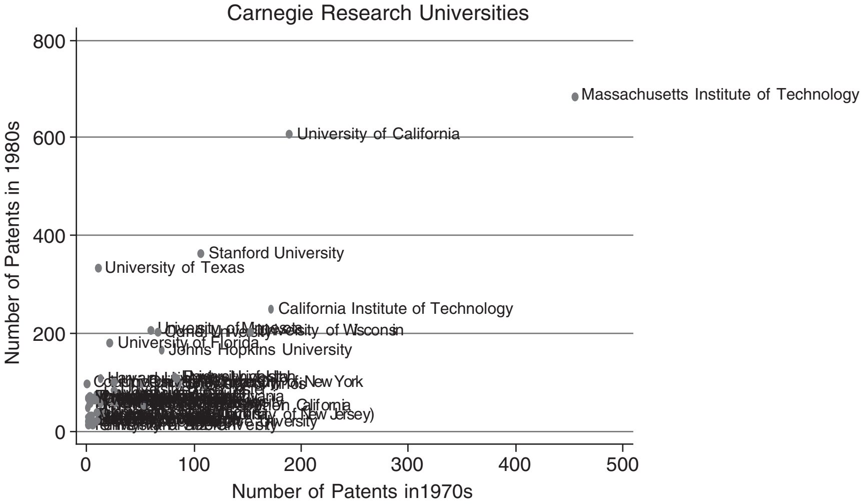

Fig. 5. U.S. Research University Patenting in the 1970s and 1980s.

leading institutional patenters in the 1970s were also the leaders in the 1980s, further underscoring the influence of the 1970s on patenting during the first decade of the "Bayh-Dole era." A log–log regression of volume of patenting in the 1980s on volume of patenting in the 1970s (for each of the 212 Carnegie research and doctoral universities) yields an estimated elasticity of 0.98.

The observations in the figure are weighted by patents per institution, a datum characterized by a very skewed distribution, and the visual correlation therefore is sensitive to outliers. A simple test that is less sensitive to outliers yields similar results, however – 38 of the 54 institutions (72%) in the top quartile of the distribution of institutional patenters for the 1970s are represented among the 53 institutions in the top quartile for the 1980s.

The characterizations of the catalytic effects of the Bayh-Dole Act that were mentioned in the Introduction to this paper cite little evidence in support of their claims beyond simple counts of university patents and licenses. But growth in both university patenting and licensing predates Bayh-Dole and is rooted in internationally unique characteristics of the U.S. higher education system. Nor does evidence of increased patenting and licensing by universities by itself indicate that university research discoveries are being transferred to industry more efficiently or commercialized more rapidly, as Colyvas, Crow, Gelijns, Mazzoleni, Nelson, & Rosenberg (2002) and Mowery, Nelson, Sampat, & Ziedonis (2001) point out. Current research thus provides mixed support at best for a central assumption of the Bayh-Dole Act, i.e., the argument that patenting and licensing are necessary for the transfer and commercial development of university inventions.

4. CASE STUDIES OF UNIVERSITY–INDUSTRY TECHNOLOGY TRANSFER

In order to shed light on the actual processes involved in university–industry technology transfer, we compiled a set of case studies of such transfer, all of which involve patented inventions that were subsequently licensed to firms. These case studies thus do not reveal as much as we would like about the other channels of technology transfer, but in almost all cases, other channels for interaction and knowledge exchange emerge as important complements to the licensing transactions. The case studies also highlight the field-specific and invention-specific differences in the technology transfer process and the role of patents and licenses in this process. There is substantial variation across the cases in the importance of patents and licenses, the role of the university, the importance and involvement of the academic inventor, and even the directionality and characteristics of the knowledge flows between university and industry.

The five case studies are the following:

1. *Cotransformation*: a process to transfer genes into mammalian cells (Columbia University).
2. *Gallium Nitride*: a semiconductor with both military and commercial applications (University of California).
3. *Xalatan*: a glaucoma treatment (Columbia University).
4. *Ames II Tests*: a bacteria assay for testing potential carcinogenic properties of pharmaceuticals, and cosmetics (University of California).
5. *Soluble CD4*: a prototype for a drug to fight AIDS (Columbia University).[19]

Columbia University's patenting and licensing activities were important to the development and commercialization of Xalatan, a glaucoma treatment. University patents and licenses were less important to transfer and commercialization, however, for two other inventions discussed in this paper (the Axel cotransformation process and Soluble CD4): firms learned about the inventions through informal scientific and technological communities and invested in commercialization without clearly established or exclusive property rights to the inventions.

Two other inventions (Gallium Nitride and the Ames II Tests) were licensed by inventor-founded start-ups after established firms elected not to license the inventions. These inventor-founders argued that protection for their intellectual property was important to the foundation of their firms, but it remains unclear whether patent protection was necessary for the commercial development of their inventions.

Previous work on university–industry technology transfer, has highlighted the importance of inventor cooperation in developing embryonic technologies (Jensen & Thursby, 2001) and inventions associated with considerable know-how or tacit knowledge (Lowe, 2002; Shane, 2002). These five cases, however, reveal considerable contrast in the role of the university inventor in technology commercialization. In three of the five cases, inventor-founded start-up firms played a central role in commercialization, and inventors necessarily were heavily involved. In the fourth case, the efforts of established firms to exploit the university invention were aided by the inventor. In the fifth case, by contrast, the licensees required no assistance from the inventor.

Moreover, these case studies highlight the influence on the process of technology transfer and "absorption" by licensees or other firms of R&D activity already underway within the relevant industry, a factor often overlooked in current research on the role of the academic inventor in technology transfer. The gallium nitride, cotransformation, and soluble CD4 inventions were exploited by industrial nonlicensees of the relevant patents, largely because the university research advances represented important "proofs of concept" that directed well-informed industrial researchers to pursue related research. The amount and extent of prior industrial R&D activity, therefore, is an important influence on the technology transfer process and can affect the role of patents and licensing.

The gallium nitride case vividly illustrates the possibility that industrial R&D activity also can directly influence the academic research agenda. Much of the early research activity in gallium nitride applications was undertaken within industry in the United States, Europe, and Japan. Sustained university patenting activity began only in the 1990s, nearly two decades after the first industrial patents. Just as university patenting of key inventions served to direct industrial attention to important areas of research, industrial R&D influenced the direction of the academic research agenda. The flow of knowledge and technology between university and industrial research is a two-way flow, despite frequent caricatures of this flow as exclusively moving from academia to industry.

In the cotransformation case, firms had the capabilities and incentives to use the process for their own research and drug production in the absence of exclusive rights to the invention. Indeed, it appears that technology transfer occurred in spite, rather than because of the patents, licenses, and involvement of the university technology transfer office. The university patent produced significant income for Columbia, but no evidence suggests that the patent and associated nonexclusive licenses facilitated commercialization. Columbia's nonexclusive licensing agreements for the Axel cotransformation patent, like the equally renowned (and lucrative) Cohen–Boyer patent licensed jointly by the University of California and Stanford University, do not appear to have accelerated or otherwise made feasible the commercial development of this invention. Instead, these licensing agreements were used by Columbia to levy a tax on the commercialization of an invention that was published in the scientific literature and whose commercial development in the absence of licensing almost certainly would have occurred on the basis of the technical information and demonstration of feasibility provided by the publication.[20] The cotransformation case also suggests that involvement by the university inventor in the commercialization process is less crucial when potential users possess sufficient "absorptive capacity" to exploit the invention.

The GaN case, like that of cotransformation, is one in which patents *per se* were not essential for university–industry technology transfer. Unlike the Axel cotransformation patents, however, the GaN patents generated little licensing income for the University of California's Santa Barbara campus (UCSB). These differences in the licensing history of the GaN and cotransformation patents reflect differences in the level of demand for the technologies they respectively supported, as well as underlying differences in the legal strength and economic value of patents in the biomedical and electronic fields. Another important contrast with the Axel case was the role of the inventors in such technology transfer as did occur with the GaN patents – faced with limited interest from established industrial firms as potential licensees for their patents, the UCSB engineering faculty who had developed these technologies started their own firm.

The Xalatan case differs from the cotransformation and GaN cases in that patents appear to have been important to the transfer and commercialization of this technology. In part, the importance of patents reflected the fact that this invention resembled the "prototypes" discussed by Jensen and Thursby (2001) – a lengthy and costly period of development was necessary to bring this invention to market. And the inventor's know-how and involvement were indispensable to this development process, in contrast to the cotransformation patents. But the Xalatan case illustrates another issue in exclusive licensing agreements for university patents that appears as well in the soluble CD4 case. Although a firm may be willing to sign an exclusive licensing agreement with the university (and although most such agreements include "due diligence" or "best efforts" clauses that commit a licensee to invest in the development of an invention), it is difficult for any licensor, let alone an academic licensor, to ensure that their licensee will undertake the costly process of technology development in a timely fashion.

The commercialization of the Ames II Tests presents some interesting similarities and contrasts with the GaN and Xalatan cases. Like GaN and Xalatan, inventor involvement was important and reflected the importance of tacit know-how for the inventions' applications. It seems likely that without the participation of the inventor, a license alone would not have sufficed to commercialize the Ames II Tests. But in contrast to GaN, patent protection for this invention and the exclusive licensing contract negotiated by its industrial commercializer proved to be important, just as was the case for Xalatan. Its license for the Ames II Test patents significantly enhanced the availability of venture finance for the startup firm that undertook the commercial development of the Ames II tests.

The CD4 case illustrates the commercial and technical uncertainties involved in bringing an embryonic invention, even one that appears to have great commercial potential, from laboratory to marketplace. This case also provides some evidence that exclusive licenses may not be necessary, even for embryonic inventions, if their potential profitability is sufficiently large and downstream innovations can themselves be patented. Moreover, the case highlights the risks associated with exclusive licensing agreements for such innovations, since it is often difficult for licensing professionals to determine which of several potential licensees (in the rare cases in which several firms are interested in pursuing licenses) is most likely to bring the invention to market successfully. Finally, this case (like the cotransformation case) suggests that in contexts where firms have strong links with the relevant scientific and technological communities, inventor involvement may be less critical for commercialization.

A central premise underpinning the Bayh-Dole Act is the belief that patenting and licensing are necessary to facilitate the development and commercialization of publicly funded university inventions. Although the Act does not mandate that universities follow any single specific policy in patenting and licensing faculty inventions, university administrators and technology licensing officers frequently assume that the technology transfer process is essentially similar in different technologies and industries. But these case studies reveal great heterogeneity within even a small sample of technologies. There are significant differences among these cases in the role of intellectual property rights in inducing firms to develop and commercialize university inventions, in the role of the inventor in postlicense development and commercialization, and in the relationship between academic and industrial research activities in different technical fields.

The heterogeneity within this small sample of cases underscores the need for caution in generalizations about the nature of the technology transfer process and the role of formal intellectual property rights in that process. This heterogeneity also highlights the importance of flexibility in the technology management policies and practices of universities. Patents and an exclusive license were important to successful commercialization in one of these five cases (Xalatan), but in at least two cases (cotransformation and GaN) it seems likely that development and commercialization would have gone forward without a patent on the university invention. In these cases, other means of appropriability, such as specialized knowledge or the prospect of a patent on downstream inventions, were sufficient to induce firms to invest in development and commercialization. The case of soluble CD4 also illustrates the difficulties that university licensing officers face in selecting among prospective licensees when the ultimate commercial prospects and commercialization capabilities of both the invention and the licensees are highly uncertain.[21]

The cases also reveal considerable differences in the extent of inventor involvement and the role of the inventor in development and commercialization. In at least two cases (soluble CD4 and cotransformation), one or more of the licensee firms had little or no interaction with the inventor, since firms had sufficient experience and internal expertise in the field of the invention or had strong relationships with external scientists with such experience. In these cases, the knowledge and know-how gap between the university inventor and a would-be industrial commercializer was relatively small, reflecting previous investments by the industrial firm in internal capabilities and external monitoring of scientific developments.[22] But two other inventions discussed in this paper (GaN and Ames II) were developed and commercialized by startup firms, in which inventors played a central role. Interestingly, however, only one of these two startups (Widegap Technologies, founded to develop the GaN invention) was founded by the inventors, and it was not a licensee. The startup that sought to commercialize the Ames II tests (Xenometrix) was not founded by the inventor, although the tests' inventor did join the firm after its foundation and Xenometrix did agree to a license for the invention.

The nature of feedback between industrial and academic research differs among these cases. Bayh-Dole was implicitly based on an assumption of a "linear model" of innovation, in which universities perform basic research with little concern for application and private firms invest in applied research and commercialization. In this view, patent-based incentives are essential to link universities, inventors, and industry in the commercialization process. But this assumption does not accurately describe university–industry interactions, before or after Bayh-Dole, in many technical fields. In most of the cases discussed in this chapter, there was considerable overlap between the scientific and industrial communities in the nature of research activities (including publication). Consistent with the work of Zucker, Darby, and colleagues on biotechnology (Zucker, Darby, & Brewer, 1998; Zucker, Darby, & Armstrong, 2001), in these cases technology transfer from universities to firms took place via a range of channels, including labor mobility and research collaboration. There is also little evidence of significant delays in the disclosure or publication by academic researchers of their research advances. All of these inventions were the subject of published papers, and in a majority of the cases the publications appeared before patent applications were filed.

There are significant differences among industries in the influence of academic research on industrial innovation as well as in the channels through which these influences operate. This research also suggests significant interindustry differences in the importance of patents as vehicles for knowledge transfer among firms or between universities and industry, and further reveals significant differences among industries in the importance of patents and licenses as channels for the transfer of knowledge and technology between universities and industry. These case studies do suggest, however, that patents may be important for start-up firms in their search for financing. Consistent with previous studies, the evidence from this very small sample of cases suggests that university patenting and licensing were more important for the biomedical inventions than for the electronics invention included in these cases. But these cases also reveal considerable heterogeneity in the technology transfer process among biomedical technologies.

5. CONCLUSION

Academic entrepreneurship (defined in this case as the involvement of university faculty and researchers in commercial development of their inventions) has been a unique and significant characteristic of the U.S. higher education system for most of the past 100 years. As noted earlier in this chapter, the unusual engagement of academic personnel in quasi-commercial pursuits reflected a longstanding history of collaborative research between university faculty and industry, as well as the unusual structural characteristics of the U.S. "system" of higher education that created strong incentives for faculty and administrators both to seek financial support and links with industry. Moreover, much of this entrepreneurial activity involved patenting of university inventions and in some cases, their licensure to industrial firms. This long history of interaction, as well as academic patenting and licensing, contributed to the formation of the political coalitions that led to the passage of the Bayh-Dole Act in 1980.

Nevertheless, it is a fallacy to associate the entrepreneurial activities of university faculty exclusively with patenting and licensing. Moreover, the occasional tendency to elevate patenting and licensing to a central position in the processes that mediate the 2-way flows of knowledge and technology between universities and industry is a serious (indeed, dangerous) distortion of the reality of these relationships. A substantial body of research suggests that industry and academic researchers interact and exchange knowledge through a diverse array of channels, among which patenting and licensing is but one and in most sectors far from the most important one. As the data discussed earlier in this chapter on academic patenting, licensing, and licensing revenues suggest, however, the biomedical sector is different, and patents appear to be especially important channels for technology transfer. Nevertheless, the case studies summarized in this paper highlight considerable variation in the importance of patents and licenses even within the biomedical sector.

In spite of the dramatic growth in the literature on this topic, research on "academic entrepreneurship" and technology transfer between universities and industry still lacks an integrated analysis of the various channels through which these processes operate. We know very little, for example, about the interactions among academic patenting, licensing agreements, and flows of personnel between universities and industry. We lack empirical data or analyses on the links between industry-funded research within universities and the operation of different channels of technology transfer between industry and academia. Little or no work has been done on the rate of licensing of university inventions by faculty-founded startups (recall that the AUTM data address the role of startups as licensees, not the reverse). Current research (including Mowery et al., 2004) is dominated by the countable rather than the most economically important forms of interaction.

NOTES

1. See Dertouzos, Lester and Solow (1989); for an earlier critique of the Commission's critique, see Mowery (1999).

2. "Regulatory reform in the United States in the early 1980s, such as the Bayh-Dole Act, have [sic] significantly increased the contribution of scientific institutions to innovation. There is evidence that this is one of the factors contributing to the pick-up of U.S. growth performance…" (OECD, A New Economy? 2000, p. 77).

3. "Possibly the most inspired piece of legislation to be enacted in America over the past half-century was the Bayh-Dole Act of 1980. Together with amendments in 1984 and augmentation in 1986, this unlocked all the inventions and discoveries that had been made in laboratories throughout the United States with the help of taxpayers' money. More than anything, this single policy measure helped to reverse America's precipitous slide into industrial irrelevance. Before Bayh-Dole, the fruits of research supported by government agencies had gone strictly to the federal government. Nobody could exploit such research without tedious negotiations with a federal agency concerned. Worse, companies found it nigh impossible to acquire exclusive rights to a government owned patent. And without that, few firms were

willing to invest millions more of their own money to turn a basic research idea into a marketable product." (Economist, 12/14/02).

4. "In 1980, the enactment of the Bayh-Dole Act (Public Law 98-620) culminated years of work to develop incentives for laboratory discoveries to make their way to the marketplace promptly, with all the attendant benefits for public welfare and economic growth that result from those innovations. Before Bayh-Dole, the federal government had accumulated 30,000 patents, of which only 5% had been licensed and even fewer had found their way into commercial products. Today under Bayh-Dole more than 200 universities are engaged in technology transfer, adding more than $21 billion each year to the economy."

5. "In the 1970s, the government discovered the inventions that resulted from public funding were not reaching the marketplace because no one would make the additional investment to turn basic research into marketable products. That finding resulted in the Bayh-Dole Act, passed in 1980. It enabled universities, small companies, and nonprofit organizations to commercialize the results of federally funded research. The results of Bayh-Dole have been significant. Before 1981, fewer than 250 patents were issued to universities each year. A decade later universities were averaging approximately 1,000 patents a year."

6. "The Bayh-Dole Act turned out to be the Viagra for campus innovation. Universities that would previously have let their intellectual property lie fallow began filing for – and getting patents at unprecedented rates. Coupled with other legal economic and political developments that also spurred patenting and licensing, the results seems nothing less than a major boom to national economic growth."

7. Etzkowitz's discussion of the debate within MIT over institutional patent policies during the 1930s (1994, p. 404) notes that "In 1936, the committee on patents of the institute put forward the view that: 'There is recognized to be danger in deriving any income whatever from inventions, first because of possible influence upon our tax exempt status, and second because of possible criticism of our methods leading to ill will among those upon whom we must depend for support. The first difficulty seems to be avoided, if the actual handling of our affairs is delegated to some other organization."

8. Columbia's policy stated "It is recognized, however, that there may be exceptional circumstances where the taking out of a patent will be advisable in order to protect the public. These cases must be brought to [the University administration] for is consideration and approval" (cited in Palmer, 1962, p. 175).

9. HEW had instituted an IPA program in 1953 and 18 universities had negotiated IPAs with the agency by 1958. But after 1958, no additional requests for IPAs were approved by HEW because "opinions of responsible agency officials differed concerning the value of such agreements" (GAO, 1968, p. 24). Pharmaceutical companies also complained that these IPAs were ambiguous about the scope of exclusive rights that licensees could retain.

10. The purpose of the HEW review was "to make sure that assignment of patent rights to universities and research institutes did not stifle competition in the private sector in those cases where competition could bring the fruits of research to the public faster and more economically", according to the testimony of Comptroller General Elmer Staats during the Bayh-Dole hearings (United States Senate Committee on the Judiciary, 1979, p. 37).

11. Identical legislation (H.R. 2414) was introduced in the House of Representatives by Rep. Peter Rodino (D-NJ) in 1979.

12. "Another IPA restriction dropped in the Dole–Bayh bill is the requirement that grantees and contractors try first to offer nonexclusive licenses. 'It's too hard and inefficient a process,' [a Bayh aide said]. 'Universities don't have the financial capability to beat the bushes and try to find someone who is willing to accept a license on a nonexclusive basis' (Henig, 1979, p. 281).

13. A contemporary account noted that limiting the bill to universities and small businesses was "a tactical exclusion taken to ensure liberal support" (Henig, 1979, p. 282). A Senate aide commented, "We'd like to extend [the policy] to everybody … but if we did the bill would never have a chance of passing" (Broad, 1979b, p. 474). The original bill also included several provisions designed to defuse criticism that it would lead to "profiteering" at the expense of the public interest, including a recoupment provision requiring that institutions pay back a share of licensing income or sales to funding agencies. The final version of the Bayh-Dole Act eliminated this provision, "because there was no agreement on whether the funds would be returned to the agencies or to general revenue, or how the collection and auditing functions would be conducted" and "fears that the costs of the infrastructure required to administer such a program would exceed the amounts collected." See http://www.nih.gov/news/070101wyden.htm.

14. As Kevles (1994) points out, the University of California also filed an *amicus curiae* brief in the *Diamond v. Chakrabarty* case, in which the U.S. Supreme Court ruled that patents on life forms were valid. Had the Chakrabarty patent not been upheld as valid, the Reimers patenting and licensing strategy for the Cohen–Boyer invention would have been utterly useless. Indeed, much of the post-1980 growth in university licensing rests on an array of other policy initiatives and judicial decisions during the 1980s that strengthened patentholder rights overall and in such new areas as computer software and biotechnology (see below and Mowery et al., 2004 for further discussion).

15. According to Katz and Ordover (1990), at least 14 Congressional bills passed during the 1980s focused on strengthening domestic and international protection for intellectual property rights, and the Court of Appeals for the Federal Circuit created in 1982 has upheld patent rights in roughly 80% of the cases argued before it, a considerable increase from the pre-1982 rate of 30% for the Federal bench.

16. See Hall and Ziedonis (2002) for an analysis of the effects of the CAFC and related policy shifts on patenting in the U.S. semiconductor industry.

17. Data on total academic R&D were obtained from National Science Board (2002), Appendix Table 4-4.

18. As we have pointed out elsewhere (Mowery et al., 2001), the Bayh-Dole Act did not dramatically affect the patenting and licensing activities of universities that had long been active in this area, such as Stanford University and the University of California. Indeed, the biomedical patents and licenses that dominated these institutions' licensing revenues during the 1980s and 1990s had begun to grow before the passage of the Bayh-Dole Act. Columbia University, an institution with little experience in patenting and licensing before 1980 (and an institution that prohibited the patenting of inventions by medical faculty until 1975), also had filed for its first "blockbuster" patent before the effective date of the Act. Nevertheless, the Act did

increase patenting of faculty inventions at both Stanford and the University of California, although many of these patents covered inventions of marginal industrial value and did not yield significant licensing royalties.

19. See Chapter 7 of Mowery et al. (2004) for a fuller description and discussion of these five cases. Professor Robert Lowe of Carnegie-Mellon University co-authored the chapter, along with David C. Mowery and Bhaven Sampat.

20. Neils Reimers, the first head of Stanford's Office of Technology Transfer and manager of the licensure of Cohen–Boyer, subsequently noted, "whether we licensed it or not, commercialization of recombinant DNA was going forward. As I mentioned, a nonexclusive licensing program, at its heart, is really a tax … [b]ut it's always nice to say" technology transfer (Reimers, 1998).

21. Nonetheless, interviews with licensing officers suggest that very few university inventions face such strong demand from prospective licensees that the officer can select among several "applicants" for a license in a given field of use.

22. The substantial flow of scientific papers from industrial scientists in AIDS research that was noted earlier also supports this characterization of the firms engaged in commercial development of the soluble CD4 invention.

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THE KNOWLEDGE SPILLOVER THEORY OF ENTREPRENEURSHIP AND TECHNOLOGICAL DIFFUSION

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ABSTRACT

The prevailing theories of entrepreneurship have typically revolved around the ability of individuals to recognize opportunities and act on them by starting new ventures. This has generated a literature asking why entrepreneurial behavior varies across individuals with different characteristics, while implicitly holding the external context in which the individual finds oneself to be constant. Thus, where the opportunities come from, or the source of entrepreneurial opportunities, are also implicitly taken as given. By contrast, we provide a theory identifying at least one source of entrepreneurial opportunity – new knowledge and ideas that are not fully commercialized by the organization actually investing in the creation of that knowledge. The knowledge spillover theory of entrepreneurship holds individual characteristics as given, but lets the context vary. In particular, high knowledge contexts are found to generate more entrepreneurial opportunities, where the entrepreneur serves as a conduit for knowledge

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spillovers. By contrast, impoverished knowledge contexts are found to generate fewer entrepreneurial opportunities. By serving as a conduit for knowledge spillovers, entrepreneurship is the missing link between investments in new knowledge and economic growth. Thus, the knowledge spillover theory of entrepreneurship provides not just an explanation of why entrepreneurship has become more prevalent as the factor of knowledge has emerged as a crucial source for comparative advantage, but also why entrepreneurship plays a vital role in generating economic growth. Entrepreneurship is an important mechanism permeating the knowledge filter to facilitate the spillover of knowledge, and ultimately generating economic growth.

INTRODUCTION

Why does entrepreneurship education matter? In particular, why should it matter for broader societal goals? In this paper, we suggest that entrepreneurship education matters because it facilitates the spillover of knowledge from universities and private firms, resulting in commercialization of ideas that otherwise would remain uncommercialized, ultimately resulting in greater innovation and economic growth. The knowledge spillover theory of entrepreneurship is used to provide a lens linking entrepreneurship to employment, growth and prosperity.

The knowledge spillover theory of entrepreneurship inverts the traditional approach to entrepreneurship. Rather than taking the context as given and then asking how variations across individual attributes shape the cognitive process underlying the decision to become an entrepreneur, instead, it is assumed that the underlying individual characteristics are constant and are analyzed to determine how the cognitive process inducing the entrepreneurial decision is influenced by placing that same individual in different contexts. In particular, high knowledge contexts are compared with impoverished knowledge contexts. This leads to a very different view of entrepreneurship. Instead of being a phenomenon that is exogenously determined by preconditioned personal attributes and family history, entrepreneurship emerges as an endogenous response to opportunities generated by investments in new knowledge made by incumbent firms and organizations, combined with their inability to fully and completely exhaust the ensuing opportunities to commercialize the knowledge. Thus, the knowledge spillover theory of entrepreneurship shows how entrepreneurship can be an endogenous response to investments in new knowledge where commercialization of that knowledge is constrained by the existence of a formidable knowledge filter.

Not only does holding the individual attributes constant while varying the knowledge context give rise to the knowledge theory of entrepreneurship, but also the view of entrepreneurship as an endogenous response to the incomplete commercialization of new knowledge results in entrepreneurship as providing the missing link in economic growth models. By serving as a conduit of knowledge spillovers, entrepreneurship serves as a significant source of economic growth that otherwise will remain underutilized. Thus, entrepreneurship is the mechanism by which society more fully appropriates its investments in generating new knowledge, such as research and education.

The next section explains how entrepreneurship combines the cognitive process of recognizing opportunities with pursuing these opportunities by starting a new firm. The third section introduces the knowledge spillover theory of entrepreneurship, which suggests that entrepreneurship is an endogenous response to investments in knowledge that are not fully appropriated by incumbent firms. The fourth section links endogenous entrepreneurship based on knowledge spillovers to economic growth. Finally, summary and conclusions are provided in the last section. In particular, we suggest that entrepreneurship education and the transfer of technology from universities for commercialization make a key contribution to the societal values of economic growth, employment creation and competitiveness in globally linked markets by reducing the knowledge filter and facilitating the missing link to economic growth – entrepreneurship.

ENTREPRENEURSHIP AS OPPORTUNITY RECOGNITION AND ACTION

Why do some people start firms and not others? This question has been at the heart of considerable research, not just in economics, but throughout the social sciences. Hebert and Link (1989) identified three distinct intellectual traditions in the development of the entrepreneurship literature. These three traditions can be characterized as the German Tradition, based on von Thuenen and Schumpeter; the Chicago Tradition, based on Knight and Schultz; and the Austrian Tradition, based on von Mises, Kirzner, and Shackle.

Generally, entrepreneurship has been viewed as involving the recognition of opportunities and the pursuit of those opportunities (Venkataraman, 1997). The entrepreneurship literature has placed a particular focus on the cognitive process through which individuals decide to start a new firm. As Sarasvathy, Dew, Velamuri, and Venkataraman (2003, p. 142) explain, "An entrepreneurial opportunity consists of a set of ideas, beliefs and actions that enable the creation of future goods and services in the absence of current markets for them."

The focus of the entrepreneurship literature on the cognitive process inherent in making the decision to start a firm has generally involved a methodology of examining differences across individuals (Sahlman and Stevenson, 1991). As Krueger (2003, p. 105) points out, "The heart of entrepreneurship is an orientation toward seeing opportunities." Thus, the central focus of research in entrepreneurship addresses the questions, "What is the nature of entrepreneurial thinking and what cognitive phenomena are associated with seeing and acting on opportunities?" (Krueger, 2003, p. 105).

Entrepreneurship literature holds the context constant and then asks how the cognitive process inherent in the entrepreneurial decision varies across different individual characteristics and attributes (Shaver, 2003; McClelland, 1961). As Shane and Eckhardt (2003, p. 187) summarize this literature in introducing the individual-opportunity nexus, "We discussed the process of opportunity discovery and explained why some actors are more likely to discover a given opportunity than others."

By contrast, a vastly different literature, associated with the model of the knowledge production function looked for an opportunity exploitation for the unit of observation of the firm. This literature implicitly assumes that opportunity exploitation takes place within the same organization that created those opportunities in the first place – the firm. By explicitly modeling and specifying the econometric estimation of the knowledge production function as linking firm innovative output to firm investments in new knowledge (Griliches, 1984), such as R&D and human capital, this literature assumed that the creation and exploitation of new opportunities occurred within the same organizational unit. Just as the firm is viewed as providing the organizational unit for the creation of the opportunities, through purposeful investments in R&D, it is also viewed as appropriating the returns to those investments through innovative activity, such as patented inventions creating new intellectual property.

However, the empirical evidence from systematic empirical testing of the model of the knowledge production function contradicted the assumption of singularity between the organization creating the opportunities and the organization exploiting the opportunities. In particular, the empirical evidence pointed to a much more vigorous contribution to small and new-firm innovative activity than would have been warranted from their rather limited investments in new knowledge, as measured by R&D and human capital (Audretsch, 1995).

THE KNOWLEDGE SPILLOVER THEORY OF ENTREPRENEURSHIP

The discrepancy in organizational context between the organization, which created the opportunities and those exploiting the opportunities that seemingly contradicted Griliches' model of the firm knowledge production function (Griliches, 1979) was resolved by Audretsch (1995), who introduced *The Knowledge Spillover Theory of Entrepreneurship*. "The findings challenge an assumption implicit to the knowledge production function – that firms exist exogenously and then endogenously seek out and apply knowledge inputs to generate innovative output. It is the knowledge in the possession of economic agents that is exogenous, and in an effort to appropriate the returns from that knowledge, the spillover of knowledge from its producing entity involves endogenously creating a new firm" (pp. 179–180).

What is the source of this entrepreneurial opportunity that endogenously generated the startup of new firms? The answer seemed to be that the spillover of knowledge created opportunities for the startup of a new firm: "How are these small and frequently new firms able to generate innovative output when undertaken a generally negligible amount of investment into knowledge-generating inputs, such as R&D? One answer is apparently through exploiting knowledge created by expenditures on research in universities and on R&D in large corporations" (p. 179).

The empirical evidence supporting the knowledge spillover theory of entrepreneurship was provided by analyzing variations in startup rates across different industries reflecting different underlying knowledge contexts. In particular, those industries with a greater investment in new knowledge also exhibited higher startup rates, while those industries with less investment in new knowledge exhibited lower startup rates, which was interpreted as a conduit transmitting knowledge spillovers (Audretsch, 1995; Caves, 1998).

Thus, compelling evidence was provided to suggest that entrepreneurship is an endogenous response to opportunities created but not exploited by the incumbent firms. This involved an organizational dimension involving the mechanism transmitting knowledge spillovers – the startup of new firms. In addition, Jaffe (1989), Audretsch and Feldman (1996) and Audretsch and Stephan (1996) provided evidence concerning the spatial dimension of knowledge spillovers. In particular, their findings suggested that knowledge spillovers are geographically bounded and localized within spatial proximity to the knowledge source. None of these studies, however, identified the actual mechanisms which actually transmit the knowledge spillover; rather, the spillovers were implicitly assumed to automatically occur (or fall like Manna from heaven), but only within a geographically bounded spatial area.

As emphasized in the previous section, while much has been made about the key role played by the recognition of opportunities in the cognitive process underlying the decision to become an entrepreneur, relatively little has been written about the actual source of such entrepreneurial opportunities. The knowledge spillover theory of entrepreneurship identifies one source of entrepreneurial opportunities – new knowledge and ideas. In particular, the knowledge spillover theory of entrepreneurship posits that it is new knowledge and ideas created in one context but left uncommercialized or not vigorously pursued by the source creating those ideas, such as a research laboratory in a large corporation or research undertaken by a university, that serves as the source of knowledge generating entrepreneurial opportunities. Thus, in this view, one mechanism for recognizing new opportunities and actually implementing them by starting a new firm involves the spillover of knowledge. The organization creating the opportunities is not the same organization that exploits the opportunities. If the exploitation of those opportunities by the entrepreneur does not involve full payment to the firm for producing those opportunities, such as a license or royalty, then the entrepreneurial act of starting a new firm serves as the knowledge spillover mechanism.

Why should entrepreneurship play an important role in the spillover of new knowledge and ideas? And why should new knowledge play an important role in creating entrepreneurial opportunities? In the Romer (1986) model of endogenous growth, new technological knowledge is assumed to automatically spillover. Investment in new technological knowledge is automatically accessed by third-party firms and economic agents, resulting in the automatic spillover of knowledge. The assumption that knowledge automatically spills over is, of course, consistent with the important insight by Arrow (1962) that knowledge differs from the traditional factors of production – physical capital and (unskilled) labor – in that it is non-excludable and non-exhaustive. When the firm or economic agent uses the knowledge, it is neither exhausted, nor can it be, in the absence of legal protection, precluded from use by third-party firms or other economic agents. Thus, in the spirit of the Romer model, drawing on the earlier insights about knowledge from Arrow, a large and vigorous literature has emerged obsessed with the links between intellectual property protection and the incentives for firms to invest in the creation of new knowledge through R&D and investments in human capital.

However, the preoccupation with the non-excludability and non-exhaustibility of knowledge first identified by Arrow and later carried forward and assumed in the Romer model, neglects another key insight in the original Arrow (1962) article. Arrow also identified another dimension by which knowledge differs from the traditional factors of production. This other dimension involves the greater degree of uncertainty, higher extent of asymmetries and greater cost of transacting new ideas. The expected value of any new idea is highly uncertain, and as Arrow pointed out, has a much greater variance than would be associated with the deployment of traditional factors of production. After all, there is relative certainty about what a standard piece of capital equipment can do, or what an (unskilled) worker can contribute to a mass-production assembly line. By contrast, Arrow emphasized that when it comes to innovation, there is uncertainty about whether the new product can be produced, how it can be produced, and whether sufficient demand for the visualized new product might actually materialize.

In addition, new ideas are typically associated with considerable asymmetries. In order to evaluate a proposed new idea concerning a new biotechnology product, the decision maker might not just need a Ph.D in biotechnology, but also a specialization in the specific scientific area. Such divergences in education, background and experience can result in a divergence in the expected value of a new project or the variance in the anticipated outcomes from pursuing that new idea, both of which can lead to divergences in the recognition and evaluation of opportunities across economic agents and decision-making hierarchies. Such divergences in the valuation of new ideas will become greater if the new idea is not consistent with the core competence and technological trajectory of the incumbent firm.

Thus, because of the conditions inherent in knowledge – high uncertainty, asymmetries and transaction cost, decision-making hierarchies can reach the decision not to pursue and try to commercialize new ideas that individual economic agents, or groups or teams of economic agents, think are potentially valuable and should be pursued. The basic conditions characterizing new knowledge, combined with a broad spectrum of institutions, rules and regulations, impose what Acs, Audretsch, Braunerhjelm, and Carlsson (2004) term *the knowledge filter*. The knowledge filter is the gap between new knowledge and what Arrow (1962) referred to as economic knowledge or commercialized knowledge. The greater the knowledge filter, the more pronounced this gap between new knowledge and new economic, or commercialized, knowledge.

The knowledge filter is a consequence of the basic conditions inherent in new knowledge. Similarly, it is the knowledge filter that creates the opportunity for entrepreneurship in the knowledge spillover theory of entrepreneurship. According to this theory, opportunities for entrepreneurship are the duality of the knowledge filter. The higher the knowledge filter, the greater the divergences in the valuation of new ideas across economic agents and the decision-making hierarchies of incumbent firms. Entrepreneurial opportunities are generated not just by investments in new knowledge and ideas, but also in the propensity for only a distinct subset of those opportunities to be fully pursued by incumbent firms.

Thus, the knowledge spillover theory of entrepreneurship shifts the fundamental decision-making unit of observation in the model of the knowledge production function away from exogenously assumed firms to individuals, such as scientists, engineers or other knowledge workers – agents with endowments of new economic knowledge. As Audretsch (1995) pointed out, when the lens is shifted away from the firm to the individual as the relevant unit of observation, the appropriate ability issue remains, but the question becomes, *How can economic agents with a given endowment of new knowledge best appropriate the returns from that knowledge?* If the scientist or engineer can pursue the new idea within the organizational structure of the firm developing the knowledge and appropriate roughly the expected value of that knowledge, he has no reason to leave the firm. On the other hand, if he places a greater value on his ideas than do the decision-making bureaucracy of the incumbent firm, he may choose to start a new firm to appropriate the value of his knowledge.

In the knowledge spillover theory of entrepreneurship, the knowledge production function is actually reversed. The knowledge is exogenous and embodied in a worker. The firm is created endogenously in the worker's effort to appropriate the value of his knowledge through innovative activity. Typically, an employee from a large, established corporation, often a scientist or engineer working in a research laboratory, will have an idea for an invention and, ultimately, for an innovation. Accompanying this potential innovation is an expected net return from the new product. The inventor would expect to be compensated for his or her potential innovation accordingly. If the company has a different, presumably lower, valuation of the potential innovation, it may decide not to pursue its development, or that it merits a lower level of compensation than that expected by the employee.

In either case, the employee will weigh the alternative of starting his or her own firm. If the gap in the expected return accruing from the potential innovation between the inventor and the corporate decision maker is sufficiently large, and if the cost of starting a new firm is sufficiently low, the employee may decide to leave the large corporation and establish a new enterprise. Since the knowledge was generated in the established corporation, the new start-up is considered to be a spin-off from the existing firm. Such startups typically do not have direct access to a large R&D laboratory. Rather, the entrepreneurial opportunity emanates from the knowledge and experience accrued from the R&D laboratories with their previous employers. Thus, the knowledge spillover view of entrepreneurship is actually a theory of endogenous entrepreneurship, where entrepreneurship is an endogenous response to opportunities created by investments in new knowledge that are not commercialized because of the knowledge filter.

As investments in new knowledge increase, entrepreneurial opportunities will also increase. Contexts where new knowledge plays an important role are associated with a greater degree of uncertainty and asymmetries across economic agents evaluating the potential value of new ideas. Thus, a context involving more new knowledge will also impose a greater divergence in the evaluation of that knowledge across economic agents, resulting in a greater variance in the outcome expected from commercializing those ideas. It is this gap in the valuation of new ideas across economic agents, or between economic agents and decision-making hierarchies of incumbent enterprises, that creates the entrepreneurial opportunity.

As already discussed, a vigorous literature has identified that knowledge spillovers are greater in the presence of knowledge investments. Just as Jaffe (1989) and Audretsch and Feldman (1996) show, those regions with high knowledge investments experience a high level of knowledge spillovers, and those regions with a low amount of knowledge investments experience a low level of knowledge spillovers, since there is less knowledge to be spilled over.

The knowledge spillover theory of entrepreneurship analogously suggests that, ceteris paribus, entrepreneurial activity will tend to be greater in contexts where investments in new knowledge are relatively high, since the new firm will be started from knowledge that has spilled over from the source actually producing that new knowledge. A paucity of new ideas in an impoverished knowledge context will generate limited entrepreneurial opportunities. By contrast, in a high knowledge context, new ideas will generate entrepreneurial opportunities by exploiting (potential) spillovers of that knowledge. Thus, the knowledge spillover view of entrepreneurship provides a clear link, or prediction that entrepreneurial activity will result from investments in new knowledge and that entrepreneurial activity will be spatially localized within close geographic proximity to the knowledge source.

Thus, the first hypothesis to emerge from the knowledge spillover theory of entrepreneurship is what Audretsch, Keilbach, and Lehmann (2005) term the Endogenous Entrepreneurship Hypothesis, which suggests that Entrepreneurship will be greater in the presence of higher investments in new knowledge, ceteris paribus. Entrepreneurial activity is an endogenous response to higher investments in new knowledge, reflecting greater entrepreneurial opportunities generated by knowledge investments.

Systematic empirical evidence consistent with the knowledge spillover theory of entrepreneurship has been provided by Audretsch et al. (2005), and Acs et al. (2004). Both studies find that entrepreneurship rates tend to be greater in the context of greater investments in new knowledge. In particular, Audretsch et al. (2005) find that even after controlling other sources of entrepreneurial opportunities, those regions with a greater investment in new knowledge induces a greater degree of entrepreneurial start-ups, particularly in high-technology and other knowledge-based industries.

Additional support for the Endogenous Entrepreneurship Hypothesis is provided by Roberts and Malone (1996) who document the startup of new companies spawned by Stanford University. Similarly, Markman, Phan, Balkin, and Giannodis (2005), Allen, Chevalier and O'Shea (2004) and DiGregorio and Shane (2003) analyze the linkages between universities and the propensity of those universities to generate new-firm start-ups. Franklin, Wright, and Lockett (2001), Ferguson and Olofsson (2004), and Lockett, Wright, and Franklin (2003) all identify how universities spawn entrepreneurial activity.

The second hypothesis emerging from the knowledge spillover theory of entrepreneurship has to do with the location of the entrepreneurial activity. Access to knowledge spillovers requires spatial proximity. While Jaffe (1989) and Audretsch and Feldman (1996) made it clear that spatial proximity is a prerequisite to access such knowledge spillovers, they provided no insight about the actual mechanism transmitting such knowledge spillovers. As for the Romer, Lucas and Jones models, investment in new knowledge automatically generates knowledge spillovers. The only additional insight involves the spatial dimension – knowledge spills over but the spillovers are spatially bounded. Since we have just identified one such mechanism by which knowledge spillovers are transmitted – the startup of a new firm – it follows that knowledge spillover entrepreneurship is also spatially bounded in that local access is required to access the knowledge facilitating the entrepreneurial startup: Knowledge spillover entrepreneurship will tend to be spatially located within close geographic proximity to the source of knowledge actually producing that knowledge. Thus, in order to access spillovers, new firm start-ups will tend to locate close to knowledge sources, such as universities.

While the knowledge spillover theory of entrepreneurship suggests that investment in the creation of new knowledge will generate opportunities for entrepreneurship as a mechanism for knowledge spillovers, the *Locational Hypothesis* places a spatial constraint on such spillovers, particularly from universities. Audretsch et al. (2005) and Audretsch and Lehmann (2005) analyze a database consisting of technology and knowledge-based start-ups making an initial public offering (IPO) and find that, in general, those universities in regions with a higher knowledge capacity and greater knowledge output also generate a higher number of knowledge and technology start-ups, suggesting that university spillovers are geographically bounded. Geographic proximity is an asset, if not a prerequisite, to entrepreneurial firms in accessing and absorbing spillovers from universities.

However, the findings of Audretsch et al. (2005) and Audretsch and Lehmann (2005) also suggest that the role of geographic proximity in accessing university spillovers is considerably more nuanced than is suggested by the *Locational Hypothesis*. The importance of geographic proximity apparently depends on at least two factors – the particular type of university output and spillover mechanism. For those university outputs and spillover mechanisms that are more tacit in nature, geographic proximity plays a greater role in accessing and absorbing university spillovers. By contrast, for those university outputs and spillover mechanisms which are less tacit and more codified, geographic proximity is less important.

LINKING ENDOGENOUS ENTREPRENEURSHIP TO GROWTH

The knowledge spillover theory of entrepreneurship, which focuses on how new knowledge can influence the cognitive decision-making process inherent in the entrepreneurial decision links entrepreneurship and economic growth, is consistent with theories of industry evolution (Jovanovic, 1982; Ericson & Pakes, 1995; Audretsch, 1995; Hopenhayn, 1992 & Klepper, 1996). While traditional theories suggest that small firms will retard economic growth, by imposing a drag on productive efficiency, these evolutionary theories suggest exactly the opposite – that entrepreneurship will stimulate and generate growth. The reason for these theoretical discrepancies lies in the context of the underlying theory. In the traditional theory, new knowledge plays no role; rather, static efficiency, determined largely by the ability to exhaust scale economies dictates growth. By contrast, the evolutionary models are dynamic in nature and emphasize the role that knowledge plays. Because knowledge is inherently uncertain, asymmetric and associated with high costs of transactions, divergences emerge concerning the expected value of new ideas. Economic agents therefore have an incentive to leave an incumbent firm and start a new firm in an attempt to commercialize the perceived value of their knowledge. Entrepreneurship is the vehicle by which (the most radical) ideas are sometimes implemented and commercialized.

A distinguishing feature of these evolutionary theories is the focus on change as a central phenomenon. Innovative activity, one of the central manifestations of change, is at the heart of much of this work. Entry, growth, survival, and the way firms and entire industries change over time are linked to innovation. The dynamic performance of regions and even entire economies, that is the *Standort*, or location, is linked to the efficacy of transforming investments in new knowledge into innovative activity.

Why are new firms started? The traditional equilibrium-based view is that new firms in an industry, whether they be start-ups or firms diversifying from other industries, enter when incumbent firms in the industry earn supranormal profits. By expanding industry supply, entry depresses price and restores profits to their long-run equilibrium level. Thus, in equilibrium-based theories entry serves as a mechanism to discipline incumbent firms. By contrast, the new theories of industry evolution develop and evaluate alternative characterizations of entrepreneurship based on innovation and costs of firm growth. These new evolutionary theories correspond to the disequilibrating theory of entrepreneurship proposed by Shane and Eckhardt (2003).

For example, Audretsch (1995) analyzes the factors that influence the rate of new firm start-ups. He finds that such start-ups are more likely in industries in which small firms account for a greater percentage of the industry's innovations. This suggests that firms are started to capitalize on distinctive knowledge about innovation that originates from sources outside of an industry's leaders. This initial condition of not just uncertainty, but greater degree of uncertainty vis-à-vis incumbent enterprises in the industry is captured in the theory of firm selection and industry evolution proposed by Jovanovic (1982). Jovanovic presents a model in which the new firms, which he terms *entrepreneurs*, face costs that are not only random but also differ across firms. A central feature of the model is that a new firm does not know what its cost function is, that is its relative efficiency, but rather discovers this through the process of learning from its actual post-entry performance. In particular, Jovanovic (1982) assumes that entrepreneurs are unsure about their ability to manage a new-firm start-up and therefore their prospects for success. Although entrepreneurs may launch a new firm based on a vague sense of expected post-entry performance, they only discover their true ability – in terms of managerial competence and of having based the firm on an idea that is viable on the market – once their business is established. Those entrepreneurs who discover that their ability exceeds their expectations expand the scale of their business, whereas those discovering that their post-entry performance is less than commensurate with their expectations will contact the scale of output and possibly exit from the industry. Thus, Jovanovic's model is a theory of *noisy selection*, where efficient firms grow and survive and inefficient firms decline and fail. The links between entrepreneurship on the one hand and growth and survival on the other have been found across a number of social science disciplines, including economics, sociology and regional studies.

A series of survey articles by Sutton (1997), Caves (1998) and Geroski (1995) summarize the findings from a plethora of empirical studies examining the relationship between firm size and growth within the North American context. The early studies were undertaken using data from the United States. These studies (Mansfield, 1962; Hall, 1987; Dunne, Roberts, & Samuelson, 1989; Audretsch, 1991) established not only that the likelihood of a new entrant surviving is quite low, but also that the likelihood of survival is positively related to firm size and age. A *stylized result* (Geroski, 1995) emerging from this literature is that, when a broad spectrum of firm sizes is included in samples of US enterprises, smaller firms exhibit systematically higher growth rates than their larger counterparts. The growth advantage of small and new firms vis-à-vis large enterprises has been shown to be even greater in high technology industries (Audretsch, 1995).

One of the important findings of Glaeser et al. (1992) and Feldman and Audretsch (1999a,b) is that economic performance is promoted by knowledge spillovers. However, their findings, as well as the corroborative results from a plethora of studies, focused on a spatial unit of observation, such as cities, regions and states. For example, Glaeser et al. (1992) found compelling empirical evidence suggesting that a greater degree of knowledge spillover leads to higher growth rates of cities. If the existence of higher knowledge spillovers bestow higher growth rates for cities, this relationship should also hold for the unit of observation of the (knowledge) firm. The performance of entrepreneurial firms accessing knowledge spillovers should exhibit a superior performance. Thus, the *Entrepreneurial Performance Hypothesis* states that "The performance of knowledge-based start-ups should be superior when they are able to access knowledge spillovers through geographic proximity to knowledge sources, such as universities, when compared to their counterparts without a close geographic proximity to a knowledge source."

The *Competitive Advantage Hypothesis* has been subjected to empirical scrutiny. Evidence supporting the *Competitive Advantage Hypothesis* at the firm level has been provided by Gilbert (2004), Audretsch et al. (2005), Audretsch and Lehmann (2005), Audretsch (2005), and Gilbert, Audretsch and McDougall (2004), all of whom find that the competitive advantage of new-firm start-ups within close geographic proximity to knowledge sources, such as universities. In particular, Audretsch et al. (2005) and Audretsch and Lehmann (2005) show the exact relationship between location and the competitive advantage of entrepreneurial start-ups is complex. Whether or not geographic proximity to a knowledge source, such as a university, bestows competitive benefits to an entrepreneurial firm depends on a number of factors. In particular, the impact of geographic proximity on competitive advantage is shaped by the amount and type of knowledge produced at a particular university. If the research output of a university is meagre, close geographic proximity to a university will not bestow a superior competitive advantage. However, close geographic proximity to a university with a strong research output and spillover mechanisms enhances the competitive advantage of entrepreneurial start-ups. Similarly, Audretsch and Lehman (2005) and Audretsch et al. (2005) show that the benefits of geographic proximity in enhancing competitive advantage are not homogeneous but apparently vary between academic fields and disciplines.

However, the *Competitive Advantage Hypothesis* and supporting empirical evidence not be interpreted as attributing the entire impact of entrepreneurship on growth to be restricted to the growth of entrepreneurial firms themselves. Such an extreme assumption of no external impacts is implicit in the analyses of new and small enterprises found in the pathbreaking Birch (1981) study as well as the more recent Davis, Haltiwanger, and Schuh (1996a, b) update. While there is severe methodological disagreement between Haltiwanger et al. and Birch approaches to measuring the impact of small firms on economic performance, both implicitly agree in an absence of external impact. Thus, in a type of statistical apartheid or segregation, in the Birch and Davis, Haltiwanger and Schuh studies, the impact of small and new firms is measured only within that set of firms.

By contrast, the impact of entrepreneurship on economic growth is not constrained to be limited to manifest itself solely in those entrepreneurial firms, but rather has an external impact of far greater significance. The link between entrepreneurship and economic growth should also exist at the more aggregated level of economic activity. A location, or *Standort* endowed with a higher degree of what Audretsch et al. (2005) and Audretsch and Keilbach (2004) term as *Entrepreneurship Capital*, will facilitate knowledge spillovers and the commercialization of knowledge, thereby generating greater economic growth. The *Growth Hypothesis* states, "Given a level of knowledge investment and severity of the knowledge filter, higher levels of economic growth should result from greater entrepreneurial activity, since entrepreneurship serves as a mechanism facilitating the spillover and commercialization of knowledge."

In introducing the model of the production function, Robert Solow (1956) argued that economic growth is determined explicitly by the stocks of capital and labor. Technical change entered the production function exogenously as a shift factor. More recently Romer (1986), Lucas (1993) and others extended the neoclassical model of growth by suggesting that not only is knowledge an important factor generating growth, but because it spills over for use by third-party firms, it is actually the most potent factor.

The knowledge spillover theory of entrepreneurship explained in the previous section suggests that this assessment of the role of knowledge overlooks some of the most fundamental mechanisms driving the process of economic growth. The spillover process that Romer and the endogenous growth theory assumes to be automatic is not at all automatic. Rather, it is a process that is actively driven by economic agents. According to Audretsch et al. (2005), *Entrepreneurship Capital* serves as a mechanism facilitating the spillover of knowledge.

While Romer (1986) and Lucas (1993) added the factor of knowledge capital to the traditional factors of physical capital and labor, Audretsch et al. (2005) do not dispute the importance of the traditional factors, but suggest an additional factor as well – the degree of entrepreneurship capital specific to a *Standort*, or location. By entrepreneurship capital Audretsch et al. (2005) mean the capacity for the *Standort*, that is, the geographically relevant spatial units of observation, to generate the start-up of new enterprises.

While the neoclassical tradition identified investment in *physical capital* as the driving factor of economic performance (Solow, 1956), the endogenous growth theory (Romer, 1986, 1990; Lucas, 1988) put the emphasis on the process of the accumulation of knowledge, and hence the creation of *knowledge capital*. The concept of *social capital* (Putnam, 1993; Coleman, 1988) could be considered as a further extension because it added a social component to those factors shaping economic growth and prosperity. According to Putnam (2000, p. 19),

> Whereas physical capital refers to physical objects and human capital refers to the properties of individuals, social capital refers to connections among individuals – social networks and the norms of reciprocity and trustworthiness that arise from them. In that sense social capital is closely related to what some have called 'civic virtue.' The difference is that 'social capital' calls attention to the fact that civic virtue is most powerful when embedded in a sense network of reciprocal social relations. A society of many virtues but isolated individuals is not necessarily rich in social capital.

Putnam also challenged the standard neoclassical growth model by arguing that social capital was also important in generating economic growth, "By analogy with notions of physical capital and human capital – tools and training that enhance individual productivity – social capital refers to features of social organization, such as networks, norms, and trust, that facilitate coordination and cooperation for mutual benefits."

A large and robust literature has emerged trying to link social capital to entrepreneurship (Aldrich & Martinez, 2003; Thorton & Flynne, 2003). However, while it was clear that Putnam was providing a link between social capital and economic welfare, this link did not directly involve entrepreneurship. The components of social capital Putnam emphasized the most included associational membership and public trust. While these may be essential for social and economic well being, it was not obvious that they involved entrepreneurship, per se.

Social capital and entrepreneurship capital are distinctive concepts that should not be confused. According to Putnam (2000, p. 19), "Social capital refers to connections among individuals – social networks and the norms of reciprocity and trustworthiness that arise from them. In that sense social capital is closely related to what some have called 'civic virtue.' …Social capital calls attention to the fact that civic virtue is most powerful when embedded in a sense network of reciprocal social relations…Social capital refers to features of social organization, such as networks, norms, and trust, that facilitate coordination and cooperation for mutual benefits."

Audretsch et al. (2005) and Audretsch and Keilbach (2004) argue that what has been called social capital in the entrepreneurship literature may actually be a more specific sub-component, which we introduce as *entrepreneurship capital*. Entrepreneurship has typically been defined as an action, process or activity. Entrepreneurship involves the start-up and growth of new enterprises. Entrepreneurship capital involves a milieu of agents and institutions that is conducive to the creation of new firms. This involves a number of aspects such as social acceptance of entrepreneurial behavior but of course also individuals who are willing to deal with the risk of creating new firms[1] and the activity of bankers and venture capital agents that are willing to share risks and benefits involved. Hence entrepreneurship capital reflects a number of different legal, institutional and social factors and forces. Taken together, these factors and forces constitute the entrepreneurship capital of an economy, which creates a capacity for entrepreneurial activity (Hofstede et al., 2002).

It should be emphasized that entrepreneurship capital should not be confused with social capital. The major distinction is that, in our view, not all social capital may be conducive to economic performance, let alone entrepreneurial activity. Some types of social capital may be more focused on preserving the status quo and not necessarily directed at creating challenges to the status quo. By contrast, entrepreneurship capital could be considered to constitute one particular sub-set of social capital. While social capital may have various impacts on entrepreneurship, depending on the specific orientation, entrepreneurship capital, by its very definition, will have a positive impact on entrepreneurial activity.

Audretsch et al. (2005) and Audretsch and Keilbach (2004) include a measure of entrepreneurship capital, along with the traditional factors of production of labor, physical capital and knowledge capital, in a production function model to estimate economic growth. Their evidence suggests that entrepreneurship capital exerts indeed a positive impact on economic growth. This finding holds for different measures of entrepreneurship capital, ranging from the more general to the more risk oriented.

While the findings by Audretsch et al. (2005) and Audretsch and Keilbach (2004) certainly do not contradict the conclusions of earlier studies linking growth to factors such as labor, capital and knowledge, their evidence points to an additional factor, entrepreneurship capital, that also plays an important role in generating economic growth.

The results from including measures of entrepreneurship capital in the context of estimating economic growth in a production function model are consistent with other studies, also finding a positive relationship between various measures of entrepreneurship and economic growth. For example, Acs et al. (2004) find a positive relationship between entrepreneurship and growth at the country level. Thurik (1999) provided empirical evidence from a 1984–1994 cross-sectional study of the 23 countries that are part of the Organization for Economic Co-operation and Development (OECD), that increased entrepreneurship, as measured by business ownership rates, was associated with higher rates of employment growth at the country level. Similarly, Audretsch et al. (2002) and Carree and Thurik (1999) find that OECD countries exhibiting higher increases in entrepreneurship also have experienced greater rates of growth and lower levels of unemployment.

In a study for the OECD, Audretsch and Thurik (2001) undertook two separate empirical analyses to identify the impact of changes of entrepreneurship on growth. Each one uses a different measure of entrepreneurship, sample of countries and specification. This provides some sense of robustness across different measures of entrepreneurship, data sets, time periods and specifications. The first analysis uses a database measuring entrepreneurship in terms of the relative share of economic activity accounted for by small firms. It links changes in entrepreneurship to growth rates for a panel of 18 OECD countries spanning 5 years to test the hypothesis that higher rates of entrepreneurship lead to greater subsequent growth rates. The second analysis uses a measure of self-employment as an index of entrepreneurship and links changes in entrepreneurship to unemployment at the country level between 1974 and 1998. The different samples including OECD countries over different time periods reach consistent results – increases in entrepreneurial activity tends to result in higher subsequent growth rates and a reduction of unemployment.

Holtz-Eakin and Kao (2001) examine the impact of entrepreneurship on growth. Their spatial unit of observation is for states. Their measure of growth is productivity change over time. A vector autoregression analysis shows that variations in the birth rate and the death rate for firms are related to positive changes in productivity. They conclude that entrepreneurship has a positive impact on productivity growth, at least in case of the United States.

CONCLUSIONS

Why should entrepreneurship education and technology matter? This Chapter has attempted to answer this question, at least in terms of contribution to the societal values of economic growth, employment generation and competitiveness. When viewed through the lens provided by the knowledge spillover theory of entrepreneurship, the contribution of entrepreneurship education and technology transfer from universities has the potential to make a clear and compelling contribution to economic growth and job creation.

The prevalent and traditional theories of entrepreneurship have typically held the context constant and then examined how characteristics specific to the individual impact the cognitive process inherent in the model of entrepreneurial choice. This often leads to the view that, given a distribution of personality characteristics, proclivities, preferences and tastes, entrepreneurship is exogenous. One of the great conventional wisdoms in entrepreneurship is "*Entrepreneurs are born not made*." Either you have it or you don't. This leaves virtually no room for policy or for altering what nature has created.

The knowledge spillover theory of entrepreneurship suggests an alternative view. In the knowledge spillover theory, the individual attributes are constant and instead focus on variations in the context. In particular, we consider how the knowledge context will impact the cognitive process underlying the entrepreneurial choice model. The result is a theory of endogenous entrepreneurship, where (knowledge) workers respond to opportunities generated by new knowledge by starting a new firm. In this view, entrepreneurship is a rationale choice made by economic agents to appropriate the expected value of their endowment of knowledge. Thus, the creation of a new firm is the endogenous response to investments in knowledge that have not been entirely or exhaustively appropriated by the incumbent firm.

In the endogenous theory of entrepreneurship, the spillover of knowledge and the creation of a new, knowledge-based firm are virtually synonymous. Of course, there are many other important mechanisms facilitating the spillover of knowledge that have nothing to do with entrepreneurship, such as the mobility of scientists and workers, and informal networks, linkages and interactions. Similarly, there are certainly new firms started that have nothing to do with the spillover of knowledge. Still, the spillover theory of entrepreneurship suggests that there will be additional entrepreneurial activity as a rationale and cognitive response to the creation of new knowledge. Those contexts with greater investment in knowledge should also experience a higher degree of entrepreneurship, ceteris paribus. Perhaps it is true that entrepreneurs are made. But more of them will discover what they are made of in a high-knowledge context than in an impoverished knowledge context. Thus, we are inclined to restate the conventional wisdom and instead propose that entrepreneurs are not necessarily made, but are rather a response – and in particular a response to high knowledge contexts that are especially fertile in spawning entrepreneurial opportunities.

By endogenously facilitating the spillover of knowledge created in a different organization and perhaps for a different application, entrepreneurship may serve as *the missing link* to economic growth. Confronted with a formidable *knowledge filter*, public policy instruments emerging from the new growth theory, such as investments in human capital, R&D, and university research may not adequately result in satisfactory economic growth.

By serving as a conduit for knowledge spillovers, entrepreneurship is the missing link between investments in new knowledge and economic growth. Thus, the knowledge spillover theory of entrepreneurship provides not just an explanation of why entrepreneurship has become more prevalent as the factor of knowledge has emerged as a crucial source for comparative advantage, but also why entrepreneurship plays a vital role in generating economic growth. Entrepreneurship is an important mechanism permeating the knowledge filter to facilitate the spillover of knowledge and ultimately generate economic growth. Entrepreneurship education and the transfer of technology from universities to commercialization in the private sector makes a significant contribution to economic growth by reducing the knowledge filter and facilitating the crucial missing link – entrepreneurship.

NOTE

1. As Gartner and Carter (2003) state, "Entrepreneurial behavior involves the activities of individuals who are associated with creating new organizations rather than the activities of individuals who are involved with maintaining or changing the operations of on-going established organizations."

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CURIOSITY-DRIVEN RESEARCH AND UNIVERSITY TECHNOLOGY TRANSFER

Katherine J. Strandburg

ABSTRACT

The debate about university technology transfer policy would benefit from increased attention to two parts of the technology transfer equation: the societal purpose of basic scientific research and the characteristics of scientific researchers.[1] *One purpose of curiosity-driven research is to provide a demand function that can serve as a proxy for the socially optimal (but unknowable) demand function for the unpredictable research that is necessary for long-term technological progress. Preserving the curiosity-driven research peer review "market" is thus important for that progress. This analysis highlights the importance of adequate funding for curiosity-driven research. A model of typical university scientists' preferences can be used to assess how technology transfer policies may affect the social norms of the research community and the long-term viability of the curiosity-driven research endeavor. The analysis suggests that patenting will be an ineffective technology transfer mechanism unless researchers are precluded from using patenting to maintain control over follow-on research.*

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1. INTRODUCTION

The passage of the Bayh-Dole Act in 1980[2] formalized a trend toward increased patenting of university research results[3] and guaranteed university researchers a share in any resulting royalties for commercialization of their inventions.[4] The avowed purpose of the act was to promote technology transfer from federally funded research projects at universities and other non-profit organizations to the commercial sector.[5] The potential for royalties is expected to provide researchers incentives to identify and disclose potentially commercializable results.

Since the Act's passage, there has been considerable controversy among legal scholars and economists, both as to the potential for the commercial incentives and exclusionary mechanism of patenting to undermine the traditional norms of the scientific research community – identified as communalism, universalism, disinterestedness, organized skepticism, independence, and invention – and as to the importance of maintaining traditional scientific norms.[6]

Extensive empirical work has been undertaken to attempt to assess the impact of increased industrial–university cooperation in general, and the Bayh-Dole Act in particular, on the conduct of federally funded basic research. The results of these studies have been mixed and difficult to interpret. There is clear evidence, for example, that patenting at universities has increased drastically over the past 30 years, but less clear evidence linking the increased patenting to the Bayh-Dole Act itself.[7] There is also considerable evidence of increasing delays and secrecy in dissemination of research results, but less clear indication of the connection between the increased secrecy and delays and university patenting.[8] Finally, there is mixed evidence as to whether scientists have shifted toward more applied research as a result of increased patenting opportunities.[9]

This chapter suggests that the theoretical debate about university technology transfer policy would benefit from increased attention to two parts of the technology transfer equation: the societal purpose of basic scientific research and the characteristics of scientific researchers.

With regard to the first aspect, there is widespread agreement that the purpose of basic scientific research is to provide inputs for technological progress in the very long term, in which the potential value of any particular scientific inquiry is largely unpredictable and unknowable. It is also widely agreed that the commercial market will fail to invest adequately in such research and that government funding is necessary to correct this market failure.[10] It is considerably less clear exactly how the government is supposed to outperform the market in allocating funding to research that will lead to the very long-term unpredictable progress that is desired. In this chapter, I suggest that one goal of the basic research endeavor is the production of a curiosity-driven demand function for basic research that can serve as a proxy for the socially optimal (but unknowable) demand function for unpredictable research.

Attention to the second aspect – the typical characteristics of basic researchers – is warranted because the reactions of these researchers to any legal or policy initiatives aimed at promoting technology transfer will determine the efficacy of these initiatives. I argue here that it is possible to infer aspects of the typical utility function for basic researchers from evidence including the fact that they choose basic research over higher-paying employment in an industrial setting. At the margin, these scientists are more likely to respond to opportunities for greater scientific productivity and autonomy than to wealth maximization per se.

An improved model of the preference structure of the typical researcher, or "*homo scientificus*," is important in assessing how particular policy changes are likely to affect the social norms of the research community. The theory of social norms suggests that norms arise to compensate for specific ways in which individual preference-seeking behavior fails to result in optimal outcomes for the members of a particular group.[11] Analyzing traditional scientific norms in this way suggests that the norms of invention, independence, and universalism are largely reflective of the individual preferences of basic researchers, while the norms of communalism, disinterestedness, and organized skepticism serve as means to provide collective goods to the research community that the pursuit of individual preferences may fail to provide. These social norms are important if the basic research community is to continue to provide a socially useful portfolio of curiosity-driven research.

Consideration of the incentives that might lead basic researchers to patent their discoveries suggests that they might tend not to patent the commercializable spin-offs of their curiosity-driven research projects, while being more motivated to patent as a means of maintaining control over future research. I argue that a strengthened experimental use exemption to infringement liability is important to redirect the patenting behavior of basic researchers in a more socially beneficial direction. Finally, I consider the potential that industry support of university research might detract from the curiosity-driven research endeavor. I tentatively conclude that the negative impact will likely be minimal as long as there is sufficient funding available to be distributed through traditional funding mechanisms for curiosity-driven research and as long as research institutions continue to provide the necessary institutional support for the basic research endeavor. This conclusion reinforces concerns on behalf of the National Academies of Sciences and other parts of the scientific community about the diminished availability and increased earmarking of federal basic science funds.[12] The analysis here strongly supports the National Academies' call for basic research funding aimed at ensuring that the United States is a leader in all fields of scientific research through a process of international benchmarking.[13]

Section 2 discusses the traditional funding structure for basic research, argues that it provides a demand structure for such research that is largely defined by the preferences of the research community, and considers whether this demand structure is socially desirable. Section 3 proposes a model for a typical basic science researcher and argues that this model will often be more appropriate for analyzing interactions between university science and industrial development than the usual ''*homo economicus*'' model of the rational wealth-maximizing individual. Section 4 provides an analysis of the ways in which scientific norms may reflect the preferences of the ''typical'' basic researcher. Section 5 provides a preliminary application of this chapter's analysis to the desirability of patenting as a mechanism for university technology transfer and some comments on the more general issue of university–industry interactions. Section 6 offers a brief conclusion.

2. THE SOCIAL FUNCTION OF PUBLICLY FUNDED BASIC RESEARCH

This chapter will focus on ''curiosity-driven basic research'' – the sense of ''basic research'' which is most relevant for university science and the problem of technology transfer, because it reflects the way that I believe that most academic scientists (except those who consider themselves ''applied scientists,'' of course) have traditionally viewed their profession. ''Curiosity-driven research'' is research that is performed without thought of application, and its goal is simply to understand nature. Scientists are direct consumers, as well as producers, of the results of this kind of research. Its direction is selected to satisfy the curiosity and interests of individual researchers and of the research community at large.

There are numerous examples of important technological advances that eventually grew out of scientific research that appeared initially to have been of the most esoteric sort.[14] Because it is impossible to predict a priori which scientific inquiries will lead to these important, and sometimes even revolutionary, technological advances, ensuring that they occur depends upon maintaining a broad "portfolio" of research investments.[15] In discussing basic research, it is common to make two distinct leaps of logic. First, it is often assumed that curiosity-driven basic research is simply equivalent to the broad portfolio of research investments that is needed to capture the benefits of unpredictable scientific advances. Second, the conclusion that public financing is warranted because the market will not provide the necessary broad portfolio of long-term research often ends the discussion. It is assumed that the government can now simply provide the necessary portfolio of research by doling out grants to the appropriate researchers. However, neither of these assumptions is unproblematical.

To see why, note that the market's inability to provide the necessary portfolio of research for long-term unexpected advances is essentially a failure of the market to provide the socially optimal demand structure for such research. This demand-side failure is not mainly a traditional public goods problem posed by non-rivalry and lack of excludability.[16] After the government sets aside the funds for its long-term research investment portfolio, how are the funds to be distributed? How does the government determine who gets the money and for what projects?

Rather than resort entirely to central planning, the "traditional," if implicit, response to the missing market demand function for unpredictable research has been to replace it with a market-type demand-generating mechanism of a different kind – the scientific community's curiosity-driven "marketplace of ideas." In theory, basic research funds are allocated to particular researchers and particular projects according to a peer review process that emphasizes the competence of the researchers and the scientific interest and feasibility of the projects.[17]

To a great degree, then, funding for basic scientific research traditionally has been allocated based on the demand for a particular scientist's work from the scientific community at large. The ability of a scientist to "stay in business" in the scientific marketplace is determined by a subtle combination of reputation, demand for his or her particular "brand" of scientific inquiry, and ability to adapt to shifting community interests as the body of scientific knowledge grows and changes and the "curiosity-driven" frontier moves. Just as in the commercial marketplace, a scientific research group will "go out of business" if its product is no longer in demand no matter how good its reputation for prior work.[18]

Thus, the traditional mechanism for funding basic research substitutes (to some approximation) the "curiosity-driven" preferences of the scientific research community for the unknowable, socially optimal demand function for the portfolio of unpredictable long-term research that is needed for technological progress. Put this way, this may seem like a strange thing to do. Who are these scientists and why should their esoteric interests be likely to produce a socially useful portfolio of research activity?

To some extent this question is answered by the absence of satisfactory alternative methods for allocating funds in the unpredictable research investment portfolio. Scientists have the advantage of expertise, meaning that they may at least be aware of potential avenues of research, and reasonably likely to select avenues of research that promise to increase understanding of the natural world. Because scientists are strong consumers of research output, both for direct enjoyment, and as input to their own research, they have a collective interest in maintaining the overall quality of research as well.[19] And basic scientists are, at least traditionally, disinterested in the financial sense and unlikely to skew the research agenda too much in favor of short-term investments.[20]

There is no proof that the curiosity-driven demand function is precisely equivalent to the socially optimal long-term demand function for unpredictable investment. But if we believe that it is a reasonable approximation, the availability of a market-type mechanism for producing that demand function has all the usual advantages over a central planning approach.

Thus, the social role of curiosity-driven research is, at least in part, to provide a demand function for a broad portfolio of research investment that cannot be efficiently allocated either by demand in the commercial market or by bureaucratic fiat. In the absence of alternative proposals, and given the curiosity-driven research market's great past success, we should be quite leery of abandoning the basic research marketplace without having identified any mechanism to take over its role in allocating a broad spectrum of basic research effort. Concern for preserving the "curiosity-driven" marketplace in the face of pressure for more short-term applied research investments is strongly warranted.

The goal of preserving (or creating) a curiosity-driven market for research can provide a touchstone for evaluating the costs and benefits of particular approaches to technology transfer. From this perspective, the ideal technology transfer mechanism would be one that "captures" the potential commercial applications which result from curiosity-driven research without distorting the well-functioning curiosity-driven research market. The goal of preserving the curiosity-driven demand function must constrain the mechanisms used to bring the spin-offs of basic research to the marketplace.[21] Of course, society may, for other reasons, also wish to provide nonprofit spaces, and even public funding, for some commercially demanded applied research.[22] Different technology transfer approaches may thus be needed for curiosity-driven and applied research.

To evaluate the impact that any given technology transfer approach will have on the curiosity-driven marketplace and on the social norms that hold sway in the scientific community, it is necessary to have a useful model of the preferences and values of the typical participant in that marketplace. The next section begins the process of describing such a model.

3. "*HOMO SCIENTIFICUS*": MODEL OF A BASIC SCIENCE RESEARCHER

The previous Section has argued that society has an interest in eliciting a research agenda that is driven by the scientific curiosity of basic researchers in order to produce a needed portfolio of unpredictable long-term scientific research. Even if this is the case, however, there is still the question of whether the scientific community is structured to produce this "curiosity-driven" research from its members. And, of course, the question of technology transfer is crucial from a social perspective, since society's investment cannot bear fruit unless the unpredictable technological offshoots of basic research are somehow captured and commercialized. The fear is that an emphasis on capturing technological applications will skew the production of research too far in the direction of short-term applicability and away from broadly based unpredictable research.

To understand the collective behavior of the basic science research community (by which I will henceforth mean that group of researchers who participate in curiosity-driven research),[23] it is useful to construct a model of the preference structure of the typical individual researcher. An approximate model of a typical researcher may be used to understand and predict the behavior of the scientific community and its response to legal and policy changes. Preference models of this sort form the basis of the theory of social norms as well and are needed to predict how such norms will evolve in the presence of changing circumstances.

One way to model the university scientist is as an individual who, once a certain fairly comfortable level of material prosperity is obtained, derives a very high marginal utility from performing autonomous, curiosity-driven scientific research and from the direct consumption of scientific knowledge. Because curiosity-driven research is conducted primarily by university researchers, a comparison of the characteristics of university and industrial scientists can help in constructing a model for the typical basic researcher.

In response to surveys, scientists place a very high value on intellectual challenge and autonomy in their work, ranking them both substantially higher than salary and prestige on a scale of job aspects.[24] Second, salary surveys indicate that academic researchers make significantly lower salaries than industrial researchers, with a 2001 survey by the National Science Foundation showing a nearly $30,000 median salary gap between academic and industrial doctoral scientists.[25] While it is conceivable that this salary differential could reflect lower demand for these particular researchers, in fact, it is well known that basic academic research attracts many of the most talented scientists and that academic positions are coveted. Moreover, surveys also indicate that academic scientists are more satisfied with their careers than industry scientists, again suggesting that something other than salary is a major source of utility for these individuals.[26]

Given the mechanisms for entry to and exit from the basic research community, this preference profile is not surprising. The size of the basic research community is limited by the availability of public funding. The availability of higher paying jobs in industry for individuals with virtually the same skill set as these scientists provides a mechanism for selecting out those who place a high value on the particular type of research traditionally practiced in universities – characterized by an emphasis on autonomous choice of research direction and on scientific, rather than technical, interest.

The gate-keeping role played by present members of the scientific community also selects members whose preferences match those of the already-present members. Researchers who gain high utility from conducting research are desirable community members in part because they are likely to be more productive. Scientists depend heavily on the research results of others to satisfy their own tastes for research. Further, most scientific research is collaborative. The individual scientist's ability to enjoy a fruitful collaboration is heavily dependent not only on the talents of her collaborators but on their willingness to put in long hours and intense intellectual effort.

For all of these reasons, I argue for the adoption of a model of a basic researcher as an individual, let us say "*homo scientificus*," with strong preferences for (1) performing curiosity-driven research; (2) exercising autonomy in choosing the topic and direction of his or her research; and (3) learning the results of the collective research project.[27] To satisfy the preferences of "*homo scientificus*," two primary scarce resources are needed:

research funding and the attention of other scientists.[28] Indeed, scientists in a survey by the American Association for the Advancement of Science ranked availability of resources and opportunities for collegial exchange just after intellectual challenge and autonomy as important factors in job satisfaction.[29]

Research funding is a crucial resource for preference satisfaction for scientists, not only because it directly facilitates the activity of research, but because control over funding may (depending upon the source of the funding) provide autonomy in the choice of research direction. The importance of research funding to academic scientists is evidenced by a survey of university technology transfer officials who suggested that faculty would place "sponsored research" at the top, ahead of royalties, of a list of potential payoffs from patenting and industry collaboration[30] and from studies showing that faculty members typically re-invest their profits from commercialization projects in further research.[31]

The attention of other researchers is a scarce and important resource for several reasons. First, it is an important factor in obtaining funding from the peer review process which is the primary allocator of basic research funding. But it is also of more direct importance. As noted, most scientific researchers work collaboratively – both as a means of increasing their personal research productivity, and because part of the utility they derive from doing and consuming science is derived from being part of the ongoing conversation between researchers. Participating in this conversation means getting the attention of other researchers – and the better the other researchers involved, the more rewarding the conversation.

Because both funding and attention are scarce, there is competition between scientists for these resources. On the other hand, while clearly in competition with other scientists for funding and attention, each scientist is also highly dependent on the productivity of other scientists for preference satisfaction. While every scientist wants more funding, no scientist wants to have all the funding. Each scientist's preference satisfaction requires that there be a vibrant research community in which she can participate. In this sense, the scientific community is somewhat analogous to a poker club. People join the club because they enjoy a good game of poker. They want to win because the resulting take will provide the stakes for their participation in the next round, but winning everything will end the game. Moreover, when the question of admitting new members to the club arises, the players have mixed motives – admitting less competent players increases the present members' chances of winning, but undermines the quality of the game, making it less enjoyable for the members both collectively and individually.

This kind of situation, in which there is a tension between what each individual prefers in the short term and what is optimal for the group in the long run, is frequently encountered. When situations of this kind occur in groups with repeated interactions, they may give rise to social norms, which serve to coordinate the behavior of the group in a mutually beneficial way and to punish the defectors.[32]

Having formed a tentative idea of the preference structure of the typical basic science researcher, we can now turn to a discussion of how these individual preferences might be reflected in the overall collective behavior of the basic science community and then to a discussion of how the community might respond to efforts to promote technology transfer through patenting and other means.

4. SOCIAL NORMS OF THE COMMUNITY OF "*HOMO SCIENTIFICUS*"

The theory of social norms focuses on understanding the functions that informal prescriptions of particular behavior, enforced not by legal means but by informal social sanctions, might serve and the ways in which such norms might arise.[33] The general idea behind the theory of social norms is that these norms serve as informal means to coordinate behavior. Regularities of behavior may also arise without coordination, simply as a result of the independent operation of individual preferences. Such regularities are not "social norms" in the sense used here.

The norms most commonly discussed in the legal literature are sanction-driven norms. Sanction-driven norms are maintained by the imposition of penalties for non-compliance. Often such norms are explained as means to deal with collective action or "free rider" problems (frequently analogized to the "Prisoner's Dilemma"[34]), in which rationally optimal behavior by individuals leads to sub-optimal social results.[35] A canonical example of such problems is the provision of infrastructure, such as street lighting or public roads. Because each individual can benefit from the lighting or road whether or not he or she contributes funds to provide it, it is individually rational not to contribute. Unfortunately, the result is that the lighting or roads are not provided.

When collective action problems arise repeatedly among a close-knit group of individuals, a social norm may arise which provides for penalties (often reputational in nature) for non-conformance, and ensures the provision of the collective good.[36] This view of social norms is suggested by Ellickson's famous study of the provision of boundary fences among farmers and ranchers in Shasta County.[37]

Professors Rebecca Eisenberg and Arti Rai have written extensively on the subject of the potential adverse effects that the Bayh-Dole Act and other attempts to define commercial and proprietary rights in basic research results might have on traditional scientific norms.[38] These traditional norms have been described as follows:

- Communalism: Research results are public property and should be accessible for all. Researchers should see themselves as contributors to the scientific community's common knowledge base. Research presses forward by building on past achievements and through cooperation. Therefore, results must be published in full as soon as possible.
- Universalism: The evaluation of research results should be based entirely on impersonal criteria and be without any form of prejudice against nationality, gender, race, personal characteristics etc., or against a person's scientific reputation.
- Disinterestedness: Researchers should be emotionally detached from their field of study and be pursuing truth with a completely open mind. Furthermore, research results should be uninfluenced by extra-scientific interests (e.g. political, economic, or religious).
- Organized Skepticism: Researchers are obliged to be critical not only towards the work of others but also towards their own work. Possible sources of error, doubts, and weak spots in the research should be presented openly and the researcher should be his or her own fiercest critic.[39]

Rai further identifies the norm of "independence," which was emphasized by Hagstrom in work building on that of Merton.[40] The "independence" norm means that "scientists are free to set their own research agendas and to criticize the work of others." Finally, Rai articulates "perhaps the strongest norm" of invention itself. In the traditional view, "the rationale of all these norms is to further the institutional goal of science, which is the progress of knowledge."[41]

Rai and Eisenberg both argue that the traditional norms of science, particularly the norms of communalism, disinterestedness, and independence, may be threatened by the increasing emphasis on and availability of proprietary rights in research results.[42] Indeed, Rai argues that the norms of microbiology research have already been shifted by the prospect of patenting the results of such research.[43] Rai further argues that traditional scientific norms are more effective than proprietary rights at producing scientific progress and that the theory of the interaction of law and norms suggests that the law could and should fruitfully be adapted to support the traditional norms.[44]

These treatments of scientific norms are illuminating, but they are incomplete insofar as they are not grounded in a model of the preference structure of the individual research scientist which might provide an explanation of why such norms might arise and how they may be sustained.

To make further headway in attempting to predict how norms will adapt to changing outside circumstances and legal regimes, a more detailed theory of these norms is needed. An understanding of the function that social norms serve for the basic research community should also help in determining whether those group norms are beneficial for the larger society. The next section considers how the individual preference model developed in Section 3 might relate to the traditional scientific norms.

4.1. Toward a Theory of Scientific Norms

A theory of how the traditional scientific norms relate to the typical basic researcher preference structure and to the collective goods problems that confront the scientific community can help to specify how these norms will apply to particular behaviors – such as patenting – and how they may change in response to legal and policy initiatives. To begin, it is helpful to distinguish social norms that involve conforming behaviors, which arise to combat problems of group coordination and conflicts between locally and globally optimal behavior, from regularities of behavior that result from individual preferences that are common within the group. The theory of social norms focuses on explaining the former.[45]

Rai identifies the “norm of invention” as possibly the strongest norm of the basic science community and argues that “invention is so highly prized that violations of other norms may be tolerated in its name.”[46] Clearly, invention is the defining behavioral regularity of the scientific community. But, since it is in line with both selfish and group interests, it may not be a social norm in the conforming sense. Invention does not pose a coordination problem for a community of typical basic scientists. Rather than being a social norm in the usual sense, the norm of invention is likely to be a regularity which arises from the self-selection and community gate-keeping that determines the membership of the community. Getting back to the poker club example discussed earlier, a poker club will by and large be composed of people who like to play poker, but the fact that members play poker is not ordinarily described as a "norm" of the Poker Club. Similarly, "*homo scientificus*" is an individual with a strong taste for doing scientific research. Thus, the collective desire for "invention" of the basic research community is a regularity arising from the individual preferences of community members, rather than a conforming behavior.

A similar analysis at least partly explains the "norm" of independence which leaves each researcher free to choose the direction of his or her own research. Basic scientists have a strong taste for such autonomy, and it is an important motivation for them to join the academic community. To the extent scientific independence is compromised, scientists will be increasingly motivated to exercise their exit options.

Turning to the specifically Mertonian norms of universalism, communalism, disinterestedness, and organized skepticism, the norm of universalism may also result primarily from a regularity of individual preference. That "[t]he evaluation of research results should be based entirely on impersonal criteria" is dictated to a great extent by the demand for interesting and accurate scientific information. If results are incorrect, they will not provide a useful basis for subsequent progress. Given the competitiveness of an international scientific research community and the fact that scientific progress is generally cumulative and incremental, any attempts to provide a biased assessment (perhaps to curry favor with a distinguished member of the community) are rather pointless even from a selfish standpoint, since subsequent research will expose shortcomings in an earlier work. Impartial evaluation of research results thus also may reflect, to a large extent, the common individual preferences of scientists.

The norms of disinterestedness, communalism, and organized skepticism are the norms that have been seen as most vulnerable to change as a result of increasing industry involvement in university-based research. Because they implicate potential conflicts between the immediate self-interest of the researcher and the longer-term good of the community, these traditional norms likely reflect the need to coordinate behavior that typically underlies social norms. The norm of disinterestedness requires that research be "uninfluenced by extra-scientific interests."[47] It thus addresses the potential conflict between an individual scientist's incentives to skew research to suit some external interest and the long-term goal of a curiosity-driven basic research system that produces accurate information about the natural world. Communalism demands that "results must be published in full as soon as possible."[48] It addresses the potential conflict between the individual scientist's incentive to maintain control of research results so as to increase his or her likelihood of maintaining priority in follow-on work and the benefit to the community as a whole of complete and relatively early dissemination of results. The norm of organized skepticism requires that "possible sources of error, doubts, and weak spots in the research should be presented openly."[49] It addresses the conflict between an individual researcher's incentive to show himself in the best light and the long-term benefit to the community of having access to the researcher's critical evaluation of his own work.

These three norms fit into the "sanction-driven norm" category. Each norm addresses a collective goods problem. Each scientist in the community benefits when others comply with these norms. Thus, every scientist would prefer that all other scientists be disinterested, that all other scientists disseminate their results as quickly as is appropriate, and that all other scientists disclose any weaknesses in their research techniques or results. The collective goods problems arises because every scientist might nonetheless prefer to skew her own research for private advantage, to hold back her own results to maintain control over follow-on research, and to hide any weaknesses in her work.

If the strengths of individual preferences are appropriate, the canonical collective goods problem could arise. Though all would be better off if everyone behaved in a cooperative way, each will choose independently to defect, with the result that all will be less satisfied. To the extent that the basic prerequisites for effective sanction-driven norms are met – a close-knit group with repeated interactions and detectable violations – social norms may arise to punish deviations from collectively optimal behavior. Sanction-driven norms are primarily effective against behavior that is detectable by the community.

Of course, with respect to each of these norms, the balance of preferences for any individual researcher depends on many factors. For example, some avenues of research may require expensive or specialized equipment or know-how of laboratory techniques so that there is a natural lead time for follow-on research to mitigate the disadvantages of early disclosure, thus lessening the private incentive to delay dissemination. The likelihood of independent discovery by others also varies from case to case and affects private incentives for rapid dissemination of results. In some cases, laboratory methods or research tools required for the research may themselves be publishable discoveries, increasing the potential reputational payoff from early publication and lessening the private payoff from delaying publication.

Each of the traditional scientific norms will thus be illuminated by a focus on its relationship to the private preference profile of the typical basic researcher. This focus will also be helpful in evaluating more specific norms and institutions that implement and reflect the traditional overarching values. Further analysis would benefit from a more thorough empirical grounding of the *homo scientificus* model and more specific enumeration of the observable manifestations of the general scientific norms.

The present discussion has been limited to the incentives of the researchers themselves because they are the direct producers of scientific research and have a significant degree of autonomy in conducting their research. University technology transfer involves several constituencies with different private agendas including faculty researchers, university administration, and university technology transfer officials. The interaction between these constituencies would be considered in a more complete analysis.

With these caveats in mind, we may proceed to draw some tentative inferences about university patenting and technology transfer from the present analysis.

5. SOME PRELIMINARY IMPLICATIONS FOR UNIVERSITY PATENTING AND TECHNOLOGY TRANSFER

As argued in Section 2, there should be two primary goals for university technology transfer efforts relating to basic research.[50] The obvious goal is to expedite the "capture" of commercially beneficial applications of basic research. But an equally important goal should be to preserve the broad-based curiosity-driven research "market" as a means of providing a demand function for socially beneficial long-term investments in an unpredictable research. In what follows I consider some of the potential effects of various approaches to technology transfer on this curiosity-driven research enterprise.

5.1. Patenting as a Technology Transfer Mechanism

The Bayh-Dole Act was intended to promote the patenting of federally funded research by universities and other funding recipients. One major purpose of the Act was to provide a mechanism for licensing the results of federally funded research to industrial entities so as to provide a motivation for them to invest in bringing relatively embryonic university discoveries to a point at which they are suitable for commercialization. A related goal was to motivate faculty and universities to participate in this process by providing them compensation, primarily through royalty revenue.[51]

There are at least two distinct ways in which patenting the results of university research might threaten the functioning of the curiosity-driven research enterprise. First, the ex post costs of the patenting process and resulting exclusive rights might introduce delays and transaction costs into the research process, slowing the progress of science. Second, the ex ante quest for patents might skew the choices of research topics toward more applied projects, threatening the socially beneficial production of the curiosity-driven research demand function. Assuming that both of these would be unintended negative side effects of a policy of encouraging university patenting of basic research results, one can analyze the circumstances under which they are likely to occur and consider how they might be mitigated.

5.1.1. Incentives to Patent the Results of Curiosity-Driven Research

To understand any potential negative effects of university patenting, it is necessary to consider what incentives would motivate basic researchers to patent the results of their research. Universities as institutions may have an interest in patenting simply as a source of revenue. Researchers, however, seem rather unlikely to be motivated to patent the results of their curiosity-driven research simply to obtain royalty revenues, except in the exceptional case. Royalty revenues from university licenses averaged $66,465 per license in 2000. Most university patents result in no revenue at all, however.[52] Researchers receive about 40% of these royalties on average.[53] So the expected royalty revenues from most research spin-offs are not large.

On the other hand, patenting may have substantial costs to researchers. Assuming for the moment that they do not shift their research agendas to increase the chances of obtaining patentable results, researchers still incur opportunity costs from patenting. Any time spent identifying patentable discoveries, writing patent applications, meeting with patent attorneys, and so forth is time that cannot be spent writing grant applications, pursuing curiosity-driven research, and writing articles for publication – activities that will in most cases be of much greater value to the basic researcher than the revenues to be derived from patent royalties.[54]

Researchers may also have penalties imposed on them by the research community if patenting of a particular discovery is viewed as a violation of the communalism norm that requires making research results freely available to the community in a timely manner. Sanctions imposed by the research community may include loss of esteem, but probably more importantly might include denial of the scarce resources of research funding and attention.[55]

Unless there is a blanket norm against patenting per se, different patenting activities will have different degrees of impact on the availability of research results to the community and probably elicit different degrees of community disapproval. Some commercializable spin-offs of curiosity-driven research may be of little value to the basic research community. Patenting such spin-offs may not implicate the communalism norm. On the other hand, patenting upstream research results or research tools may affect the feasibility of future curiosity-driven research for other scientists and may excite significant community disapproval.

Of course, in the pursuit of curiosity-driven research there will be occasional discoveries that are of great commercial importance and have the potential for very large royalty revenues. In such cases, the revenues to be obtained from patenting will probably outweigh the opportunity costs and any penalties for norm violation that the research community could impose, especially because the royalty revenues can be used to fund further research. With occasional exceptions, however, it seems unlikely that royalty revenues will be a primary incentive to patenting in light of the costs and benefits described above. This simple cost-benefit analysis may explain why many scientists continue to resist the efforts of university administrators and technology transfer officers to get them to make invention disclosures and participate in the patenting process.[56]

While the prospect of royalty revenues may not provide a sufficient incentive for basic researchers to patent their discoveries, researchers may have other private incentives to patent. One such incentive might be the ability to maintain exclusive control over follow-on research that relies on the invention. Patenting that is motivated by the ability to prolong exclusive control over a particular line of research is pernicious from the perspective of the curiosity-driven research enterprise and from the perspective of the patent system itself.[57]

Licensing is unlikely to mitigate the exclusivity problem in such cases because university researchers who patent for these reasons would not be seeking to recoup the costs of their research investment, but to maintain priority in subsequent research. Of course, patents on these inventions will probably be owned by the university, rather than the individual researcher. Universities may have revenue-driven incentives to license patents regardless of researchers' desires to maintain exclusive control over follow-on research. Their technology transfer offices may have the power to grant licenses without researcher approval. Even such separation of control over licensing from control over research may not solve the problem, however. First, the main scientific competitors to university researchers may be other university researchers, for whom a license fee large enough to be of interest to the university as a source of revenue may be a substantial deterrent. Second, if university licensing policies do not preserve an advantage in follow-on research for university inventors, the inventors may simply not bother to incur the opportunity costs of patenting these inventions.

Of course, such exclusive control of follow-on research would violate the communalism norm, but patenting may make it more difficult for the community to enforce the communalism norm. Without patenting, the private payoff from attempting to maintain exclusive control is naturally capped because of the need to maintain secrecy and refrain from publication, along with the threat of independent discovery by another researcher. Patenting may drastically increase the potential private payoffs for defecting from the communalism norm, by making the exclusivity option much more effective. As the private payoff for defection increases, the effectiveness of community sanctions lessens.

The community's ability to maintain a norm in the face of shifting private incentives depends on the preference distribution of community members and the strength of the sanctions that the community is able and willing to impose. Thus, an increase in payoffs for uncooperative behavior resulting from patenting might weaken the communalism norm overall, eventually leading to an increase in other kinds of uncooperative behavior (such as withholding data or materials that are not patentable).

Another possible motivation for patenting by basic researchers – other than obtaining royalty revenues from commercial applications – is the possibility of obtaining research funding from an industrial exclusive licensee. Indeed, a survey of technology transfer officials found that research funding is the faculty's preferred compensation from patent licensing.[58] Such funding is unlikely to come without strings attached, however. Research funding is a greater incentive to patenting than royalty revenue only if it is greater than the potential royalty revenue. It is difficult to imagine that an industrial partner would provide research funding greater than the royalty value without placing restrictions on the research that could be performed with the funding. Such funding thus has the potential to turn what was originally a spin-off of curiosity-driven research into a distortion of the basic research demand function.

One other, somewhat counter-intuitive, possible incentive for university basic researchers to patent may be the ability to participate actively in the commercial development of their inventions. At first glance, such an incentive may seem inconsistent with the picture of "*homo scientificus*" painted above. Why would a scientist interested in commercial research not have become an industrial scientist in the first place? The strong preference for autonomy expressed by basic scientists may provide an answer. Curiosity-driven research is one arena in which a strong preference for autonomy may be satisfied. However, entrepreneurial development of an invention might also satisfy the taste for autonomy while offering larger financial payoffs than university research.

Researchers no doubt vary in their relative preferences for autonomy and for learning about the natural world. A strong taste for autonomy may explain why some faculty members who shunned employment in industrial settings have started businesses or become actively engaged in the commercialization of their discoveries.[59] Since such scientists are strongly motivated by autonomy, they may maintain a rather traditional, curiosity-driven research agenda alongside their commercial activities. There is some evidence that some of the most productive entrepreneur-scientists have maintained strong traditional research programs even after being personally involved in commercializing the results of their earlier research.[60]

5.1.2. Incentives to Skew Research Directions to Obtain Patents

One possible side effect of allowing basic researchers to patent their results is the possibility that a scientist might slant her research direction ex ante in hopes of obtaining a patent, thereby distorting the curiosity-driven demand function. The extent to which the ex ante prospect of patenting can produce such a distortion is questionable, however, given the preference structure of those who go into the field of basic academic research. Since royalty revenues are not substantial on average, the expectation of royalty revenues may be unlikely to compensate for the diminished ability to satisfy the tastes for autonomy and "doing science" that such a shift would entail. Furthermore, great entrepreneurial opportunities are hard to predict ahead of time and unlikely to provide extensive ex ante incentives.

The strongest motivation for a basic researcher to skew her research direction in an effort to obtain a patent is probably the possibility of industrial research funding. Since industry funding will probably come with strings attached, however, basic researchers will prefer traditional sources of curiosity-driven research funding when funding from those sources is available. Thus, as long as traditional basic research funding is *available*, the ex ante prospect of patenting seems unlikely to have a major skewing effect on the portfolio of curiosity-driven research. This conclusion is consistent with at least some empirical studies, which suggest that increased patenting has not been responsible for a shift toward more applied research.[61]

5.1.3. Effects of Patenting on Curiosity-Driven Research and Technology Transfer

While patenting may not yet have led to a dramatic shift toward applied research, the bottom line of this analysis of the incentives provided by patenting is not particularly encouraging. The analysis suggests that neither of the dual goals of university technology transfer – neither preserving a vibrant regime of curiosity-driven research nor facilitating the commercialization of spin-offs of that research – is advanced by the availability of patents to university basic researchers. On the one hand, incentives to patent commercializable spin-offs of curiosity-driven research ex post may be insufficient, since royalty revenues will not usually offset the opportunity cost of patenting. On the other hand, patenting may threaten the communalism norm, and thus the entire curiosity-driven research enterprise, by increasing the private payoffs from exclusive control over promising avenues of research. Basic researchers may thus be motivated to patent upstream research results while leaving spin-offs with more immediate commercial potential undisclosed.

For the commercial sector, the patent exclusivity period is an integral part of the incentive structure, translating consumer demand into a means to recoup investment into commercially desirable inventions. In the commercial context, a degree of control over follow-on innovation is necessary to recoup the costs of research and development and thus provide incentives to invent and disclose. The curiosity-driven research market is funded by an entirely different mechanism, however, which allocates funds according to the curiosity-driven demand function. Exclusive rights to make and use research results are not needed as incentives for innovation in that marketplace, since research funding is awarded without the need for exclusive control of research results. Only at the interface between the curiosity-driven marketplace and the commercial marketplace, where exclusive rights provide incentives for commercial actors to develop embryonic research results into commercial products, do typical patent-type exclusive rights play a positive role. Thus, exclusive rights may be needed by commercial actors who are suppliers of laboratory equipment and materials or, as emphasized in the present discussion, by commercial actors who serve as conduits of basic research spin-offs to the commercial marketplace. Since the rationale for patent exclusivity does not apply to university researchers, however, it would be socially beneficial to reduce the ability of university researchers to use patent exclusivity primarily to keep other researchers from competing with them to follow up on their results.

5.1.4. An Experimental Use Exemption Might Improve the Effectiveness of Patenting as a Technology Transfer Mechanism

There has been considerable support from legal scholars and, increasingly, from policy makers, for some form of exemption from infringement liability for experimental use of patented inventions.[62] Such an exemption would reduce the potential for holdups in follow-on innovation. I have argued elsewhere that, even for commercial actors, an infringement exemption that permits "experimenting on" a patented invention for the purpose of studying or improving it does not undermine the patent incentives to invent and disclose the invention.[63] The arguments in favor of such an exemption are even stronger when the patentee is a basic researcher, since there is no need for *any* commercially driven incentive to invent or disclose. Indeed, such commercially driven incentives can only distort the demand structure of the curiosity-driven research marketplace.

An exemption for "experimenting on" a patented invention to understand or improve it leaves in place the potential for exclusive licensing of a commercializable spin-off so as to provide a conduit from university to marketplace. An exemption from infringement liability for "experimenting on" a patented invention could even play a subtle positive role in encouraging the patenting of spin-off inventions that would be of commercial interest. A robust "experimenting on" exemption could shift the social meaning of patenting in the basic research community. If patenting could no longer be used to prevent follow-on research, it would no longer be at odds with the communalism norm. Patents could then serve the desired function of providing an incentive for industrial actors to commercialize university inventions, without playing a negative role in the curiosity-driven research marketplace.

Unfortunately, while an "experimenting on" exemption would address some concerns about exclusive control of upstream research, it would not solve the problem of patented research tools. Research tools might also be patented as a means to control downstream research. This possibility poses an important problem, to which I have suggested a possible general approach in earlier work.[64] That general approach did not take into account the special situation of curiosity-driven researchers, but assumed that a commercial payoff was a necessary incentive for tool invention. Analysis of the research tool problem thus might also be furthered by considering the special incentives and rewards available to university researchers as potential patentees. However, such an analysis is beyond the scope of this chapter.

5.2. University–Industrial Interactions and the Curiosity-Driven Research Endeavor

While the attention of the legal community has naturally focused on patenting as a mechanism for technology transfer, patenting is only one avenue for commercial influence on university research.[65] Industry research funding and university–industry collaborations are also important ways in which commercial demand may influence university research.

5.2.1. Industry Funding of University Research

Industry funding of university research might be considered a mechanism for technology transfer. Industry funding is not a means of transferring technology that is developed as a spin-off of curiosity-driven research, however. Instead, it is a means for enticing university researchers to perform research the demand for which is driven by commercial considerations. Industrial demand for university-based research may result from a number of factors, including the lower salaries paid to university researchers and the ability to tap into the pool of cheap and highly motivated graduate student labor; increased commercial demand for research that is basic in the sense of "fundamental" or, far from application, for which university researchers may have superior skills compared to industrial scientists; the efficiency of involving researchers in developing spin-offs of their own inventions into commercial products (given the large amount of know-how which these researchers may have accumulated in the course of their curiosity-driven research);[66] a desire to influence the training of a scientific labor force for the industry; and a desire to involve particular highly talented scientists who are not interested in industrial employment in commercially motivated research.

None of these objectives is illegitimate, yet the increasing role of industry funding raises the question whether industry funding will diminish the ability of universities (and other non-profit research institutions such as government laboratories) to produce a portfolio of curiosity-driven research. In answering that question, one must not lose sight of an obvious, but very important point. Given the preference set of basic researchers and the fact that there is intense competition for the opportunity to perform curiosity-driven research, the primary determinant of the amount of curiosity-driven research that is performed in universities will be simply the amount of basic research funding available. Funding is a scarce and essential resource for scientific research and to the extent funding from traditional basic research sources, such as the National Science Foundation, diminishes or becomes more targeted, researchers at the funding margins will either compromise their autonomy interests by performing more targeted research or seek other career opportunities to balance their individual tastes.

Thus, the most important means to ensure a sufficient portfolio of curiosity-driven research is for the public to provide sufficient funding for the institutions that support that enterprise. The funding available for such research has been diminishing, resulting in statements of alarm from various scientific organizations.[67] The level of public support for curiosity-driven research is a political issue, which calls for political advocacy of the importance of the basic research endeavor, independent of the level of industry funding for university research.

Given a particular level of funding for curiosity-driven research, the primary effect of industry funding of university research, along with other more direct joint university–industrial endeavors, is to mix the basic and applied research communities. In principle, mixing the two endeavors might affect the curiosity-driven research enterprise in several ways. First, the separation of individual researchers into university and industrial positions according to their preference sets might be affected if university institutions become less tuned to satisfying the preference for autonomous, curiosity-driven research and if the salary differential between university and industrial positions diminishes. In other words, the less clear the separation between university and industry in terms of research opportunities, the less accurate the "*homo scientificus*" profile will be as a description of the university basic scientist.

Moreover, if the "*homo scientificus*" preference set is at least partly produced exogenously by the process of graduate education, the presence of significant applied research in departments that have traditionally focused on basic research may reduce the extent to which graduates are encouraged to form strong preferences for autonomous, curiosity-driven research. If preferences are exogenous and dynamic, interactions between industrial and university researchers might also result in preference changes for more established researchers. To the extent the institutional structure and social norms of the curiosity-driven research market depend on characteristics of "*homo scientificus*," they will change as a result.

Increased interaction between the industrial and academic communities could also affect the social norms of the curiosity-driven research community, quite apart from any shifts in the preference profiles of members of the two communities. It is a nearly universal experience that when two formerly isolated communities come into contact with one another, the social norms of both are affected, sometimes drastically. But there are reasons to expect these effects to be mitigated in the case of increased mixing between industrial and university researchers. Mechanisms for "norm drift" may not be particularly relevant to the "cultural exchange" between industrial and university scientists. The separation of these two communities has been voluntary, based upon knowledge of the characteristics of both, and never particularly complete. Scientists have always been able to move between the two communities. Of course increasing interaction between individuals in the two communities will provide increased opportunities for members of one community to impose sanctions, including esteem penalties, on members of the other when they do not conform to social expectations. The social impact of increased interaction between the industrial and university communities is thus a complicated question that warrants further investigation, taking into account the preference profiles of typical community members.

Despite the complications, it is worth noting that the potential for mere interaction to produce major preference and norm shifts can be exaggerated. As long as there is a supply of competent scientists with the traditional "*homo scientificus*" preference set, sufficient money to fund their research, and an available institutional framework for them to provide a "market" for one another's research results, it seems likely that they will continue to produce a curiosity-driven research portfolio. Thus, the most serious threat to the curiosity-driven research community is not industry funding of university research per se, but the extent to which industrial funding diminishes social and university commitment to providing the kinds of funding and institutional structures that the basic research enterprise requires. The rather prosaic bottom line may be simply that if we want curiosity-driven research we have to pay for it.

5.2.2. University–Industry Collaborations as a Mechanism for Technology Transfer

Much of the above discussion about industry funding of research is directly applicable to university–industrial collaborative projects and will not be repeated here. A collaborative project may be one form of funding mechanism aimed at producing targeted research. As such, it is industry funding, for better or for worse, and not a technology transfer mechanism that provides a conduit for commercially interesting spin-offs of curiosity-driven research.

However, there are collaborative projects that do not fit the industry funding pattern, arising ex post after curiosity-driven research produces a commercializable spin-off. Commercialization of such spin-offs may require or benefit from the active participation of the scientist inventor.[68] It is not clear what impact the involvement of scientists in such entrepreneurship is likely to have on the market for curiosity-driven research.

For example, an entrepreneur-scientist might seek to use the peer review process to suppress the work of another scientist if that work had the potential to threaten the commercial success of his entrepreneurial project. The usual personal preferences and social norms that mitigate such a scientist's desire to suppress competing work in the basic research community are still operative, of course, but they may be less effective against the entrepreneurial scientist because of the added personal incentives that the commercial enterprise provides. The basic research community might effectively avoid this potential distortion of the curiosity-driven demand function by using more stringent conflict of interest screening of peer reviewers. Scientists with commercial stakes in enterprises related to particular areas of curiosity-driven research could be precluded from reviewing proposals and publications in those areas.

6. CONCLUSIONS

This chapter has argued that the curiosity-driven basic research "marketplace" plays an important social role in providing a demand function for a portfolio of long-term investments in an unpredictable scientific research. Technology transfer efforts relating to such basic research should be aimed at developing the commercial potential of spin-offs of this research without distorting its curiosity-driven incentive structure. Attempts to preserve a domain of curiosity-driven research must take into account the typical preference structure of the basic researcher, which is apparently characterized by strong marginal utility for doing autonomous curiosity-driven research and directly consuming the knowledge created by that research. Analyses of the social norms of the basic research community and of the potential for those norms to change in light of university–industry contacts should be premised on a model of such a researcher.

When these preferences are taken into account, they suggest that patenting may not be a particularly effective mechanism for capturing the commercializable spin-offs of curiosity-driven research. Rather than expend effort to commercialize such spin-offs, basic scientists are more likely to seek to patent upstream research results which will allow them to gain priority in follow-on research. While the traditional scientific norm of communalism denounces such behavior, the availability of patent protection has the potential to shift individual payoff functions enough to weaken the communalism norm.

Patenting aside, there is a possibility that increased interaction between industrial and university scientists will lead to a weakening of traditional scientific norms and, thus, of the curiosity-driven research endeavor. However, the self-selected nature of the basic research community means that strong individual preferences support the norms of that community. Given an adequate supply of individuals with a preference for curiosity-driven research, the greatest threat to maintaining a socially valuable long-term research portfolio is probably not from industrial involvement per se, but from diminishing availability of funding for curiosity-driven research and the possibility that the institutions that support such research may be weakened by lack of funding and by administrative attention to other priorities.

NOTES

1. This Chapter was prepared for the Colloquium on University Entrepreneurship and Technology Transfer hosted by the Karl Eller Center of the University of Arizona and sponsored by the Ewing Marion Kauffman Foundation. I am grateful to them for their support. I am also grateful to the participants in the Colloquium for helpful comments. Finally, I thank my research assistant, David Zelner, for assistance with this project.
2. 35 U.S.C. §§ 200 *et seq.*
3. See David C. Mowery, Richard R. Nelson, Bhaven N. Sampat and Arvids A. Ziedonis, Ivory Tower and Industrial Innovation: University-Industry Technology Transfer Before and After the Bayh-Dole Act (2004) for a review of trends in university patenting.
4. See, e.g., 37 CFR 401.14 (k)(2).
5. 35 U.S.C. § 200.
6. See, e.g., Mowery *et al.*, *supra* note 3; John P. Walsh, Ashish Arora and Wesley M. Cohen, *Effects of Research Tool Patents and Licensing on Biomedical Innovation*, Patents in the Knowledge-Based Economy (Wesley M. Cohen and Stephen A. Merrill, eds, 2003); Brett Frischmann, *Innovation and Institutions: Rethinking the Economics of U.S. Science and Technology Policy*, 24 Vt. L. Rev. 347 (2000); Robert W. Hahn, *The Economics of Patent Protection: Policy Implications from the Literature* (October 30, 2003). http://ssrn.com/abstract=467489 (summarizing and reviewing the economic

literature); Rebecca Eisenberg and Arti K. Rai, *Bayh-Dole Reform and the Progress of Biomedicine*, 66 L. & Contemp. Probs. 289 (2002); Jerry G. Thursby and Marie C. Thursby, *University Licensing and the Bayh-Dole Act*, 301 Science 1052 (2003).

7. See, e.g., Mowery *et al.*, *supra* note 3.

8. Erik G. Campbell, B.R. Clarridge, M. Gokhala, L. Birnbaum, S. Hilgartner, N. Holzmann and D. Blumenthal, *Data Withholding in Academic Genetics, Evidence from a National Survey*, 287 JAMA 473 (2002); David Blumenthal, E.G. Campbell, M.S. Anderson, N. Causino, and K.S. Louis, *Withholding Research Results in Academic Life Science*, 277 JAMA 1224 (1997); Jeremy M. Grushcow, *Measuring Secrecy: A Cost of the Patent System Revealed*, 33 J. Legal St. 59 (2004); J. H. Reichman and Paul F. Uhlir, *A Contractually Reconstructed Research Commons for Scientific Data in a Highly Protectionist Intellectual Property Environment*, 66 L. & Contemp. Prob. 315 (2003).

9. Jerry G. Thursby and Marie C. Thursby, *University Licensing Under Bayh-Dole: What are the Issues and Evidence?*, available at http://opensource.mit.eud/papers/Thursby.pdf; Jerry G. Thursby and Marie C. Thursby, *Who is Selling the Ivory Tower: The Sources of Growth in University Licensing*, Mgmt. Science (January 2002).

10. See, e.g., Frischmann, *supra* note 6.

11. See, e.g., Steven A. Hetcher, Norms in a Wired World (2004) for an overview of social norm theory and many pertinent references.

12. See, e.g., National Academy of Sciences, National Academy of Engineering, Institute of Medicine, Observations on the President's Fiscal Year 2003 Federal Science and Technology Budget (2002).

13. See, e.g., National Academy of Sciences, National Academy of Engineering, Institute of Medicine, Evaluating Federal Research Progress (1999); National Academy of Sciences, National Academy of Engineering, Institute of Medicine, Science, Technology, and the Federal Government: National Goals for a New Era (1993); National Science Board, Federal Research Resources: A Process for Setting Priorities (2001).

14. See Observations on the President's Fiscal Year 2003 Federal Science and Technology Budget, *supra* note 12 at 14–16 for some examples.

15. See Michael McGeary and Phillip M. Smith, *The R&D Portfolio*: *A Concept for Allocating Science and Technology Funds*, 274 Science 1484 (1996), for an argument that federal R&D should be viewed as a long-term investment portfolio.

16. For a more general discussion of the importance of demand-side market failure, *see* Brett Frischmann, *An Economic Theory of Infrastructure and Commons Management*, 89 Minn. L. Rev. (forthcoming, Spring 2005).

17. This description is an exaggeration, of course. There has always been an element of central planning in the funding of "curiosity-driven" research. Allocations of funds between disciplines and among programs are determined by government policy makers. However, to a surprising extent, the allocation of funding for basic research has been left in the hands of the scientific community itself – through peer review, program committees and the like. And while peer review is widely seen as a mechanism of quality control, it is also a mechanism for determining the scientific "demand" for particular research projects.

18. Perhaps this point is obscured by the fact that many basic researchers are professors with tenure whose livelihood is not on the line in the scientific

marketplace. However, except for those in the most theoretical sub-disciplines, a scientist's ability to "do science" is contingent on a continuing competition for research funds.

19. This interest in quality of research is tempered by other interests, of course, as will be discussed in more detail below.

20. It is important to emphasize that to suggest that scientists are disinterested in this sense is not to suggest that they are particularly public-spirited or altruistic, but only that they have a distinctive flavor of private agenda that is not dominated at the margin by commercial concerns.

21. This perspective also has implications for the funding of basic research. It validates the concerns expressed in the National Academy of Sciences reports discussed *supra* notes 12 and 13, which assert that the United States should aim to excel in all areas of research as measured by an international standard. Since the curiosity-driven basic research marketplace is quite international, the United States can thus benefit from a demand function created by the entire international scientific community.

22. See, e.g., for a discussion of this issue, Frischmann, *supra* note 6.

23. Of course, this definition is highly over-simplified. There are many researchers whose work spans the boundary between basic and applied; there are many different basic research communities associated with different scientific specialties; and there is an increasing amount of inter-disciplinary work that complicates the social structure of the scientific community.

24. Constance Holden, *General Contentment Masks Gender Gap in First AAAS Salary and Job Survey*, 294 Science 401 (October 2001) (reporting results of survey of life scientists); Thomas B. Hoffer, *Employment Sector, Salaries, Publishing, and Patenting Activities of Science & Engineering Doctorate Holders*, InfoBrief, NSF 04-328 (June 2004), comparing results of 1995 and 2001 surveys of doctoral scientists.

25. *Id.*

26. Holden, *supra* note 24.

27. For a similar point, *see* Reichman, *supra* note 8, noting that "academic researchers typically are not driven by the same motivations as their counterparts in industry .... Rather, the motivations of not-for-profit scientists are predominantly rooted in intellectual curiosity, the desire to create new knowledge, peer recognition and career advancement, and the promotion of the public interest."

28. There are exceptions to this contention of course: some sufficiently theoretical work may require no more than pencil and paper and some individual scientists may work independent of collaborators and keep up with the progress of others purely by reading scientific journals. But such scientists are extremely rare. Most scientific work requires significant funding and most researchers work collaboratively.

29. Holden, *supra* note 24.

30. Thursby, *University Licensing*, *supra* note 8.

31. Joanna Poyago–Theotoky, John Beath, and Donald S. Siegel, *Universities and Fundament Research: Reflections on the Growth of University–Industry Partnerships*, 18 Oxford Rev. Econ. Pol. 10 (2002).

32. See Hetcher, *supra* note 11 at 56–67 for a recent discussion of this function of social norms.

33. The term "norm" can have meanings ranging from a prescriptive rule to a mere descriptive regularity. *See id.* for a discussion of these different meanings. Hetcher distinguishes between what he calls "rule-based" and "pattern-based" conceptions of social norms and argues in favor of a pattern-based conception. *Id.* at 17–37. For our purposes, we need not distinguish between these two definitions, both of which are centered on *conforming* behavior. Conforming behavior is distinct from mere regularities which occur as a result of following purely individual preferences. It is the distinction between conforming norms and regularities that is of interest in the present analysis.

34. See, e.g., Hetcher, *supra* note 11 at 56–57 for a discussion of the Prisoner's Dilemma and its relationship to sanction-driven norms.

35. *Id.*

36. See, e.g., *id.* at 58–59 for a discussion of social norms as solutions to iterated Prisoner's Dilemmas.

37. Robert C. Ellickson, Order Without Law: How Neighbors Settle Disputes (1991). See also Robert Axelrod, The Evolution of Cooperation (1984), discussing how cooperation can arise as a strategy to deal with an iterated Prisoner's Dilemma.

38. Rebecca S. Eisenberg, *Proprietary Rights and the Norms of Science in Biotechnology Research*, 97 Yale L. J. 177 (1987); Arti Rai, *Regulating Scientific Research: Intellectual Property Rights and the Norms of Science*, 94 Nw. U. L. Rev. 77 (1999).

39. Erik Erno–Kjolhede, Scientific Norms as (Dis)Integrators of Scientists?, WP 14/2000, Copenhagen Business School (2000).

40. Rai, *supra* note 38 at 91. *See also* Erno–Kjolhede, *supra* note 39 at 4–10, discussing various formulations of scientific norms and the controversies surrounding them.

41. Rai, *supra* note 38 at 91.

42. Eisenberg, *supra* note 38 at 230–31; Rai, *supra* note 38 at 109–11.

43. *Id.*

44. *Id.* at 136–51.

45. Regularities in observed behavior are sometimes called "descriptive norms," but for clarity I will reserve the term norms for conforming behavior in this discussion.

46. Rai, *supra* note 38 at 92.

47. Erno–Kjolhede, *supra* note 39.

48. *Id.*

49. *Id.*

50. No doubt a large fraction of university technology transfer efforts relate to applied research. I do not address that research here because the social goal of generating a demand function for unpredictable research is not relevant to applied research. University applied research must have a different justification. Possible justifications for applied research in universities include a need for public funding of targeted research for which a large investment is needed before getting to a commercializable result and the education of future applied researchers. But a discussion of applied research is beyond the scope of this chapter.

51. See references at notes 3 and 6 *supra* for discussion of the Bayh-Dole Act.

52. Thursby, *University Licensing*, *supra* note 9.

53. Richard Jensen and Marie Thursby, *Proofs and Prototypes for Sale: The Tale of University Licensing*, 2001 Amer. Econ. Rev. 240 (2001).

54. See Thursby, *Ivory Tower*, *supra* note 9 (describing a survey of technology transfer officers who reported faculty reluctance to make invention disclosure because of unwillingness to delay publication or to spend time on activities necessary to interest businesses in licensing inventions).

55. The community's ability to impose high penalties is complicated by the fact that different members of the research community make different contributions to the community. The norms of universalism and disinterestedness and the purely private interest that each scientist has in consuming scientific output make it difficult for scientists to impose loss of funding or denial of publication sanctions on productive scientists. Scientists who are particularly productive or particularly desirable as collaborators thus may be able to "get away with" more flagrant violations of community norms than less productive members of the community.

56. Thursby, *Ivory Tower*, *supra* note 11.

57. See Katherine J. Strandburg, *What Does the Public Get? Experimental Use and the Patent Bargain*, 2004 Wis. L. Rev. 81 (2004) (discussing the distinction between patenting to recoup R&D investment and patenting to control follow-on invention); Rochelle C. Dreyfuss, *Varying the Course in Patenting Genetic Material: A Counter-Proposal to Richard Epstein's Steady Course*, Perspective on Properties of the Human Genome Project (F. Scott Kieff, ed., 2003) (distinguishing between product markets and innovation markets).

58. Thursby, University Licensing, *supra* note 9.

59. See *id.*; Poyago-Theotoky *et al.*, *supra* note 31.

60. *Id.*

61. Thursby, Ivory Tower, *supra* note 9.

62. See references *supra* note 57; see also Rochelle Dreyfuss, *Protecting the Public Domain of Science: Has the Time for an Experimental Use Defense Arrived?*, 46 Ariz. L. Rev. 457 (2004); American Intellectual Property Law Association, AIPLA Response to the National Academies Report entitled "A Patent System for the 21st Century," available at www.aipla.org (endorsing an "experimenting on" exemption) (visited on February 1, 2005).

63. Strandburg, *supra* note 57.

64. *Id.*

65. See, e.g., Mowery *et al., supra* note 3 at 152–178.

66. See Thursby, *Ivory Tower*, *supra* note 9.

67. See, e.g., references *supra* note 12 and 13.

68. See Thursby, *Ivory Tower*, *supra* note 9.

THE IRRATIONALITY OF SPECULATIVE GENE PATENTS

David E. Adelman

ABSTRACT

The burgeoning interest over the last decade in technology transfer at universities in the United States has driven contentious debates over patent policy. In this context, biotech patenting has become the poster-child for claims that the proliferation of patenting by universities, and in the private sector, is undermining scientific norms and threatening innovation. Commentators have expressed particular fears about the negative effects of biotech patenting on the public information commons and concerns about emerging "patent anticommons." This chapter argues that the standard (finite) commons model is being misapplied in the biotech arena because, owing to the complexity of biological processes and the power of existing biotech methods to produce genetic data, biomedical science is, in crucial respects, an unbounded, uncongested common resource. These findings imply that strategic biotech patenting of problem-specific research tools (i.e., single-nucleotide polymorphisms, drug targets) is not economically justified and therefore is irrational.

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1. INTRODUCTION

The burgeoning interest over the last decade in technology transfer at universities in the United States helps to drive the contentious debates over patent policy. In this context, biotech patenting has become the poster-child for claims that the proliferation of patenting by universities, and in the private sector, is undermining scientific norms and threatening innovation. Numerous commentators have expressed fears about the negative effects of biotech patenting on the public information commons and concerns about emerging "patent anticommons."[1] This chapter eschews the standard arguments premised on demonstrating the negative effects of unbridled strategic patenting. It argues instead that speculative biotech patenting, particularly of genetic probes, putative drug targets, and uncharacterized genetic sequences, is irrational.[2]

The debate over biotech patenting has remained surprisingly indifferent to this line of argument because it ignores the conditions of innovation in the biomedical sciences. The science at the heart of the biotech revolution is conspicuously absent from the current debate over biotech patent policy. To the extent that it is considered, the science is filtered through an economic lens or treated generically.[3] Typically, this means that the unique features of biotech science are important only insofar as they affect the dynamics of innovation, such as whether biotechnology evolves discretely or cumulatively.[4] More often, legal commentators have focused their attention, often quite understandably, on the protection of scientific norms, such as communalism and free access to data, which are even further removed from the science itself.[5] As a consequence, little, if any, of this discourse considers how the practical limits, specific research tools, and technical details of biomedical science shape patent incentives.[6]

The hyperbole surrounding advances in biotechnology, particularly genomics and other "omic" sciences, has contributed to the superficial treatment of biotech science in the patent policy debate. Overly optimistic claims have obscured the technical barriers and experimental uncertainties that continue to dog biotech research and development.[7] Most importantly, this rosy vision has hidden the disparity that exists between the power of biotech methods to generate data, such as genome sequences, and their efficacy in discovering effective medical procedures and drugs. Biotech methods have produced vast quantities of genetic data, much of which are useful as research tools (e.g., drug targets, genetic probes), but their capacity to generate new products has been far less impressive.[8] This dichotomy and the complexity of biological processes themselves have created an environment in which research opportunities far exceed the capacities of the scientific community. It is this basic dynamic that makes biotech science, in important respects, an uncongested common resource and that negates the value speculative biotech patenting.[9]

The discussion that follows proceeds in three sections: Section 2 evaluates the available data on biotech patenting and discusses the implications for universities and patent policy generally. Section 3 explains the central features of biomedical science that should be factored into patent policy, paying particular attention to the roles of two important classes of research tools – common-method and problem-specific.[10] Section 4 argues that the standard (finite) commons model is being misapplied in the biotech area because, owing to the complexity of biological processes and the power of existing biotech methods to produce genetic data, biomedical science is, in crucial respects, an unbounded, uncongested common resource. Taken together, these findings imply that strategic biotech patenting of problem-specific research tools (e.g., single nucleotide polymorphisms, drug targets) is not economically justified.

2. CURRENT TRENDS IN BIOTECH PATENTING

Several factors have combined to put biotech patents in the spotlight. Arguably the single most important event was passage of the Bayh-Dole Act in 1980, which expanded both the range of entities patenting inventions and the types of inventions being patented.[11] The Bayh-Dole Act has also led to dramatic increases in patenting by universities and research institutes, further blurring the line between commercial and basic-science research.[12] This increase in university patenting has been accompanied by a steep rise in the patenting of basic-science research tools (also referred to as ‘‘upstream technologies’’) that are integral to a broad cross-section of biotech research.[13] At the same time, the rapid scientific developments that occurred during the 1980s and 1990s led to large influxes of private funding for biomedical research, which outpaced government funding for the first time in 1992 and continues to exceed public-sector funding today.[14] These trends have transformed biomedical science and brought private- and public-sector research closer together, and sometimes into conflict.[15]

The legal community has responded to these developments with a panoply of proposals and concerns. Commentators have paid particular attention to the increased patenting of research tools and the rapid growth in the number of biotech patents, both of which have the potential to impede innovation and research.[16] Broadly speaking, legal commentators are separable into two camps, one optimistic, and the other pessimistic about whether licensing, and other market agreements, can resolve these tensions. The optimists appeal to experience in well-established industries (e.g., electronics, automobile) to argue that the market will work out any tensions between patents and scientific progress.[17] The pessimists typically focus on anecdotal evidence and other incipient signs that aggressive patenting is threatening biomedical research and development.[18]

Three central views dominate the discussion of patent law: (1) traditional law-and-economics theories, which emphasize bright-line rules and markets, (2) an agency-based approach, which relies on experts to intervene when necessary to overcome market failures or to protect scientific norms, and (3) a judicial activist model that relies on so called patent "policy levers" latent in existing legal doctrines. Notably absent is a legislative approach, which a broad consensus of commentators believes would succumb to public choice pressures from specific industry interests.[19] The Federal Circuit, for its part, has opted for bright-line rules and legal formalism over discretionary standards to promote clarity and predictability.[20]

Neglect of the underlying science, however, has diverted the debate over biotech patent policy towards economic theorizing that overlooks the defining characteristics of biomedical science that influence biotech patenting. Legal commentators have proposed several theories on patent scope and strategies for mitigating the negative impacts of patenting on biomedical innovation.[21] Patent scholars have advocated a variety of contrasting policies that range from arguments that biotech patents should have narrow scope[22] to claims that federal agencies, such as the National Institutes of Health, should be empowered to protect biotech innovation from incipient patent anticommons.[23] Other commentators have argued for an eclectic approach premised on a technology-specific synthesis of patent policy, which maintains that biotech patents should be both broader and fewer in number.[24]

Despite their limitations and failure to consider the underlying science more concretely, the competing patent policy proposals have lent considerable insight into the relationship between patent policy and innovation. Building on the legal literature, this part of the chapter focuses on the available economic information and recent survey data on biotech patenting. It then evaluates the patent policy debate in light of this empirical information.

2.1. Effects of Biotech Patents on Innovation

Studies of patenting in the biomedical sciences remain very limited. There are nevertheless a few things that we do know. First, there has been a well-established and "pronounced surge in patenting of research tools, previously more freely available in the public domain" and a significant rise in defensive patenting, particularly in the genomic sciences.[25] Although, recent data suggests that this rise has flattened and that biotech patent applications may be declining.[26] Second, university patenting accounts for a significant fraction of this increase. Their share of the patents issued in three key biomedical utility classes increased from 8 to 25% of the total patents granted in these classes between the early 1970s and the mid-1990s.[27] The broad data available on patenting therefore lend support to concerns about emerging patent anticommons in the biotech sector and the important role that universities are playing in this process.

Anecdotal evidence is also troubling. One of the most publicized and debated cases have involved efforts to reduce the incidence of blindness due to vitamin A deficiency by genetically modifying rice to produce vitamin A. In order to undertake this research, licenses to 70 patents and access to 15 pieces of technical property spread over 31 institutions had to be negotiated.[28] Although, ultimately resolved through a collective set of agreements for royalty-free licenses, this case has become the poster-child for many critics of biotech patents.[29]

Similar examples have been identified in more traditional areas of the biomedical sciences. The andrenergic receptor, which is important in metabolic pathways, was found to have 100 related patents.[30] Less extreme, but still troubling, the Hepatitis-B vaccine is covered by 14 patents controlled by several organizations and burdened by stacking royalties that totaled $1.47 per dose, or 13–15% of sales.[31] Furthermore, significant alarm persists over patents that restrict access to critical drug targets (e.g., receptors, mutated genes) or biotech techniques (e.g., genechips, diagnostic tests).[32]

Prompted by these concerns about biotech patenting, the National Academy of Sciences commissioned a study (NRC Study) on the effects of patenting in the biomedical sciences and prepared a report on patent policy issues (NRC Report).[33] To many people's surprise, the authors of the NRC Study found "little evidence of routine breakdowns in negotiations over rights, although research tool patents are observed to impose a range of social costs and there is some restriction of access."[34] They also concluded that although "access to foundational upstream discoveries has not yet impeded biomedical innovation significantly, [their] interviews and prior cases suggest that the prospect exists and ongoing scrutiny is warranted.''[35] The authors opined that, in addition to several ''working solutions'' that had evolved over time, the large number of opportunities in biotech research had neutralized much of the potential for patents to impede innovation.[36]

The more detailed findings of the NRC Study are also instructive. In a series of interviews, the NRC Study found near unanimity that the patent landscape has become more complex and requires much more extensive due diligence.[37] Yet, while respondents acknowledged that a large number of patents may need to be considered initially (sometimes 100s), ''in [general] practice there may be, in a complicated case, about 6–12 that they have to seriously address, but that more typically the number was zero.''[38] In sum, the number of patents one must evaluate is generally manageable. Consistent with this general result, the NRC Study found that, although time consuming, negotiations over licensing agreements rarely halted projects[39] and that royalty payments did not threaten biotech research and development.[40]

The NRC Study is more equivocal and raises greater concerns about patents on research tools. Access to important research tools, such as drug targets and stem cells that are covered by one or a few patents is the primary concern in this context.[41] Half of the study's respondents complained of licensing fees on research tools, but nevertheless conceded that the costs did not preclude projects.[42] Further, while royalties are often high, respondents acknowledged that fees on research tools were more than offset by productivity gains.[43] Redirecting research projects around research tool patents was also found to be common, but in most cases did not entail shifting to an entirely new research area (e.g., new disease or technical approach).[44] The complexity of most diseases apparently permits a range of different research strategies.

The NRC study concludes by describing a number of working solutions that have mitigated the potential impact of strategic patenting in the biomedical sciences. Most of them are obvious, such as licensing, inventing around, and court challenges, but a few are more unexpected. Two working solutions of special significance are the use of technology without a license and the resurgence of support for public databases in the public and private sectors.[45] Norms of the research community, as Arti Rai has argued, play an important role in these developments.[46] In particular, researchers, whether public or private are ''somewhat reluctant to assert their intellectual property against one another if that means they will sacrifice the goodwill and information-sharing that comes with membership in the community.''[47] As a consequence, university researchers, and to a lesser extent even those in the private sector, routinely use patented inventions without obtaining a license under the guise (at least until recently) of a “research exception” to patent liability.[48] The viability of this working solution is aided by the difficulty of enforcing patent rights against research infringement, which is far harder to detect because of its small scale and the absence of the open sale or manufacture of an infringing product.

The creation of public databases has been one of the most important, and surprising, developments. Several major databases exist for genes (e.g., Genebank), proteins (e.g., Blueprint Worldwide, Protein Data Bank), and genetic probes (e.g., the quasi-public Merck Gene Index and SNPs Consortium).[49] Similarly, Merck has initiated a program to create 150 patent-free transgenic mice that will be made available to the research community at cost and without patent or use restrictions.[50] The scientific community has also been instrumental in preserving and enhancing openness and access to technologies. Biology journals, for example, have required authors to deposit sequences in public databases, such as Genebank or Protein Data Bank.[51] More recently, the National Institutes of Health (NIH) has negotiated generic license agreements for academic researchers to ensure that they have access to important privately owned research tools, provided funding for development of new research tools (e.g., transgenic lab animals), and even conditioned receipt of grants on commitments not to patent inventions that derive from NIH-supported research.[52]

2.2. Legal Policy and Biotech Patenting

The dynamics of patenting in the biomedical sciences are not readily captured by any of the legal theories mentioned above. First, while the NRC Study found that the expanding number of patents is requiring more licenses to be negotiated and increasing the costs of biomedical research,[53] it has not led to the emergence of significant anticommons problems. Biomedical research has not been markedly impeded by the growing number of biotech patents.[54] It appears instead that working solutions aided, as I will argue below, by the characteristics of the science itself have mitigated many of the negative effects of this trend.

Second, the most serious threats the NRC Study identified were from discrete patents on key research tools.[55] This finding undercuts legal policies premised on restricting the breadth of patents because, even where narrowly drawn, patents on key research tools can be used to limit a diverse range of work by competitors. For example, even a narrow patent on the Cohen-Boyer method, or other irreplaceable research tools, would have a broadly preclusive effect if access to the technology were denied. Conversely, where numerous alternative research tools are available, promotion of narrow patents will be unnecessary, as alternative avenues for conducting research will already exist. For similar reasons, the eclectic prescriptions that Professors Dan Burk and Mark Lemley have advocated are simply inappropriate.[56] Raising the standard for obviousness in patent law, as Burk and Lemley advise, will have little or no effect because key research tools, by their very nature, represent major advances beyond the prior art. Worse still, the loosening of disclosure requirements only stands to aggravate technology-access problems by allowing patents on research tools to claim a broader constellation of uses.[57]

The failings of these legal theories might incite market enthusiasts to claim victory for traditional economic theory. According to this line of argument, patent scope is secondary to maintaining clear rules, strong property rights, and low transaction costs for technology licensing. The problem with this view is that transaction costs for licensing biotech patents are in fact significant and are not diminishing.[58] More importantly, the most effective working solutions identified by the NRC Study do not center on reducing transaction costs or clarifying the law, but instead involve abrogating property rights and abandoning private ownership altogether.[59] The two most prominent working solutions were reliance on the (now defunct) research exemption, and dedications of research tools to the public domain.[60]

The dynamics of biotech patenting (including the working solutions described in the NRC Study) are not solely attributable to either legal or economic factors, though both are obviously important.[61] Making sense of the interplay between law, economics, and science in the biomedical sciences requires that the third prong of this trio be more fully understood and taken into account. The NRC Study includes two revealing observations in this regard. First, one of the respondents remarked that "we have more targets than we have chemists to work on them" and noted later that the value for targets has decreased over time due to their abundance.[62] Second, another respondent made the following comment:

> I have never worked with a disease where one particular protein makes the only difference. A patent gets you exclusive rights to a class of drugs, but there may be other classes.... I could imagine a genetic disease where a single target was involved, but I don't think that the big medical problems fall into this case.[63]

Both observations highlight the diverse set of research options that have emerged in the biomedical sciences.[64] This diversity has lowered the economic value of protectionist tendencies of inventors in the private and public sectors and, equally importantly, afforded numerous opportunities for developing new research tools.[65] As argued more fully below, the nature of biomedical science itself has played a critical role in reducing potential frictions between biotech innovation and the patent system.

3. BIOLOGICAL BARRIERS TO INNOVATION

The systemic technical barriers inherent in the biomedical sciences are rarely factored into patent policy.[66] This section aims to address this oversight. I begin by highlighting the gulf that exists between the popularized version of biotech science and the far more complex, less deterministic reality with which scientists must contend. I also challenge the common portrayal of genes as rigid blueprints for biological processes that fully determine an individual's susceptibility to disease. These distinctions are critical to appreciating the relationship between biomedical science and biotech patenting.

The public and scientific images of human genetics are chronically estranged. In its most simplistic form, the public image of human genetics is that genes determine the person and control their susceptibilities to disease. This view is analogous to the claim that the food one eats fully determines who one is and what one does. Literally speaking, we certainly are constructed out of what we eat, but it is equally true that we are much more than these constituent parts – traits and characteristics emerge at the level of a whole organism that cannot be reduced to the elements that make them up.[67] It is also true that under certain circumstances what we eat (or do not eat) may determine our behavior or fate (e.g., starvation, poisons, pharmaceuticals), but it would be absurd to infer from these instances that humans are fully determined by what they eat. The relationship between an individual's genetic makeup and disease susceptibilities is no different; some susceptibilities have strong genetic influences (the minority as it turns out), and many have relatively weak or diffuse genetic influences that are causally complex.[68]

The significance of this less deterministic understanding is illustrated by the limitations of the highly touted discovery of the BRCA1 and BRCA2 genes, which are strongly associated with breast and ovarian cancers. The BRCA genes represent a best-case scenario for biotech methods because they involve single genes that have a large impact on risk. But, consistent with the low rates of single-gene disorders, approximately 90% of women with breast cancer do not have mutations in either of these genes.[69] Moreover, the estimates of the genetic link (85% for breast cancer; 45% for ovarian cancer) are subject to significant uncertainties, as other genetic and environmental factors are also important.[70] As a result, even if a test is positive, it is not clear how doctors should counsel women given the underlying uncertainties and the probabilistic nature of the causal link.[71]

These qualifications have led patients and doctors alike to view genetic testing and genomic methods skeptically.[72] They also highlight the many complexities and uncertainties that underlie biomedical research – even after specific genetic anomalies have been identified. Many legal commentators fail to appreciate fully the seriousness of these obstacles, or the degree to which the biomedical sciences are open-ended at this point in their development.[73] The discussion that follows explains the scientific origins of these uncertainties and barriers to development and examines how they impact biotech patenting.

3.1. Genetics and Epigenetics

The human genome and the processes involved in transcribing genes are far more complex than popularized versions of genetics would lead one to believe. First, less than 2% of the human genome codes for proteins, and more than 50% consist of repeat sequences of several types that have currently undefined functions.[74] Second, genes themselves are oddly constructed – most are not unbroken segments of DNA, but instead are interspersed with long segments of non-coding DNA.[75] Third, many critical processes are not genetically controlled, but nevertheless alter the activity of a gene or its protein product.[76] Cellular processes, for example, may include complex feed-back mechanisms, involving multiple biological pathways that influence gene activity levels.[77] These complex "epigenetic" dynamics are a distinguishing feature of human biology.[78] They also cannot be ignored because epigenetic processes play an important role in many disease processes.[79]

The structural and dynamic features of human biology make the process of identifying genes far from trivial, let alone the much more difficult task of linking genes to specific diseases.[80] Finding the genetic origin of a disease is further complicated by the well-established fact that disease susceptibilities do not derive predominantly from genetic mutations.[81] Environmental factors, such as nutrition, exercise, and chemical exposures, are typically more important.[82] As we will see, this multifactor etiology follows from "almost all human diseases [being] complex context-dependent entities to which our genes make a necessary, but only partial, contribution."[83]

Two central barriers to biomedical innovation emerge from this understanding: (1) genes do not have a fixed (either negative or positive) impact on human health, and (2) a weak causal association exists between a person's genetic makeup and their susceptibility to disease.[84] These barriers place the most significant limits on biotech science. They are also responsible for the disparity that exists between the power of biotech methods to generate data, such as genome sequences and probes, and their ability to promote the discovery of new medical procedures and drugs. Biotechnology is in somewhat paradoxical position that it can produce vast quantities of genetic data, much of which are useful as research tools (e.g., drug targets, genetic probes), but has so far had great difficulty overcoming these two fundamental barriers to innovation.[85] The discussion that follows describes each of these barriers to innovation in greater detail.

A canonical principle in biology is the dependence of a gene's function on other genes and environmental factors. According to this principle, known as the "Genetic Theory of Relativity," a gene may be highly beneficial "on one genetic background and be virtually lethal on another."[86] As a consequence, genes typically have multiple effects that are dependent on one's genetic background and the environment in which one lives.[87] This variation creates two central challenges: first, it negates the central genomic mission of ascribing fixed disease susceptibilities to genes; second, it introduces a source of variability that undermines biotech methods designed to fingerprint disease states using gene-expression levels.

The context-dependence of genetic traits is evident in even single-gene diseases.[88] The effect of the genetic mutation that causes sickle cell anemia provides a simple example of this variability. Sickle cell anemia has counterbalancing effects – it both degrades the functioning of red blood cells and makes carriers resistant to malaria. Symptoms consequently range from severe anemia for individuals with two copies of the mutation, to none for individuals with two normal copies of the gene who are not exposed to malaria, to protective against exposure to malaria for individuals with one mutated and one normal copy of the gene.[89] For complex diseases, the variation will be more intricate because a number of interacting genes will be involved. The end result is the same. Genes do not have fixed effects that are invariant between individuals with different genetic backgrounds or across different environments.

The causal relationship between genetic makeup ("genotype") and disease susceptibility ("phenotype") is also not a simple one.[90] First, natural selection acts directly on phenotype, but only indirectly on genotype.[91] This indirect relation decouples genotype from phenotype, such that while a phenotype may remain fixed under the pressures of natural selection, the underlying genotype may vary significantly.[92] As a consequence, it is generally not possible to infer genotype from an observed phenotype because the same phenotype can arise from multiple genotypes.[93] The absence of a unique, or even well-defined, genotype – phenotype relationship complicates the process of identifying meaningful genetic signatures of disease, and may erode the association between genetics and disease altogether.

Second, biological processes actively buffer phenotype from variations in genotype.[94] A genetic mutation that, for example, inhibits the activity of an important metabolic enzyme may be neutralized by other processes that counteract the impact of the mutation on the enzymes' function or by redundancies built into the specific metabolic process.[95] Buffering mechanisms may also cause specific genotypes to be associated with diverse phenotypes.[96] Genetic buffering therefore weakens the association between gene-activity levels, which are central to genomic studies, and disease susceptibility by further disassociating genotype from phenotype.[97]

Third, a simple one-to-one relationship does not exist between genotype and phenotype because they are separated by intervening epigenetic and stochastic (i.e., random) processes.[98] For example, epigenetic processes may determine whether or not a gene is activated and, for example, play a significant role in the toxicity of certain compounds.[99] Similarly, growing evidence indicates that stochastic processes are integral to disease – response mechanisms.[100] This innate uncertainty adds to the complexity of the genotype – phenotype relation: "each genotype [will] specify a number of different phenotypes depending on the environment; in a given environment, a probability function determines the mapping between any particular genotype and a set of phenotypes."[101]

All three of these factors – natural selection acting on phenotype (not genotype), active genetic buffering, and stochastic biological processes – expose the many obstacles to using biotech methods to discover medical procedures and drugs. Each of these processes complicates the interpretation of genetic studies by attenuating and, in some cases, eliminating the connection between gene-expression levels and the biological processes relevant to the disease responses and susceptibilities that scientists are attempting to monitor and understand. This decoupling makes the process of identifying useful drug targets and understanding the biology of diseases very challenging and uncertain, often necessitating extensive trial-and-error research.[102]

Two additional factors compound the problems described above. First, most human health conditions are complex and multigenic;[103] the simple cases in which biotech methods have been applied successfully are the relatively rare exceptions.[104] Second, the most important, typically chronic, diseases in the United States have late onsets, which are even less likely "to be genetic in the traditional deterministic sense of the term."[105] This additional barrier arises because the late onset (i.e., after an individual's reproductive years) of these diseases makes them selectively neutral.[106] The end result is that biotech methods will have great difficulty overcoming the complex etiologies of many important diseases (e.g., cancer, heart disease, diabetes) found in the United States and elsewhere.[107] This complexity also means that multiple approaches will exist for understanding and treating most diseases, as multiple genes, biochemical pathways, and epigenetic factors are likely to be involved.

The blue-print model of the relationship between genetics and disease proves to be overly simplistic. Human biology does not fit into a simple Newtonian model of science in which genes are the elementary objects that define biological systems as a whole, such that once genes are discovered they lead inexorably towards an understanding of disease processes and viable treatment options.[108] Biotech methods are uncertain in large part because genes play a limited causal role in disease processes.[109] Because of this, developing effective methods for monitoring and understanding common diseases will ultimately require scientists to address these more complex dynamics.[110] Until then, and likely beyond, biomedical science will be subject to large, unavoidable uncertainties that will require a great deal of trial-and-error research, creating a few islands of significant advances and insights in an ocean of rapidly proliferating genetic data.

3.2. Implications for Biotech Patenting

The ideals of rational drug design and personalized medicine hyped in the biomedical sciences are more aspiration than reality. The decline in new drug therapies, despite large infusions of public and private support, exposes the seriousness of these technical barriers,[111] as does the recent stream of published reports for which experimental results could not be reproduced.[112] Ironically, the power of biotech methods – particularly their ability to monitor thousands of genes simultaneously – comes at a significant price. The vast quantities of data generated raise extremely challenging problems for data analysis.[113] Indeed, the process of discerning meaningful results from the masses of background noise is requiring development of novel methods that are computationally intensive and highly complex.[114] Predictably, the few successful applications of biotech methods have involved relatively simple cases.[115]

The difficulty of these challenges is perhaps best illustrated by the genetic variation found in DNA repair genes, which play an essential role in correcting cancer-causing mutations. Scientists have identified over 450 variants of DNA repair genes using genetic screens of a representative sample of the US population.[116] The large number of variants creates a near-intractable problem for biotech methods:

> The complexity of…associating genetic variation with risk becomes apparent when it is realized that these repair pathways require activity of 20–40 different proteins to complete the repair process. Thus, given the large number of different variant[s], the typical individuals will be variant for 10–15 proteins required for repair of a specific class of damage. But, these typical individuals will not have similar pathway genotypes as these 10–15 variants will be drawn from a pool of 100–200 different [genetic variants].[117]

The numerous combinations possible imply that few people will have the same genetic variants, making genetic associations much harder to detect. Further, because the pathway as a whole determines disease risk, causal links between genetic variants and disease susceptibility will be obscured by the small impact that any given genetic variant is likely to have. In essence, identifying gene–disease associations is analogous "to search[ing] for a needle in a needle stack," where the challenge is to identify the subset of genes that is causally related to the disease in question from a far greater number that are not.[118] Moreover, the process is confounded by the underlying biological mechanisms discussed in the preceding subsection.

Three central areas pose particularly difficult problems for biotech researchers: (1) identifying genes and linking proteins to genes (or genes to proteins), (2) characterizing and exploiting gene targets, and (3) using genomic technologies to understand disease etiology and effects. The scientific uncertainty and complexity feed into the dynamics that make patenting so important, namely, by creating a large differential between the cost of discovery, which requires much trial and error research, and the cost of copying and producing an invention, which utilizes standardized processes for generating genetic data. Further, because scientists are reliant on ostensibly the same tools, they are both limited by the same technical barriers and readily able to reproduce competitors' products.

The biomedical sciences are currently in a unique state in which powerful methods exist for determining the structure of biologically important molecules and collecting genetic information, but the complexity of most biological processes is such that the power of these methods cannot be exploited without extended trial-and-error research.[119] Biotechnology is still a science dominated by statistics and probabilities, rather than one driven by deterministic models and a rigorous understanding of human biology. Genetic data are therefore the starting point for much more arduous and extended research. More importantly for the present discussion, the dichotomy between genetic-data production and invention creates an environment in which research opportunities are, as a practical matter, unbounded because they far exceed the capacities of the scientific community.

4. THE SCIENTIFIC LANDSCAPE OF BIOTECH PATENTING

Biotech patenting has been pursued aggressively from the start, beginning with the seminal Cohen-Boyer process.[120] This patent set the stage for the surge in patenting of research tools that was to follow, which reached its apex in the mid-1990s with the rush to patent DNA probes (e.g., expressed sequence tags (ESTs), single nucleotide polymorphism (SNPs)). Since this time, while concerns have been raised about patents on important drug targets, we have witnessed a significant return to dedicating research tools, such as SNPs and genome maps, to the public domain. The rising number of patent applications on gene sequences has also flattened and begun to decline.[121]

Developments in the underlying science, as well as its limitations, provide a number of important insights into the evolution of biotech patenting. The single most important factor is the most obvious one. Research and development in the biomedical sciences are shaped by the high costs and uncertainties of biotech methods and the disparity that exists between the costs, in both time and dollars, of initial discovery versus the costs associated with copying and producing biotech inventions. This disparity derives in large part from the extensive trial-and-error research required to evaluate the large number of potential drug targets and to navigate the complexity of the biochemical interactions involved.

Biological complexity, however, also mitigates the potential for patents to create broad monopoly power. The diversity and complexity of human biology make the biomedical sciences relatively open-ended and less susceptible to patent anticommons. Many biological systems, for example, have built-in redundancies that protect against failures of specific processes, and this redundancy is more prevalent the more important the process. The DNA repair process discussed in the previous section contains these types of parallel functions. Further, diversity is found in the huge range of genetic variants scientists are discovering and the multigenic nature of common diseases. This complexity belies an atomistic, gene-by-gene analysis of disease processes.[122] More importantly for patent policy, common diseases will, as a consequence, be associated with multiple pathways or molecules, implying that most important diseases will have numerous potential drug targets.[123] Thus, by both affording numerous opportunities for research and a variety of treatment options, the complexity of biological processes reduces the potential for conflict between patenting and biomedical innovation.

The NRC Study corroborates the importance of these complex biological traits. Respondents in the NRC Study acknowledged that few, if any, common diseases will have only a single drug target and commented that "we have more [drug] targets than [personnel needed] to work on them."[124] The rapid rise in dedicating information to the public domain (e.g., the SNPs Consortium, GeneBank) also reflect this understanding and the fruitlessness of protecting research tools when they are both available in such overabundance and difficult to enforce in a research setting. As another respondent in the NRC Study observed, dedicating research tools, including drug targets, to the public domain, likely benefits the established pharmaceutical companies.[125] By making them freely available, the cost of acquiring rights to use research tools from biotech companies, which rely on patenting such research tools, is eliminated, and pharmaceutical companies are generally better positioned to compete "on the exploitation of this shared information to develop drug candidates."[126]

The status of biomedical science therefore plays an important role in shaping patent strategy and business models in the biotech sector. These effects are evident in the evolution of biotech patenting and changing biotech business patterns. The subsections that follow return to the patent policy debate, recasting it in light of these scientific influences. In subsection 4.1, the traditional commons metaphor is reexamined in light of the open-ended nature of biomedical science. Subsection 4.2, draws on this discussion, but focuses on how these factors eliminate the economic incentives to engage in speculative biotech patenting.

4.1. Biomedical Science Unbound

The metaphor of the (finite) public commons provides the principal conceptual framework for biotech patent policy. Prospect theory employed the commons metaphor to argue for broad patents. Narrow patents, according to this theory, would lead to uncoordinated development of intellectual prospects, much as common resources, such as public lands, are inefficiently exploited in the absence of clear property rights and full internalization of development costs.[127] Rejecting prospect theory, Professors Robert Merges and Richard Nelson argued for granting narrow patents on the ground that knowledge, unlike the physical model of property in traditional commons theorizing, cannot be overexploited and the belief that innovation proceeds most rapidly when multiple investigators attack a problem.[128] Similarly, Professors Michael Heller and Rebecca Eisenberg used the commons metaphor to expose the risk that highly fragmented and broadly dispersed patent rights can impede innovation by creating a patent anticommons.[129]

All three theories assume implicitly that the underlying science is strictly finite and congested (or congestable).[130] Biomedical science is distinctive in that, while some types of research tools are not plentiful, the many potential avenues for research create conditions in which others are practically unbounded – at least at this time. In this context, two types of research tools exist: (1) the relatively small number of common methods (e.g., the Cohen-Boyer, Kohler-Milstein, PCR processes) that are critical to a broad range of biotech research, and (2) problem-specific tools that are plentiful (e.g., ESTs, SNPs, drug targets).[131] The differences between the two classes of research tools are critical to patent policy. Restricting access to patented common-method tools has the potential to impede scientific research and innovation, whereas problem-specific tools, because of their abundance, are unlikely to negatively affect biotech innovation if access is restricted to them.[132]

Two distinct policy regimes emerge from the two categories of research tools. The first regime falls within traditional commons theorizing, where a difficult balance must be struck between making key upstream research tools broadly available and ensuring that researchers have the proper incentives to develop them in the first place. Although, the issue is not the risk of an anti-commons emerging, but whether access to critical technologies will be limited. For reasons that many commentators have already identified, conflicts between patenting, scientific norms, and innovation are the most acute for common-method research tools.[133] A large body of legal scholarship exists on these issues, much of which I am sympathetic to, but there is no need to revisit these issues here.

The second category deviates significantly from standard public commons-based policy arguments. The unbounded nature of the field – scientists have more drug targets than they know what to do with – neutralizes the central problem created by a finite public commons. In the traditional commons scenario, individual self interest inexorably leads to overexploitation of the resource. However, the tragedy of the commons disappears if individuals cannot collectively overexploit a common resource.[134] For similar reasons, the threat of an anticommons emerging is also neutralized, as areas of dense patenting can always be avoided. In fact, one might argue that the broad distribution of research activity caused by extensive patenting is a positive outcome. This abundance also has the salutary effect of diminishing the value of patents on problem-specific research tools, which is consistent with recent trends toward dedicating these types of research tools to the public domain.[135]

Borrowing a somewhat worn metaphor, biomedical science remains a relatively unexplored continent in which the frontier is nowhere near any obvious geographical boundary. The standard commons arguments therefore simply do not apply. This framework explains why anticommons have not been a major factor in biotech patenting, and why they are unlikely to arise anytime soon. On the other hand, the biotech analogues of technologies, such as railroads, that allow broad access to this emerging territory serve unique purposes and are limited in number. Accordingly, just as control of railroads determined who had access to the American West, patents on common-method research tools can be used to restrict access to emerging areas of biomedical research. Stated simply, the public commons model at the heart of the debate over biotech patent policy must be readjusted to reflect the important respects in which biotech patenting is uncongested and biomedical science is unbounded at this stage of its development.

4.2. Patently Irrational: Speculative Gene Patents

The contrasting features of common-method and problem-specific research tools have three practical implications for patent policy. First, as a number of commentators have recognized, patents on common-method research tools do present potentially significant risks to innovation and warrant continuing scrutiny.[136] Second, fears about the patenting of abundant problem-specific research tools (e.g., SNPs, ESTs, targets) are unwarranted because the public commons-based arguments that have provoked concern erroneously assume that biomedical science is a bounded and congested resource. This conclusion is borne out not only by recent moves to dedicate these types of research tools to the public domain, but also by the rapid growth in the number of problem-specific research tools over the past decade.[137] Third, drawing on the commons fallacy, speculative patenting of problem-specific research tools is generally not economically justified. It is this third point that I wish to discuss here.

Speculative biotech patenting of problem-specific research tools has centered on putative drug targets, genetic probes, and uncharacterized genetic sequences. The irrationality of this form of strategic patenting stems from the highly unpredictable value of such research tools and the difficulty of enforcing them against scientific researchers. First, inventors cannot predict ex ante which problem-specific research tools will be valuable for drug development. At the same time, many problem-specific research tools exist for prospective research, but only a tiny subset will be necessary for the development of a viable drug product. In this regard, the current state of biotech research and development represents the worst conditions for strategic patenting. If the number of potentially valuable patents were relatively circumscribed and the potential value of any given research tool still highly uncertain, inventors could at least hedge their bets through expansive speculative patenting. Here, however, the number of patentable research tools is virtually unlimited, making the expected utility of such a strategy diminishingly small. Indeed, the only economically viable option for such research tools is licensing them for use in commercial microarrays used in biological assays.

Second, the variety of approaches to studying or treating a disease that derive from the complexity of human biology creates a further disincentive for speculative patenting. As respondents in the NRC report observed,[138] the redundancy and intricacy of biological processes allow for multiple lines of research that enable scientists to circumvent existing problem-specific patents. Thus, while the complexity of biological processes offers many opportunities for strategic patenting, potentially creating aggravating circumstances for a patent anti-commons emerging, this characteristic is a double-edged sword, as it also affords many potential routes for engineering around existing patents. Patentees, as a result, cannot be sure that their patent rights will be sufficient to exclude competitors, particularly as so little will be known about the relevant biological processes when a speculative gene patent is first filed.

Third, enforcement of problem-specific research tools is challenging. Except where a sequence is used as a probe in a commercial microarray assay, detection of infringing uses of problem-specific research tools will be costly and onerous. In the absence of an infringing product or sale, infringing uses will be occurring in specific labs and generally will not be obvious from the publicly available research results laboratories produce. This will be particularly true if the lab is constructing its own microarrays in which the patented research tool is just one of hundreds or thousands of probes. Only in the very rare instance in which the specific sequence is integral to the reported results will infringement be detectable in an easily accessible form (i.e., without gaining access to the lab itself).[139] Moreover, the ex ante value of the patented sequence in large microarrays will presumably be small, making damage claims commensurately modest and reducing the incentive to spend valuable time and money enforcing speculative patents in the first place. None of these factors argues in favor of speculative genetic patenting as a viable business model for biotech companies.

These dynamics also help explain the recent willingness of scientists and companies to dedicate problem-specific research tools to the public domain.[140] While it is true that companies and universities started with a gold-rush mentality of patenting everything in sight as genomics methods rose in prominence and power, the diminishing returns of speculative patenting may be coming to be appreciated. This is not to say that speculative patenting is no longer occurring – many hundreds of patents on genetic sequences are still being filed.[141] My point is simply that there is evidence that speculative patenting may be on the decline and, more importantly, that there are good economic and scientific reasons for companies and universities to be eschewing speculative patenting in the biotech area.

5. CONCLUSIONS

The legal debate over biotech patent policy has rightly focused attention on the patenting of important biotech research tools and potential threats to innovation. The influence of biomedical science itself on biotech patenting, however, has been surprisingly absent from this discourse. This chapter has sought to remedy this oversight. The chapter develops two central points. First, the standard (finite) commons model is not representative of the essentially unbounded opportunities in biotech research that exist at this early stage of its development. Once the premise of a finite, congested commons is abandoned, the potential for patent anticommons to emerge largely disappears and patents on most research tools pose far less of a threat than the typical public commons model predicts. Second, the uncertainty and complexity of biomedical science provide powerful reasons for abandoning the practice of speculative patenting of genetic sequences (e.g., ESTs, SNPs) that arose in the 1990s. A deeper understanding of the science demonstrates that the economic returns do not justify strategic patenting of such problem-specific research tools.

NOTES

1. The standard model for the public commons is an area (e.g., public lands, body of water) that is vulnerable to overexploitation by multiple actors because none of them bears the full impact of poor management. By contrast, a patent anticommons impedes development because narrow patent rights are dispersed among different entities too broadly, creating conditions under which no single entity has access to the technology needed to conduct research and development. *See* Michael A. Heller & Rebecca S. Eisenberg, *Can Patents Deter Innovation? The Anitcommons in Biomedical Research*, 280 Science 698, 698 (1998); Rebecca S. Eisenberg, *A Technology Policy Perspective on the NIH Gene Patenting Controversy*, 55 U. Pitt. L. Rev. 633, 640 (1994). This paper is drawn from the following paper: David E. Adelman, *A Fallacy of the Commons in Biotech Patent Policy*, 20 BERKELEY TECH., lj. 253 (2005).

2. By speculative, I mean simply that the actual function of the genetic sequence or target is unknown.

3. See, e.g., Robert P. Merges & Richard L. Nelson, *On the Complex Economics of Patent Scope*, 90 Colum. L. Rev. 839, 880 (1990).

4. *Id.* at 880–84. In particular, while Merges and Nelson argue that issues of patent policy, such as patent scope, ‘‘depend on the nature of the technology,’’ they limit their consideration to ‘‘the relationship between technical advances in the industry, and the extent to which firms license technology to each other.’’ *Id.* at 843.

5. Arti K. Rai & Rebecca S. Eisenberg, *Bayh-Dole Reform and the Progress of Biomedicine*, 66 L. & Contemp. Probs. 289, 289 (2003); Arti K. Rai, *Regulating Scientific Research: Intellectual Property Rights and the Norms of Science*, 94 Nw. U. L. Rev. 77, 90–92 (1999).

6. Economic data are similarly missing from the debate, although recent studies are beginning to have an impact. A 2003 study conducted for the National Research Council (NRC Study) contains the most extensive data. John P. Walsh et al., *Effects of Research Tool Patents and Licensing on Biomedical Innovation* in Patents in the Knowledge-Based Economy 285 (2003).

7. The significance of the scientific barriers should not be underestimated, and is best illustrated by the declining rate of new drug development over the past decade, despite increased spending (and patenting) by the public and private sectors. See Food & Drug Administration, Innovation or Stagnation: Challenge and Opportunity on the Critical Path to New Medical Products 2 (March 2004) <http://www.fda.gov/oc/initiatives/criticalpath/whitepaper.pdf>. Robert F. Service, *Surviving the Blockbuster Syndrome*, 303 Science 1797, 1799 (2004) (‘‘The plain truth is that many of the most dramatic scientific advances that have recently been made in the lab have not transformed medicine.’’); Richard S. Cooper & Bruce M. Psaty, *Genomics and Medicine: Distraction, Incremental Progress, or the Dawn of a New Age?*, 138 Ann. Internal Med. 576, 577 (2003) (‘‘To date, both [gene expression] studies and genome-wide scans have identified only weak and inconsistent genetic signals....’’ for common diseases such as cardiovascular disease and cancer.).

8. *Id.*

9. In other contexts, particularly environmental regulation, property theorists have recognized that commons problems do not emerge until a commons becomes ‘‘congested,’’ that is the number of users rises beyond the point of sustainable

exploitation of the resource. See Carol Rose, *Rethinking Environmental Controls: Management Strategies for Common Resources*, 1991 Duke L.J. 1, 5–7. The distinction I make here is a simple variation on this basic insight, with the proliferation of patents restricting access to intellectual resources taking the place of the mounting numbers of resource extractors in the typical tragedy of the commons scenario.

10. Common-method research tools involve uniquely powerful methods of broad applicability (e.g., the polymerase chain reaction (PCR), which is used to replicate DNA), whereas problem-specific research tools involve data or information that are of narrow applicability and available in many forms (e.g., drug targets, gene probes).

11. Rebecca S. Eisenberg, *Bargaining Over the Transfer of Proprietary Research Tools: Is This Market Failing of Emerging?* in Expanding the Boundaries of Intellectual Property: Innovation Policy for the Knowledge Society 226–227 (Rochelle Cooper Dreyfuss et al., eds., 2001).

12. Walsh, *supra* note, at 295 (university share of biomedical patents in three classes increased from 8% in the early 1970s to over 25% by the mid-1990s) (viewed as a major change by the private sector).

13. John R. Allison & Mark A. Lemley, *The Growing Complexity of the United States Patents System*, 82 B.U. L. Rev. 77, 80 (2002). Archetype examples of upstream technologies are the famous Cohen–Boyer patent, which covered the canonical methods for replicating and expressing foreign genes in microorganisms, and the Kohler–Milstein process, which was not patented, for producing monoclonal antibodies. Merges, *supra* note, at 905–906.

14. Eisenberg, *supra* note, at 227, n. 15.

15. National Research Council, A Patent System for the 21st Century 17, 20 (Stephen A. Merrill et al., eds., 2004).

16. Robert P. Merges, *Institutions for Intellectual Property Transactions: The Case of Patent Pools* in Expanding the Boundaries of Intellectual Property: Innovation Policy for the Knowledge Society 129 (Rochelle Cooper Dreyfuss et al., eds., 2001) "the key issue is the cost of integrating disparate rights"; Eisenberg, *supra* note, at 231 (the primary problem in biomedical sciences is not terms of agreements but the transactions costs of negotiating technology licenses).

17. Merges, *supra* note, at 130.

18. *Id.*

19. Burk, *supra* note, at 1578, 1631–1638; Rai, *supra* note, at 1028–1030.

20. Burk, *supra* note, at 1672.

21. See, e.g., Rebecca S. Eisenberg, *Patents and the Progress of Science: Exclusive Rights and Experimental Use*, 56 U. Chi. L. Rev. 1017, 1040–1041 (1989); Lawrence M. Sung, *On Treating Past as Prologue*, 2001 U. Ill. J.L. Tech & Pol'y 75; Maureen A. O'Rourke, *Toward A Doctrine of Fair Use in Patent Law*, 100 Colum. L. Rev. 1177 (2000); Artia K. Rai, *Engaging the Facts and Policy: A Multi-Institutional Approach to Patent System Reform*, 103 Colum. L. Rev. 1035 (2003); John H. Barton, *Non-Obviousness*, 43 IDEA 475 (2003).

22. Merges, *supra* note, at 843.

23. Heller, *supra* note, at 698; Eisenberg, *supra* note, at 640.

24. Dan L. Burk & Mark A. Lemley, *Is Patent Law Technology-Specific?*, 17 Berkeley Tech. L.J. 1155, 1202–1203 (2002); Dan L. Burk & Mark A. Lemley, *Policy Levers in Patent Law*, 89 Va. L. Rev. 1575 (2003).

25. Walsh, *supra* note, at 295; NRC, *supra* note, at 9, 20–21. Consistent with Walsh et al., "research tools" will be defined broadly to include "any tangible or information input into the process of discovering a drug or any other medical therapy or method of diagnosing disease." Walsh, *supra* note, at 287.

26. Finnegan, Henderson, Farabow, Garrett & Dunner, LLP, Biotechnology Innovation Report 2004 8–9 (Arie M. Michelsohn, ed., 2004).

27. Walsh, *supra* note, at 295.

28. *Id.* at 288 n. 6.

29. *Id.* at 298.

30. Heller, *supra* note, at 699. However, a subsequent review identified 135 patents using the search term "andrenergic receptor," but concluded that, at most, a handful of patents needed to be licensed for typical research on the receptor. Walsh, *supra* note, at 294–295.

31. *Id.* at 298 n. 18. Other upstream patents that have garnered attention include those on DNA probes, such as expressed sequence tags (ESTs) and single-nucleotide polymorphisms (SNPs), although recent changes in the PTO's written description and utility requirements have defused some of these concerns. *Id.* at 287, 299.

32. Eisenberg, *supra* note, at 302; NRC, *supra* note, at 62.

33. According the NAS committee, "there was only one area-biotechnology research and development, primarily where applied to humans health – where it was repeatedly suggested that there might be a significant problem of access to patented technology." NRC, *supra* note, at 59.

34. Walsh, *supra* note, at 289, 331. This includes the risks from patent anticommons that were paramount in many people's minds. *Id.* at 317. The NAS committee also "found little evidence, one way or the other, of the economic effects of the many steps taken during the 1980s and 1990s to extend and strengthen intellectual property rights." NRC, *supra* note, at 8.

35. Walsh, *supra* note, at 331. The committee notes further that it is important to distinguish between research tools with only rival uses (Geron's stem cells; diagnostic tests) versus those that have non-rival uses as well, as the latter are much less likely to be used exclusively by the patentee. *Id.* at 332–333.

36. *Id.* at 331–332.

37. *Id.* at 294.

38. *Id. at* 294–295.

39. *Id.* at 315–316. In fact, 54 of 55 respondents could not even identify a specific incident. *Id.* Further, although only indirectly related to patenting, material transfers were found to be "a source of some concern and vexation," as the process is very bureaucratic and time intensive. *Id.* at 319–321. Even when a willingness to share process is complicated, with time increasing from days often to months. *Id.*

40. *Id.* at 299. The norm for royalty payments on drug development programs, for instance, is 1–5% of sales, with exclusives being higher, and royalties of 10% being viewed as "high" or "ridiculous." *Id.* at 300. Royalty stacking could affect decision at the margins (if two equally viable candidates); probability of success and size of market more central. *Id.* at 304.

41. *Id.* at 305–306 Importantly, "this is not a problem of accessing multiple rights but one of accessing relatively few – perhaps even one – patent on a key tool or discovery." Particular concern has been expressed about exclusivity arrangements

for drug targets i.e., "any cell receptor, enzyme, or other protein implicated in a disease, thus representing a promising locus for drug intervention." *Id.* at 310. Indeed, one of the genes with a strong association with breast cancer, BRCA1, has been the subject of substantial controversy because of the limited access that the patent owner for the gene is permitting. *Id.* at 312.

42. *Id.* at 300.

43. *Id.* at 301, 335. Exceptions to this general finding do of course exist. DNA chips were singled out as particularly expensive and beyond the reach of most small labs, forcing – for better or worse – collaborations between companies. *Id.* at 302. There also have been some efforts by companies to allow access to research tools at reduced costs to academic researchers. *Id.*

44. *Id.* at 303. Moreover, most redirection associated with patents on specific compounds, not on processes or techniques. *Id.*

45. *Id.* at 331.

46. Rai, *supra* note, at 90–92.

47. NRC, *supra* note, at 331 (companies, in particular, rarely sue universities for fear of the bad press that would ensue). The importance of scientific norms is also reflected in the patentees' view of the early landmark biotech patents (e.g., the Cohen–Boyer process). Rai, *supra* note, at 93–94.

48. NRC, *supra* note, at 324, 327, 334. The recent Federal Circuit opinion in *Madey v. Duke*, 307 F.3d 1381 (Fed. Cir. 2002) may foreclose this working solution. *Id.* at 335.

49. *Id.* at 329. Some have argued that this openness benefits the large pharmaceutical companies at the expense of the biotech sector, as it is in the interest of the pharmaceutical companies to undercut business opportunities of biotech firms and then "to compete on the exploitation of shared information." *Id.*

50. *Id.*

51. *Id.* at 329. In one important case, the editors of Science succeeded convincing Celera to make its human genome map available to academic researchers on a largely unrestricted basis. *Id.*

52. *Id.*

53. See *infra* Section 2.2.

54. *Id.*

55. NRC, *supra* note, at 305–306.

56. Burk and Lemley conclude that "Biotechnology is in part about pharmaceuticals – and therefore prospect theory – and in part about DNA research – and therefore anticommons theory." Burk, *supra* note, at 1676.

57. These problems also lend credence to Wagner's micro-specificity argument, for it appears that different biotech inventions pose different sets of problems for patent policy. If this is the case, it makes no sense to treat biotech patents on a technology-specific basis. Further, it appears that different problems in biotech patents demand policy shifts that are mutually exclusive under the Burk-Lemley synthesis.

58. NRC, *supra* note, at 300.

59. In a recent article that challenges the "Conventional Critique in the intellectual property world," Merges refers to strategies that involve dedicating technology and data to the public domain as "property-preempting investments," which he argues are motivated by the desire of firms and individuals to "preempt or

undermine the potential property rights of economic competitors." Robert P. Merges, *A New Dynamism in the Public Domain*, 71 U. Chi. L. Rev. 183, 183 (2004). Although dealing with the same phenomena, this paper ascribes this development to factors that go beyond broad economic theorizing, which is not to deny that the scientific factors discussed here do not have a significant impact on individual economic calculations.

60. *Id.* at 331.

61. For example, the recent cases that have narrowed the scope, or invalidated, several important patents, have eased some concern over a patenting, and folks are closely watching *Rochester v. Searle* case, which will determine how broadly claims over a drug target can be. Walsh, *supra* note, at 330.

62. *Id.* at 304–305. See also Allison Abbott, *Geneticists Prepare for Deluge of Mutant Mice*, 432 Nature 541, 541 (2004).

63. *Id.* at 324.

64. These statements are borne out by estimates that the total number of "druggable" targets is about 5,000–10,000 – notably, the number of targets for existing drugs is a mere 483. Jurgen Drews, *Drug Discovery: A Historical Perspective*, 287 Science 1960, 1962 (2000). *Cf.* Andrew L. Hopkins & Colin R. Groom, *The Druggable Genome*, 1 Nat. Rev. Drug Disc. 727. 728–729 (2002) (estimating that the number of druggable targets is more likely between 600 and 1,500). However, regardless of what the exact number of druggable targets is, a great deal of sifting of genetic data will be required given that scientists estimate there are 20,000–25,000 genes in the human genome and that the number of proteins is possibly about 1 million. Christopher P. Austin et al., *NIH Molecular Libraries Initiative*, 306 Science 1138, 1138 (2004).

65. *Id.* at 250, 314.

66. I do not mean to suggest here that the interplay between science and patenting is absent from the legal literature as a whole, only that it has not been adequately considered in the biotech context. See, e.g., Mark A. Lemley, *The Economics of Improvement in Intellectual Property Law*, 75 Tex L. Rev. 989, 1036–1037 (1997) (describing how "subsequent inventors…must work within the parameters of the physical laws, and hence may be forced to build on the original inventors work)."

67. Kenneth M. Weiss & Anne Buchanan, *Evolution by Phenotype: A Biomedical Perspective*, 46 Perspectives Bio. Med. 159, 178 (2003).

68. A number of cancers, for example, have been associated with genetic variations in tens of genes. Weiss, *supra* note, at 174. Further, the relationship between genetics and disease can be complicated by much more mundane factors, such as physiological differences that may aggravate or neutralize the effect of a genetic mutation. See, e.g., Walsh, *supra* note, at 5–6 describing how basic physiological differences between animal models and humans are determinative of whether certain chemicals heighten this risk of bladder cancer and concluding that "[g]enomics will contribute little to this risks assessment".

69. Hubbard & Richard C. Lewontin, *Pitfalls of Genetic Testing*, 334 New Engl. J. Med. 1192, 1192 (1996). Over 100 variants of the two genes have been identified, but only a few have been linked to tumor growth, and all in women whose family histories provide independent grounds for finding a high familial risk of breast cancer. *Id.*

70. *Id.* Recent work, for example, has shown that lifetime risks vary significantly (e.g., depending on the decade when the woman was born), suggesting that the cancer risks associated with these mutations may be overstated. Weiss, *supra* note, at 175. An important potential source of error is confounding factors in multiply affected families. *Id.* In other words, scientists have not even demonstrated that BRCA1 & 2 are the cause of the increased susceptibility, as other genes or factors in these families could be the putative "cause." Hubbard, *supra* note, at 1192. This ambiguity arises because one cannot know a priori whether a trait is common because of an inherited characteristic, or because of a functional genetic reason. Weiss, *supra* note, at 174. A disease may be common because an environmental factor affects a particular genetic or molecular-level pathway shared by everyone, or because a specific underlying genetic variant is common. *Id.*

71. Weiss, *supra* note, at 175. Furthermore, in the case of relatively rare genetic disorders, such as BRCA1 & 2, broad public genetic testing may not even be cost effective, particularly given the risk of false positives. Hubbard, *supra* note, at 1193–1194; Neil A. Holtzman & Theresa M. Marteau, *Will Genetics Revolutionize Medicine?*, 343 New Engl. J. Med. 141, 142–144 (2000); Paolo Vineis et al., *Misconceptions About the Use of Genetic Tests in Populations*, 357 Lancet 709, 710–711 (2001).

72. Hubbard, *supra* note, at 1192–1193; Richard S. Cooper & Bruce M. Psaty, *Genomics and Medicine: Distraction, Incremental Progress, or the Dawn of a New Age?*, 139 Ann. Internal Med. 576, 577 (2003) "(the available empirical data support the argument against a clinical role for susceptibility testing for chronic disease)."

73. See, e.g., Rai, *supra* note, at 1070 "deducing a gene sequence from its amino acid sequence not…a particularly risky or uncertain step"; Burk, *supra* note, at 1677–1678 "The availability of research tools has made the isolation and characterization of biological macromolecules routine"; Eisenberg, *supra* note, at 289 "Once largely a matter of serendipity or trial-and-error, drug discovery is now critically dependent on basic knowledge of genes, proteins, and associated biochemical pathways."

74. Guttmacher & Francis S. Collins, *Genomic Medicine – A Primer*, 347 New Engl. J. Med. 1512, 1514 (2002).

75. *Id.* In fact, different coding sequences of a gene may be linked together in a variety of ways, such that the 30,000–35,000 genes in the human genome code for more than 100,000 proteins. *Id.*

76. *Id.* (examples include the signals that turn genes on and off and molecules that activate and deactivate critical proteins). These alternate control mechanisms have emerged because "[t]he evolution of additional complex attributes is essentially an organizational one," not a product of major genetic modifications. Gerald M. Rubin et al., *Comparative Genomics of the Eukaryotes*, 287 Science 2204, 2214 (2000). Current evidence suggests that "the majority of phenotypic variation between individuals (and species) results from differences in the control architecture, not the proteins themselves." John S. Mattick & Michael J. Gagen, *The Evolution of Controlled Multitasked Gen Networks: The Role of Introns and Other Noncoding RNAs in the Development of Complex Organisms*, 18 Molecular Bio. Evolution 1611, 1611, 1622–1623 (2001); see also David K. Gifford, *Blazing Pathways Through Genetic Mountains*, 293 Science 2049, 2450 (2001).

77. A recent issue of the Science journal contained a special section on "*Mathematics in Biology*," and other recent articles have also highlighted the rising importance of mathematical modeling and the study of complexity in biological systems. 303 Science 781, 781 (2004); Ronald N. Germain, *The Art of the Probable: System Control in the Adaptive Immune System*, 293 Science 240, 244 "it is now time to add the power of mathematics, systems analysis, and quantitative cell-based modeling to the study of complex biological systems e.g., the immune system"; Robert F. Service, *Exploring the Systems of Life*, 284 Science 80, 82 (1999) (scientists will need to develop complex models for biological systems); Hiroaki Kitano, *Systems Biology: A Brief Overview*, 295 Science 1662, 1662 (2002). This focus on modeling is motivated both by the needs of genomics research and the realization that biological systems often operate more as networks, with different pathways interacting, than as systems driven from the smallest level up by the same fundamental forces.

78. Epigenetics is the study of heritable changes in gene expression that occur without a change in DNA sequence. Rebecca E. Watson & Jay I. Goodman, *Epigenetics and DNA Methylation Come of Age in Toxicology*, 67 Toxicologic Sci. 11, 11 (2003). "[A]daptive epigenetic inheritance challenges the 'central dogma' that information is unidirectional from DNA to protein" and that epigenetic processes are unimportant in assessing potential chemical toxicity. *Id.* Examples of epigenetic phenomena include silencing of tumor genes through chemical modifications, and short double-stranded RNA (RNAi) segments that mediate gene expression, and DNA – DNA, DNA – RNA, and RNA – RNA interactions that trigger gene silencing. Alan P. Wolffe & Marjorie A. Matzke, *Epigentics: Regulation Through Repression*, 286 Science 481, 481, 483 (1999).

79. Frederica P. Perera & I. Bernard Weinstein, *Molecular Epidemiology: Recent Advances and Future Directions*, 21 Carcinogenesis 517, 521 (2000) (many carcinogenic chemicals act "through indirect genotoxic or epigenetic mechanisms").

80. A test of gene detection methods on the Drosophilia genome, for instance, was mixed. The accuracy of the methods used to find genes varied between 5 and 95%, and they incorrectly identified up to 55% of the genes studied. Teresa K. Attwood, *The Babel of Bioinformatics*, 290 Science 471 (2000).

81. Walter C. Willett, *Balancing Life-Style and Genomics Research for Disease Prevention*, 296 Science 695, 696 (2002) "the majority – probably the large majority – of important cancers in Western populations are due to environmental rather than genetic factors"; Weiss, *supra* note, 172. Indeed, critics of genomics methods reject the view "that the genetic determinants of complex traits are tractable, and that knowledge of genetic variation will materially improve diagnosis, treatment or prevention of a substantial fraction of cases of the diseases that constitute the major public health burden of industrialized nations." Kenneth M. Weiss & Joseph D. Terwilliger, *How Many Diseases Does It Take to Map a Gene With SNPs?*, 26 Nature Genetics 151, 151 (2000).

82. *Id.*

83. Richard Strohman, *Maneuvering in the Complex Path From Genotype to Phenotype*, 296 Science 701, 701 (2002); Jonathan Rees, *Complex Disease and the New Clinical Sciences*, 296 Science 698, 699 (2002).

84. Weiss, *supra* note, at 152 (the central inferential problem is that a specific genotype does not imply a specific phenotype nor does a specific phenotype imply a specific genotype; they are not equivalent or even necessarily correlated).

85. *Id.*

86. Elliot Sober & Richard C. Lewontin, *Artifact, Cause, and Genic Selection*, 49 Phil Sci. 157, 159 (1982); Glazier et al., *Finding Genes That Underlie Complex Traits*, 298 Science 2345, 2345 (2002).

87. Mark S. Boguski, *Biosequence Exegesis*, 286 Science 453 (1999). Some scientists have argued that, "If only 1 in 10,000 of the [mutations] present in the human population has some [tangible] effect, then there would be more than enough unique combinations of these polymorphisms to assure that every human being (with the exception of identical twins) should have a unique [set of susceptibilities]." John L. Hartman et al., *Principles for the Buffering of Genetic Variation*, 291 Science 1001, 1001 (2001).

88. Julian Little et al., *The Human Genome Project Is Complete: How Do We Develop A handle for the Pump?*, 157 Am. J. Epidemiology 667, 669 (2003); Weiss, *supra* note, at 167; Hartman, *supra* note, at 1001 (In nature no wild type exists; all disease and chemical toxin susceptibilities are "arbitrarily defined [at a] point along a spectrum").

89. Ernst Mayr, *The Objects of Selection*, 94 Proc. Nat'l Acad. Sci. USA 2091, 2092 (1997); Sober, *supra* note, at 165–167.

90. Robert Milliken, *The Changing Face of Epidemiology in the Genomics Era*, 13 Epidemiology 472, 474 (2002) (A huge gap exists between genotype and phenotype because unmeasured genetic and environmental factors can influence expression); Strohman, *supra* note, at 701 (The progression from genotype to phenotype extends over four basic levels of control, "each level of which is defined by a dynamic system of self-organizing proteins, the output of which is governed by laws that are still poorly understood").

91. Weiss, *supra* note, at 159; Mayr, *supra* note, at 2093. This distinction is important because the indirect relationship between natural selection and genotype allows genetic drift (i.e., selectively neutral genetic variation) to propagate over time. Weiss, *supra* note, at 159 ("[g]enetic variation is abundant in all natural species, and most is expected to be neutral or nearly neutral with respect to fitness.").

92. Weiss, *supra* note, at 164; Hubbard, *supra* note, at 1192 (appearance of the same trait in different people need not be associated with the same genetic polymorphism e.g., 200 different nucleotide variations appear to produce hemophilia B. In fact, "even strong [natural] selection favoring a specific phenotype closely tied to specific genes does not usually purify [genetic] variation." Weiss, *supra* note, at 170–171.

93. Weiss, *supra* note, at 165. Moreover, once the classical two-allele (abnormal, wild-type) classification scheme is abandoned, substantial phenogentic equivalence and a broad genotype – phenotype distribution results from numerous alleles. *Id.* at 167–168.

94. Suzanne L. Rutherford, *Between Genotype and Phenotype: Protein Chaperones and Evolvability*, 4 Nat. Rev. Genetics 263, 263–264 (2003) (specific biological molecules exist that buffer the "expression of genetic variation as phenotypic variation"). The prevalence of genetic buffering is driven by the important role it plays in natural selection. Genetic buffering allows "a reserve of neutral genetic variation" to build

up in a population under stable conditions. Rutherford, *supra* note, at 271. This reserve is critical to a species' resiliency to environmental change and altered natural selection pressures because it provides a genetic reservoir upon which species can draw in response to changed circumstances. Rutherford, *supra* note, at 263, 271.

95. Suzanne L. Rutherford, *From Genotype to Phenotype: Buffering Mechanisms and the Storage Genetic Information*, 22 BioEssays 1095, 1095 (2000) (many ways exist in which phenotypes are buffered from perturbation by genomic and environmental variation).

96. Hubbard, *supra* note, at 1192 (having the same DNA nucleotide sequence in a gene does not guarantee that different people will display the same phenotype; for example, autosomal dominant retinitis pigmentosa display range of effects from complete blindness to completely functional vision); Rutherford, *supra* note, at 1095 (the genotype of essential biochemical pathways, for instance, can be disrupted in some strain backgrounds with minimal phenotypic effect, while in other genetic backgrounds the organism is severely affected).

97. *Id.* at 1097. An important problem for genomics methods is that they cannot distinguish between cases in which a phenotype arises because of limited genetic variation, because of a high degree of buffering, or because the trait is constrained in some other way (e.g., biochemical constraints). *Id.* at 1102.

98. Mayr, *supra* note, at 2092; Germain, *supra* note, at 241 "the difference between health and disease could be the 'stochastic' activation of a single cell, followed by positive feedback in the form of a gain in sensitivity and multiplication of the responding cells to high numbers."; Simon A. Levin et al., *Mathematical and Computations Challenges in Population Biology and Ecosystems Science*, 275 Science 334, 337 (1997) "stochastic effects become paramount" in biological systems; Michael B. Elowitz et al, *Stochastic Gene* Expression *in a Single Cell*, 297 Science 1183, 1183, 1186 (2002) (random epigenetic signaling can generate long-term heterogeneity among animals with identical genetic backgrounds).

99. Watson, *supra* note, at 12–13 (describing how chemical modifications to DNA that affect gene activity have been connected to chemical toxicity); Elizabeth Pennisi, *Behind the Scenes of Gene Expression*, 293 Science 1064, 1065 (2001) (describing how epigenetic deactivation of tumor-suppressor genes can cause cancer).

100. Germain, *supra* note, at 240–241; Rutherford, *supra* note, at 1100; Hartman, *supra* note, 1001 (diseases or toxic susceptibilities can be influenced differentially by environment factors, stochastic events, or interactions with other genes).

101. Rutherford, *supra* note, at 1100.

102. Austin, *supra* note, at 1138–1139 (describe the importance of small molecules in the trial-and-error research that will be necessary to exploit the Human Genome Project).

103. Weiss, *supra* note, at 174 (Evidence to date indicates that simple genetic variants with major effects on risk are the exception, not the rule); Vineis, *supra* note, at 710–711 (mutations in genes coding for proteins that metabolize environmental toxins are prototypical of common, but weakly associated genetic defects that affect individual susceptibility to toxins.).

104. Even simple organisms, such as yeast, display a high degree of complexity in their gene – gene interactions. In one recent study, scientists found an average of 34 gene – gene interactions per gene based on an analysis of 143 genes in yeast mutants.

Lee Hartwell, *Robust Interactions*, 303 Science 774, 775 (2004). As the author acknowledges, "[f]or those interested in uncovering the genetic basis of disease susceptibility in the human population, this result is daunting." *Id.*

105. Weiss, *supra* note, at 156 "Late-onset chronic diseases – whose elimination through genetics is currently the supreme object of our affections – are much more complex by comparison."; Julian Peto, *Cancer Epidemiology in the Last Century and the Next Decade*, 411 Nature 390, 390 (2002) (some studies suggest, for example, that cancer risks in old age may depend on diet in early life as much as a person's habits when they contract the cancer).

106. Weiss, *supra* note, at 153. Type 2 diabetes, for example, has become much more severe in recent times, implying that environmental factors dominate. *Id.* at 154 Further, even the pandemic among certain Native American tribes, which clearly has a genetic component, is still dominated by environmental factors because it was rare in the same populations 60 years ago. Weiss, *supra* note, at 175.

107. Weiss, *supra* note, at 153 "genetic factors are not likely to explain [common, chronic] diseases in the usual causal sense"; Strohman, *supra* note, at 701 (scientists are particularly ignorant of the interplay between disease and environmental factors); Nelson Freimer & Chiara Sabatti, *The Human Phenome Project*, 34 Nature 15, 16 (2003) "there is still relatively little known about how to integrate this effort with investigation of environmental influence on phenotype."

108. Richard C. Lewontin, The Triple Helix 113–214 (2000). "It is not new principles that we need but a willingness to accept the consequences of the fact that biological systems occupy a different region of the space of physical relations than do simpler physico-chemical systems, a region in which the objects are characterized, first, by very great internal physical and chemical heterogeneity and, second, by a dynamic exchange between processes internal to the objects and the world outside of them. That is, organisms are internally heterogeneous open systems." *Id.*

109. Biological signaling processes that control cellular responses to environmental exposures, for example, involve networks with "complex properties that are independent of genetic factors." Upinder S. Bhalla & Ravi Iyengear, *Emergent Properties of Networks of Biological Signaling Pathways*, 283 Science 381, 381, 386 (1999).

110. Strohman, *supra* note, at 703 (objecting to policies that "continue to see complex phenotypes as primarily derivable from genomic and proteomic databases"). Biomedical scientists also acknowledge the need to come to terms with complex biological processes. Geoffrey Duyk, *Attrition and Translation*, 302 Science 603, 603–604 (2003) (arguing that the shrinking number of drugs being discovered is attributable to the failure of scientists to address biological complexity in a systematic manner).

111. Strohman, *supra* note, at 702; Rees, *supra* note, 698 (2002).

112. Kenneth M. Weiss & Andrew G. Clark, *Linkage Disequilibrium and the Mapping of Complex Human Traits*, 18 Trends Genetics 19, 22 (2002); Weiss, *supra* note, at 171–172; Habibul Ahsan & Andrew G. Rundle, *Measures of Genotype Versus Gene Products: Promise and Pitfalls in Cancer Prevention* 24 Carcinogenesis 1429, 1429 (2003); Kirk E. Lohmueller et al., *Meta-Analysis of Genetic Association Studies Supports a Contribution of Common Variants to Susceptibility to Common Disease*, 33 Nat. Genetics 177, 177 (2003) meta-analysis of 301 published studies covering 25 different disease associations finding that "approximately 20–30% of [the] genetic association studies [were] statistically significant."

113. Pierre Baldi & Wesley Hatfield, DNA Microarrays and Gene Expression: From Experiments to Data Analysis and Modeling viii (2002). "The bioinformatics solutions to problems associated with the analysis of data on this scale are a major current challenge."; Richard D. Irwin et al., *Application of Toxicogenomics to Toxicology: Basic Concepts in the Analysis of Microarray Data*, 32 Toxicologic Pathology 72, 72 (2004) "The amount and complexity of the data means that confounding factors can be easily missed and potential[ly] important changes may be overlooked."; Hopkins *supra* note, 729 (the viability of "targets identified by proteomic or transcriptional-profiling studies is likely to be low."

114. Baldi, *supra* note, at 55–56 (discussing the multidimensional nature of biological systems and the sophisticated probabilistic methods that are being used to analyze them).

115. Robert F. Service, *Surviving the Blockbuster Syndrome*, 303 Science 1797, 1799 (2004) "The plain truth is that many of the most dramatic scientific advances that have recently been made in the lab have not transformed medicine."; Richard S. Cooper & Bruce M Psaty, *Genomics and Medicine: Distraction, Incremental Progress, or the Dawn of a New Age?* 138 Ann. Internal Med. 576, 577 (2003) "To date, both [gene expression] studies and genome-wide scans have identified only weak and inconsistent genetic signals…" for common diseases in the U.S. such as cardiovascular disease and cancer.

116. Mohrenweiser, *Genetic Variation and Exposure Related Risk Estimation: Will Toxicology Enter a New Era? DNA Repair and Cancer as a Paradigm*, 32 Toxicol. Pathology 136, 139 (2004).

117. *Id.*

118. Weiss, *supra* note, at 155 "current genetic approaches…have been likened to a search for a needle in a needle stack (a great many individually modest effects)".

119. Austin, *supra* note, at 1138.

120. Rai, *supra* note, at 93–94.

121. Finnegan, *supra* note, at 8–9.

122. See *supra* note.

123. Walsh, *supra* note, at 324 [other cites].

124. Walsh, *supra* note, at 304–305, 324.

125. *Id.* at 329.

126. *Id.* Merges has argued that there is a natural counterbalancing that occurs in markets between those interests that are seeking to privatize certain types of inventions and those whose business interests actually favor dedicating them to the public domain. Merges, *supra* note, at 185–186. Merges claims that recent efforts to dedicate biotech data and materials to the public domain fit this model. *Id.*

127. See *infra* Section 2.1.

128. *Id.* They also singled out biotechnology as a field in which particular care should be taken to constrain the scope of patents because such science-based technologies are particularly vulnerable to the negative effects of broad pioneer patents. *Id.*

129. *Id.*

130. Prospect theory presumes that biotech science can be bounded and managed. Merges and Nelson's proposal assumes some bounding and congestion, otherwise their advocacy of narrow patents is superfluous. Finally, Heller and Eisenberg's

theory is explicitly premised on intellectual resources being "scarce," and in any event, only makes sense if the commons is both finite and seriously congested.

131. Admittedly borderline or variable cases will exist. For example, certain "promoters," which are DNA segments that turn genes on and off, are probably best categorized as common-method research tools because they are so broadly used. Powerful constitutive promoters, i.e., those that cause a gene to be continuously expressed in all cell types, would fall into this category because they are so broadly applicable and valuable in genetic engineering. However, other promoters, such as those that are cell-specific or activated only under certain circumstances, may be more accurately categorized as problem-specific because their activation properties are so circumscribed. Judgments about how to categorize research tools will therefore by necessity have to take into account context, which will naturally change over time.

132. Rose, *supra* note, at 5–7 (uncongested resources do not suffer from commons problem by virtue of the fact that they cannot be adversely impacted by individual actions – control of the resource is beyond the capacity of either individual or collective action).

133. See*,* e.g., Eisenberg, *supra* note, at 302; NRC, *supra* note, at 62.

134. Rose, *supra* note, at 5–7.

135. See *infra* Part I.B. The reduced value of the patents also has important implications for cases, which apparently occur routinely, where a successful scientist conducts research without obtaining a license. The low value of the patents limits the damages a patentee could extract from an inventor in a patent infringement suit after a valuable product is discovered. Other factors also mitigate against such windfalls occurring, most important among these being the extensive research that will be required even after a research tool (such a drug target) is discovered and the weak connection that will exist between the research tool and the final product, whose discovery will only be nominally attributable to the research to itself.

136. The NRC Report, as well as other commentators, also identifies this second issue as one deserving special attention. NRC, *supra* note, at 60–63. Robert Merges also highlighted this as a major issue years ago. Merges, *supra* note, at 839–840.

137. The human genome contains three billion base pairs and an estimated 30,000–100,000 genes, and rapidly evolving genomics methods are generating information at a stunning speed. Guttmacher, *supra* note, at 1512.

138. See *supra* Part I.A.

139. Indeed, for problem-specific research tools, it is not even clear whether the patentee could prevent production of a down-stream drug product, which in most cases will be distinct from the research tool itself.

140. *Id.*

141. Finnegan, *supra* note, at 8–11.

COMMERCIALIZING UNIVERSITY RESEARCH SYSTEMS IN ECONOMIC PERSPECTIVE: A VIEW FROM THE DEMAND SIDE

Brett M. Frischmann

ABSTRACT

Universities face incredibly difficult, complex decisions concerning the degree to which they participate in the process of commercializing research. The U.S. government has made an explicit policy decision to allow funded entities to obtain patents and thereby has encouraged participation in the commercialization of federally funded research. The Bayh-Dole Act enables universities to participate in the commercialization process, but it does not obligate or constrain them to pursue any particular strategy with respect to federally funded research. Universities remain in the driver's seat and must decide carefully the extent to which they wish to participate in the commercialization process.

The conventional view of the role of patents in the university research context is that patent-enabled exclusivity improves the supply-side functioning of markets for university research results as well as those markets further downstream for derivative commercial end-products. Both the reward and commercialization theories of patent law take patent-enabled exclusivity as the relevant means for fixing a supply-side

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problem – essentially, the undersupply of private investment in the production of patentable subject matter or in the development and commercialization of patentable subject matter that would occur in the absence of patent-enabled exclusivity.

While the supply-side view of the role of patents in the university research context is important, a view from the demand side is needed to fully appreciate the role of patents in the university research context and to fully inform university decisions about the extent to which they wish to participate in the commercialization process. Introducing patents into the university research system, along with a host of other initiatives aimed at tightening the relationship between universities and industry, is also (if not primarily) about increasing connectivity between university science and technology research systems and the demands of industry for both university research outputs (research results and human capital) and upstream infrastructural capital necessary to produce such outputs.

In this chapter, I explore how university science and technology research systems perform economically as infrastructural capital and explain how these systems generate social value. I explain how the availability of patents, coupled with decreased government funding, may lead to a slow and subtle shift in the allocation of infrastructure resources.

1. INTRODUCTION

There are substantial, ever-growing literatures both supporting and challenging the commercialization of universities and university research. Not surprisingly, different literatures approach the commercialization question from different perspectives, some focusing broadly on the university system and others focusing more narrowly on university research. As a law professor who teaches and writes about the law and economics of intellectual property,[1] I approach the debate, at least initially, from the legal and economic literatures and with a focus on university research rather than the university on the whole. As I explain below, however, I would like to offer an intermediate level of analysis – in between university-focused and university research-focused, so to speak – that considers commercialization of the *university science and technology research system.*[2]

The legal and economic literatures focus extensively on university research results, how research results are managed, developed, licensed, transferred, priced, and so on. The introduction of patents into the university research system as a tool to encourage and indeed enable technology transfer, utilization and commercialization has been lauded by some as a major success and criticized by others as a major failure. Those who claim success focus on increased rates of patenting, licensing, and commercialization. Patents encourage and enable transactions; they serve as the focal point for researchers, technology transfer officers, lawyers, venture capitalists, entrepreneurs, engineers, marketers, and other participants in the commercialization process. Without patents, the proponents argue, potentially valuable research languishes underutilized. On the other hand, those who claim failure focus on transaction costs, patent "thickets," deadweight losses, increased costs to the public, increased secrecy, and shifts in academic norms. Patents, they argue, are unnecessary impediments to widespread, competitive utilization of research results that the public already has paid for.

This debate is by no means resolved. Its resolution will depend upon continued empirical testing of the various types of costs and benefits that each side has highlighted. Moreover, at least in my opinion, the strength of the arguments offered by each side will vary considerably across research areas (e.g., compare computer science, biotechnology, and materials science) and across research result types (e.g., consider and compare upstream basic research, midstream research tools, and downstream commercial technology). As mentioned above, with the exception of some discussion of academic norms, most of the attention in this debate (within the legal and economic literatures, at least) seems focused on research results – the outputs from the research process.

In this chapter, I do not wish to focus on the *management* of outputs per se. Instead, I would like to focus on the type or nature of the outputs produced, the research process and other related university-based processes, and mostly, even further upstream, on the "university science and technology research system" itself.

As illustrated in Fig. 1 and discussed below, "university science and technology research system" refers to the system of complementary university resources that together act as inputs into different types of productive processes (research, education, training, and socialization) that generate a wide range of socially valuable research outputs (research results and human capital).

The Conference organizers asked me to consider the following question: *Given decreases in government funding of research, how should universities employ intellectual property to transfer technology, encourage entrepreneurship and generate revenues that may support research efforts*? Implicit in this

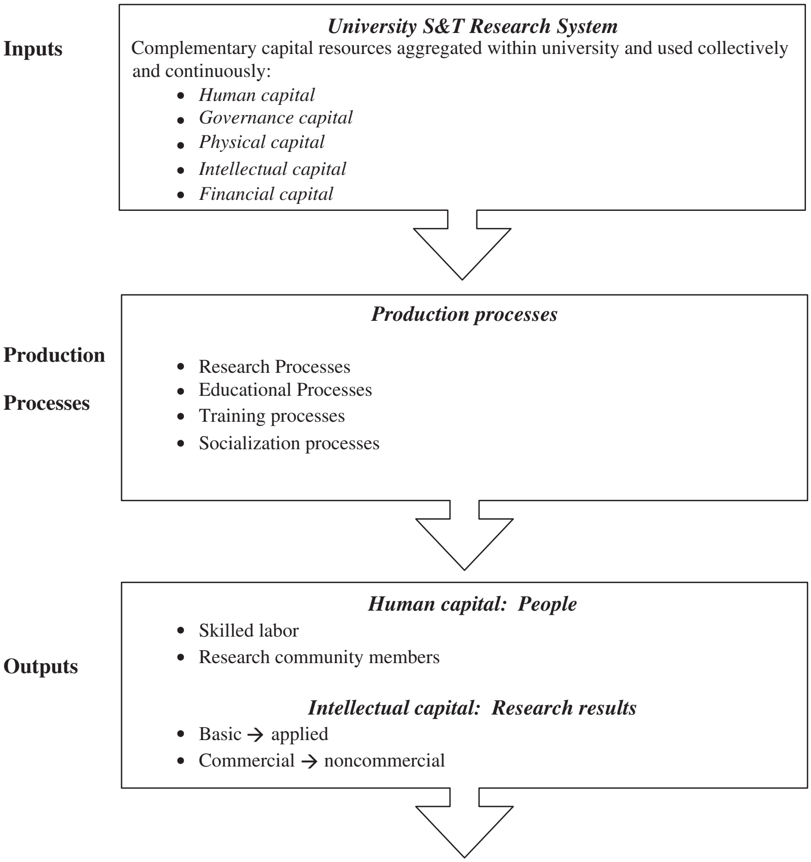

Fig. 1. Simple View of University Science and Technology Research System and its Outputs.

question is the notion that universities ought to go down this road (as many have already done) that participation in the commercialization process is an end worth aiming for and even worth making a priority. Also implicit in the question posed by the Conference organizers (and quite important) is the notion that universities do not have a *choice*. And yet they do.

Universities face incredibly difficult, complex decisions concerning the degree to which they ought to participate in the commercialization process. While shrinking government funds may be the immediate, most visible factor forcing such decisions upon universities, there are more fundamental forces at work. In *Academic Capitalism*, Larry Leslie and Sheila Slaughter (1997) present a compelling argument that globalization, changing economic conditions, and other macro-level factors are increasing pressure on universities on the whole to behave more and more like market actors (Leslie & Slaughter, 1997).

Another (complementary) explanation can be found in the dominant economic mindset that has emerged in the past few decades (Croissant & Restivo, 2001). This mindset focuses on the perceived social benefits of commercialization, privatization and deregulation, on minimizing government intervention in markets, and arguably on maximizing market intervention into government and academia, although proponents of such increased reliance on the market mechanism would not put it this way.[3] As Paul Krugman (2004) recently noted, "Decades of conservative marketing have convinced Americans that government programs always create bloated bureaucracies, while the private sector is always lean and efficient." In my opinion, universities often are typecast like government in a manner that marginalizes their social and economic contributions and their respective roles in society. Along with a glorified view of the market and a pessimistic view of government, universities are cast as ivory tower havens for (liberal) academics out of touch with reality and the demands of society.

This is not the place to develop these arguments fully, but I raise them to suggest that the commercialization question is not unique to the university research context, but rather is endemic to evolving notions of modern societal organization in capitalist economies. To grapple with the commercialization question, universities should step back from their immediate context, compare their situation with that of other industries and social contexts, reflect on their role in society, and proceed carefully.

In three previous papers, I have argued that the dominant economic mindset ignores critical social and economic values and that overreliance on the market mechanism may involve significant social (opportunity) costs that escape consideration within conventional economic analyses. In these papers, I used the tools of the economics discipline to challenge the dominant economic mindset as it pertains to specific areas.

In *Innovation and Institutions: Rethinking the Economics of U.S. Science and Technology Policy*, I focused on science and technology policy. I critiqued the "linear" model of scientific and technological progress and developed a "dynamic" model of the process by which progress is made (Frischmann, 2000). Recognizing that progress is contingent upon one's point of reference, I first suggested that research processes involve three progressive stages – (1) *Ex ante investment decision*: wherein private or public investors decide how to allocate resources among prospective research projects; (2) *Research production*: wherein discrete research outputs are produced; and (3) *Ex post utilization*: wherein research results are used or consumed (including use in further research production) (Frischmann, 2000, pp. 356–357). Then, to focus attention on incentives to invest in research, I found the *ex ante* estimation of the expected applications of a research output to be a useful point of reference. I distinguished the basic-applied research continuum, which I believe should be defined solely on the basis of the variance in expected applications, from the commercial–noncommercial continuum, which I believe should be defined solely on the basis of the type of expected applications (e.g., private goods production vs. public goods production)[4] (Frischmann, 2000, pp. 365–366). In the final part of the paper, I criticized the use of intellectual property (patents) to encourage the transfer of federally funded research results (Frischmann, 2000, pp. 403–413). Among other reasons, I argued that other institutions, such as tax incentives and cooperative R&D, could accomplish the desired transfer at lower social cost and that mixing public funding with patents would lead to a systemic skewing of incentives toward applied commercial research (more on this below).

In *Privatization and Commercialization of the Internet Infrastructure: Rethinking Market Intervention into Government and Government Intervention into the Market*, I focused on the Internet infrastructure (Frischmann, 2001). I argued that "society should question the common assumption that handing off publicly developed resources and technologies to industry is always in the public's best interest and to reevaluate the momentum towards deregulation, privatization and commercialization" (Frischmann, 2001, p. 84). In addition to a series of well-understood justifications for government intervention into the market, I suggested that "there are important public goods applications dependent upon the Internet that will be under-supplied with required interconnection infrastructure, …, unless government takes an active role in ensuring their provision" (Frischmann, 2001, p. 84). In essence, I argued that relying on the market mechanism to supply access to Internet infrastructure may lead to hidden social costs because the market mechanism would favor private good outputs that generate observable and appropriable surpluses over public good outputs that generate positive externalities (Frischmann, 2001).

Finally, in *An Economic Theory of Infrastructure and Commons Management*, I build from these two papers and develop a theory of infrastructure that can be applied across different industries (Frischmann, 2005). The theory differs from conventional economic analyses in that it focuses extensively on demand-side considerations and fully explores how infrastructure resources generate value for consumers. Three key insights relevant to the discussion below emerge from this demand-side, value-creation-focused analysis: First, infrastructure resources are fundamental resources that generate value when used as inputs into a wide range of productive processes; second, the outputs from these processes are often public and non-market goods that generate positive externalities that benefit society; and last, managing infrastructure resources in an openly accessible manner may be socially desirable when it facilitates these downstream activities. The problem with relying on the market mechanism to allocate access to such infrastructure is that potential positive externalities may remain unrealized if they cannot be easily valued and appropriated by those that produce them (i.e., downstream output producers), even though society as a whole may be better off if those potential externalities were actually produced.

In this chapter, I build from previous work and extend the infrastructure theory to the university research context – in a sense folding the third paper back into the first. Specifically, I explore how university science and technology research systems perform economically as infrastructural capital, explain how these systems generate value, and reframe the commercialization question. I explain the role of patents in the university science and technology research system and how its availability, coupled with decreased government funding, may lead to a creeping systemic optimization – a slow and subtle shift in the allocation of infrastructure resources, priorities, relationships, norms, and so on. This optimization is not simply an adjustment in incentives, an ‘‘incentive shift’’ for researchers to ‘‘better’’ align their incentives with the commercialization objective and thereby encourage more efficient technology transfer, which boils down to more efficient *supply* of university derived technology to downstream markets. While this is part of the dynamic, it is critical that universities take a wider view and recognize the demand-side effects of commercialization. The role of patents in the university research context (and the commercialization question more generally) is not simply about using patent-enabled exclusivity to fix the supply-side problem of underutilization of government funded research results; it is also (if not primarily) about increasing connectivity between university science and technology research systems and the *demands* of industry for both university research outputs (research results and human capital) and infrastructural capital necessary to produce such outputs.

The U.S. government has made an explicit policy decision to allow funded entities to obtain patents and thereby has encouraged participation in the commercialization of federally funded research. The Bayh-Dole Act enables universities to participate in the commercialization process, but it does not obligate or constrain them to pursue any particular strategy with respect to federally funded research. Universities must decide carefully the extent to which they wish to participate in the commercialization process. As Richard Florida has argued, "universities need to be more vigilant in managing the process" and should "reconsider their more aggressive policies toward technology transfer and particularly regarding the ownership of intellectual property" (1999). Universities remain in the driver's seat and may decide which road to take and at what speed.

The chapter is organized as follows: Part II introduces a demand-side theory of infrastructure; Part III discusses university science and technology research systems and explains how they perform economically as infrastructure; Part IV explains how patents were introduced based on "supply-side" reasoning without due care for "demand-side" issues. It then describes how patents create a demand-pull for optimization created by market-driven incentives in the university research context; Part V suggests that universities have a choice and must carefully decide on the degree to which they participate in commercialization; Part VI offers some thoughts on technology transfer and entrepreneurship education; and Part VII concludes.

2. A DEMAND-SIDE THEORY FOR INFRASTRUCTURE

I am currently engaged in an interdisciplinary research project that raises significant concerns regarding the economic analysis of infrastructure resources. At the core of these concerns, I argue, is an inordinate focus on supply-side considerations that obfuscates demand-side analysis and leads to an underappreciation of the social demand for public and social infrastructure. Such myopicism is present in the debate over commercialization of university research, and, as I discuss below, a reframing in light of demand-side considerations is needed.

This part introduces a demand-focused model of infrastructure that provides a better means for understanding and analyzing societal demand for infrastructure resources (Frischmann, 2005).[5] To understand demand, one must focus attention on the manner in which a resource generates value, which, for infrastructure, leads to consideration of the downstream outputs that are produced by those that obtain access to and use the infrastructure. When discussing demand, I am referring to human desire to realize value (or utility), and when discussing societal demand, I am referring to society's aggregated desires. With respect to infrastructure resources, I would like to better understand how value is created and realized by human beings, and thus, where demand for infrastructure comes from. Only with such an understanding can one analyze and compare provisional mechanisms (in other words, supply systems such as markets, government, universities, community, family, and so on), and institutions aimed at optimizing these mechanisms (for example, law, norms, subsidies, taxes, and so on). This is critical because these mechanisms vary in their capacity to generate, communicate, process, and respond to demand signals effectively.

2.1. Defining Infrastructure from the Demand Side

Infrastructure resources are resources that satisfy the following demand-side criteria:

1. The resource may be consumed nonrivalrously;
2. Social demand for the resource is driven primarily by downstream productive activity that requires the resource as an input; and
3. The resource is used as an input into a wide range of goods and services, including private goods, public goods, and non-market goods.

Traditional infrastructure, such as roadways, telephone networks, and electricity grids, satisfy this definition, as do a wide range of resources not traditionally considered as infrastructure resources, such as lakes, ideas, and the Internet.

The first criterion captures the consumption attribute of nonrival and partially (non)rival goods. In short, this characteristic describes the "sharable" nature of infrastructure resources. Infrastructure are sharable in the sense that the resources can be accessed and used by multiple users for multiple uses at the same time.[6]

The second and third criteria focus on the manner in which infrastructure resources create social value. The second criterion emphasizes that infrastructure resources are capital goods that create social value when utilized productively downstream and that such use is the primary source of social benefits. In other words, while some infrastructure resources may be consumed directly to produce immediate benefits, most of the value derived from the resources results from productive use rather than consumption.

The third criterion emphasizes both the variance of downstream outputs (the *genericness* of the input) and the nature of those outputs (particularly, public goods and non-market goods). The reason for emphasizing variance and the production of public goods and non-market goods downstream is that when these criteria are satisfied, the social value created by allowing additional users to access and use the resource may be substantial but extremely difficult to measure. The information problems associated with assessing demand for the resource and valuing its social benefits plague both infrastructure suppliers and consumers, where consumers are using the infrastructure as an input into the production of public goods or non-market goods. This is an information problem that is pervasive and not easily solved.

Whether we are talking about transportation systems, the electricity grid, basic research (ideas), environmental ecosystems, Internet infrastructure, or university science and technology research systems, the bulk of the social benefits generated by the resources derives from the downstream uses. Value is created downstream by end-users that rely on access to the infrastructure. Yet social demand for the infrastructure itself is extremely difficult to measure. As recognized by the National Research Council, "Infrastructure is a means to other ends, and the effectiveness, efficiency, and reliability of its contribution to these other ends must ultimately be the measure of infrastructure performance" (National Research Council, Measuring and Improving Infrastructure Performance, 1995). Despite general recognition that social demand for infrastructure is driven by downstream applications, theoretical modeling of this relationship and empirical measurement of value-creation downstream appear underdeveloped and incomplete.

2.2. An Infrastructure Typology

To better understand and evaluate these complex economic relationships, I define three general categories of infrastructure resources, illustrated in Table 1, based on the nature of the distribution of downstream activities: commercial, public, and social infrastructure.

These categories are neither exhaustive nor mutually exclusive. Real-world infrastructure resources often fit within more than one of these categories at the same time. The analytical advantage of this general categorization schema is that it provides a means for understanding the social value generated by these infrastructure resources and identifying different types of market failures.

Table 1. Typology of Infrastructure Resources.

Type	Definition	Examples
Commercial infrastructure	Nonrival or partially (non)rival input into the production of a wide variance of private goods.	1. Basic manufacturing processes 2. Cable television 3. Internet 4. Road systems 5. University Science and Technology Research system
Public infrastructure	Nonrival or partially (non)rival input into the production of a wide variance of public goods.	1. Basic research 2. Ideas 3. Internet 4. University Science and Technology Research system
Social infrastructure	Nonrival or partially (non)rival input into the production of a wide variance of non-market goods.	1. Lakes 2. Internet 3. Road systems 4. University Science and Technology Research system

2.2.1. Understanding the Outputs

When analyzing infrastructure, the outputs matter. The typology above defines three infrastructure types based on the nature of the outputs. The value of an infrastructure resource ultimately is realized by consumers of these downstream outputs. It is thus the demand for these outputs that determines demand for the infrastructure.

Private goods and public goods (pure and impure) are supplied by the market mechanism with varying degrees of effectiveness. For private goods, the market mechanism generally works very well from both the supply and demand sides, assuming markets are competitive. For public goods, the market mechanism may fail from both the supply and demand sides, even if markets are competitive. In some cases, the market may be "corrected" through institutional intervention. For example, if the costs of excluding nonpaying users are sufficiently high that undersupply is expected, legal fences may be employed to lessen the costs of exclusion and thereby improve incentives to invest in supplying the desired public goods. This is one significant role of patents, as discussed below.

"Non-market goods" refer to those (private or public) goods that are neither provided nor demanded effectively through the market mechanism.

Generally speaking, we do not "purchase" such goods (Boyle, Brown, & Champ, 2003). We may recognize their value but we simply do not rely on the market as a provisional mechanism. Instead, we rely on other provisional mechanisms, including government, universities, community, family, and individuals. Consider, for example, the preservation of certain resources, perhaps historic or environmental, for generations in the distant future. It may very well be the case that society as a whole considers such an objective to be worthwhile, but for various reasons not worth explaining in this chapter, the market mechanism simply will not accurately measure or respond to societal demand for preservation of this sort. The same can be said for active participation in democratic dialogue, voting, free speech, society-wide education, redistribution of wealth to aid those in need, etc. Many of the things we strongly value (and thus demand) are non-market goods.[7]

From the demand side, the important distinction between these outputs – what distinguishes non-market goods from public goods – is the means by which they create value for society. The value of public goods is realized upon consumption. That is, upon obtaining access to a public good, a person "consumes" it and appreciates benefits (value or utility). The production of public goods has the potential to generate positive externalities. Whether the benefits are external to production depends upon the conditions of access and whether the producer internalizes the full value realized by others upon consumption, which often depends upon the effectiveness of exclusionary fences, legal, technical, or otherwise.[8]

By contrast, the value of non-market goods is realized in a more osmotic fashion and not through direct consumption. Non-market goods change environmental conditions and social interdependencies in ways that increase social welfare. Take, for example, active participation in democratic dialogue or education. While participants may realize direct benefits as a result of their activity, non-participants (non-consumers) also benefit – not because they also may gain access to the good (dialogue or education), but instead because of the manner in which dialogue or education affect societal conditions. For example, active participation in online discussions regarding political issues such as the Iraq war and the 2004 election benefit participants as well as those who never log onto the Internet.

In sum, the production of public goods has the potential to generate positive externalities for nonpaying consumers (incidental beneficiaries or free-riders), and the production of non-market goods generates diffuse positive externalities, often realized by non-participants or non-consumers.

2.2.2. Commercial Infrastructure

Commercial infrastructure resources are used to produce private goods. Consider the examples listed in the Table above. Basic manufacturing processes, such as die casting, milling, and the assembly line process, are nonrival inputs into the production of a wide variety of private manufactured goods. Basic agricultural processes and food processing techniques similarly are nonrival inputs into the production of a wide variety of private agricultural goods and foodstuffs. Many commercial infrastructure resources are used productively by suppliers purely as a deliver mechanism for manufactured goods, agricultural goods, foodstuffs, and many other commercial products. A cable television system, for example, acts as an input into the delivery of digital content purely for consumption by an end-user (e.g., a cable customer). Content providers use the infrastructure to provide a private service to the consumer (delivery of content for consumption) under conditions that render the output rivalrous and excludable. At least in theory, a wide variety of content suppliers can deliver a wide variety of content under such conditions. The Internet and road systems, similarly, are used by a wide range of suppliers to deliver private goods and services.

For pure commercial infrastructure, basic economic theory predicts that (1) *competitive* output markets should work well and effectively create demand information for the input; (2) market actors (input suppliers) will process this information; and (3) satisfy the demand efficiently.[9] Simply put, for commercial infrastructure, output producers should fully appropriate the benefits of the outputs (via sales to consumers) and thus should accurately manifest demand for the required inputs in upstream markets. Therefore, with respect to demand for commercial infrastructure, the key is maintaining competition in the output markets, where producers are competing to produce and supply private goods to consumers. Competition is the linchpin in this context because the consumptive demands of the public can best be assessed and satisfied by competitive markets.

2.2.3. Public and Social Infrastructure

Public and social infrastructure resources are used to produce public goods and non-market goods, respectively. For much of the analysis that follows, I have grouped public and social infrastructure together because the demand-side problems generally take the same form.

For both public and social infrastructure, the ability of competitive output markets to effectively create and process information regarding demand for the nonrival input is less clear than in the case of commercial infrastructure. Competitive output markets will not necessarily work well in generating demand information for the required inputs in upstream markets.

Infrastructure users that produce public goods and non-market goods suffer valuation problems because they generally do not fully measure or appropriate the (potential) benefits of the outputs they produce and consequently do not accurately represent actual social demand for the infrastructure resource. Instead, for public and social infrastructure, "demand [generated by competitive output markets will] tend[] to reflect the individual benefits realized by a particular user and not take into account positive externalities" (Frischmann, 2001, p. 51). As I noted in an earlier article

> To the extent that individuals' willingness to pay for [access to infrastructure] reflects only the value that they will realize from an [output], the market mechanism, … will not [fully] take into account (or provide the services for) the broader set of social benefits attributable to the public goods[, non-market goods] and network externalities. [Infrastructure consumers] will pay for [access to infrastructure] to the extent that they benefit (rather than to the extent that society benefits) [from the outputs produced] (Frischmann, p. 66).

Difficulties in measuring and appropriating value generated in output markets thus translates in a valuation/demand measurement problem for infrastructure suppliers.

To make matters even more complicated, for some, though not all, infrastructure resources, and particularly those that act as inputs into cumulative production processes, there may be considerable uncertainty as to what types of downstream applications may arise in the future. Prospective uncertainty can exist along various dimensions that affect investment and management decisions (Scotchmer, 1991). Such uncertainty complicates decision making and raises transaction costs (e.g., costs associated with identifying and dealing with future contingencies). Moreover, market actors may be averse to uncertainty itself. All of these factors suggest that competitive output markets may fail to accurately manifest social demand for public and social infrastructure because of the presence of demand-side externalities.

Moreover, to the extent that infrastructure resources can be optimized for particular applications, which is often the case, there is a risk that infrastructure suppliers will favor existing or expected applications. More importantly, to the extent that infrastructure suppliers take cues from market actors downstream, there is a related risk that infrastructure suppliers will favor applications that generate appropriable benefits at the expense of applications that generate positive externalities.

Even putting aside the generation and processing of demand signals, it remains unclear whether markets will operate efficiently with respect to the supply of public and social infrastructure. There may be significant transactions cost problems that may hamper markets. For example, transaction costs associated with price setting, licensing, and enforcement (may) increase as the variance of public good and non-market good outputs increases.

3. UNIVERSITY SCIENCE AND TECHNOLOGY RESEARCH SYSTEMS AS INFRASTRUCTURE

To this point, I have introduced my demand-side theory of infrastructure, which is developed in significantly more detail elsewhere. In this part, I contend that "university science and technology research systems" constitute infrastructure within the meaning of this theory. (I focus on the concept of a university science and technology research system, although much of the analysis that follows can be applied to the university system on the whole.)

3.1. University Science and Technology Research Systems

A university science and technology research system is a system of productive resources aggregated within a university setting and used to produce a stream of research-related outputs.[10] The system is comprised of at least five different sets of related, complementary resources, including:

1. *human capital*, including complementary networks of people (professors, researchers, students, administrators, technicians, and other support staff);[11]
2. *governance capital*, such as rules, norms, policies and other collective constraints that guide system participants' behavior;
3. *physical capital*, such as land, facilities and equipment;
4. *intellectual capital*, such as knowledge, information, and ideas;[12] and
5. *financial capital*.

Each of these capital resources is an essential component of the system, although the bundle of such resources and manner in which they are bundled varies considerably across universities. I have referred to the various components of the system as *capital* because, aggregated together within a university, these resources are used collectively and continuously as inputs into a variety of production processes, including research, education, training, and socialization, among others.

These production processes yield a wide variety of research-related outputs, which can be grouped into two major categories – intellectual capital and human capital. Intellectual capital outputs[13] are the intangible information goods, essentially the research results, which may or may not be embedded in some artifact (e.g., equipment design), be fixated in some tangible form (e.g., written down), or simply reside in the minds of researchers. Generally, when we refer to "science," "research," "invention," "innovation," "technology," and so on, we are talking about various types of intellectual capital that are outputs from some intellectual process. These outputs are public goods with varying potential to yield positive externalities (or conversely, appropriable benefits) when utilized productively further downstream. The types of downstream uses may vary considerably (Frischmann, 2000).

Equally, if not more important than pure intellectual capital outputs – *research results* – are human capital outputs – *people with (a) higher levels of education, knowledge, experience, and research-oriented skills (b) who are prepared for entry into the research community.*[14] The importance of human capital outputs is well-understood. Many commentators, such as Richard Florida (1999), have emphasized the critical role of U.S. universities in educating and training (graduate) students – in creating "talent" that fuels the knowledge economy. Education, knowledge, experience, and research-oriented skills must be absorbed by students and consequently often are standard (in contrast with the cutting edge nature of the research result outputs). Once absorbed through the processes of research, education and training, the intellectual capital residing within the university science and technology research system is disseminated and shared. Thus, research-oriented education, knowledge, experience, and skills may be viewed as forms of intellectual capital that are disseminated to students and used productively to augment their human capital. As David Audretsch and Max Keilbach (2005) explore in their chapter in this volume, entrepreneurship may serve a very similar knowledge-dissemination (or spillover) function.

Both intellectual and human capital outputs are inputs that generate value when used productively downstream. As Fig. 2 illustrates, "downstream" use of these outputs may entail use in further research (internally or externally) or use in commercialization processes (internally or externally).

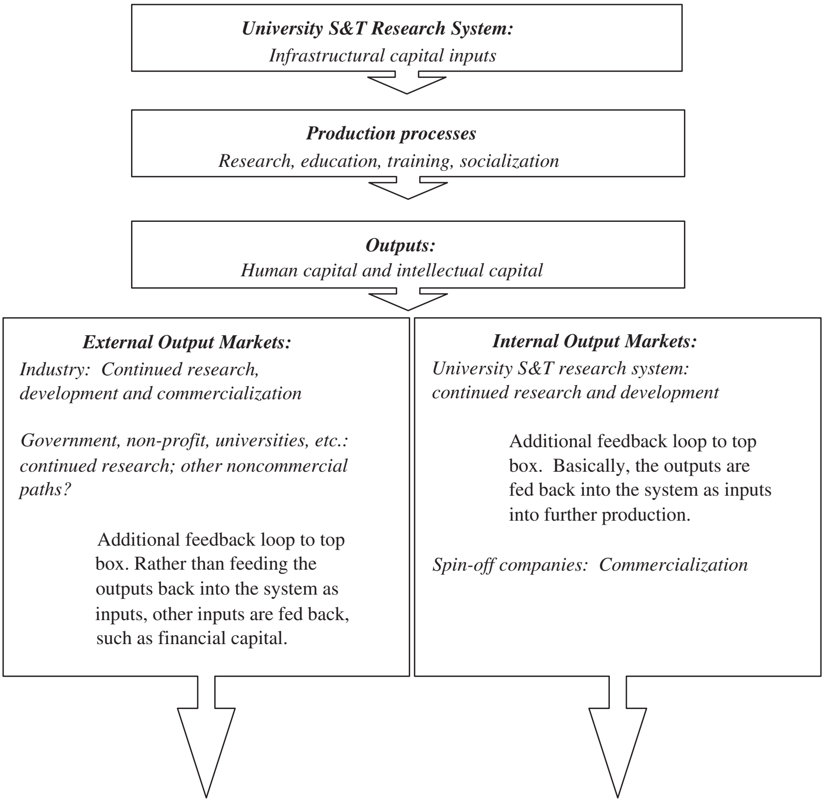

Fig. 2. Simple View of University Science and Technology Research System, Its Outputs, and the Downstream Markets for Outputs.

For the most part, then, universities are "vertically integrated" with respect to the production of research systems and research-related outputs; some outputs are consumed internally while others are consumed externally. The manner in which the outputs are used depends, of course, on the nature of the specific outputs.

Viewed as an integrated system of complementary resources that generate value primarily when used to produce a stream of research-related outputs, the university science and technology research system begins to look like other forms of infrastructural capital.

3.2. University Science and Technology Research Systems as Mixed Infrastructure

University science and technology research systems meet all three demand-side criteria for infrastructure. The systems are "sharable" goods in the sense that multiple users may access and use the system resources to engage in productive processes and produce research-related outputs. Some components of the system have infinite capacity (i.e., are purely nonrival in consumption) – such as intellectual and governance capital – while others have finite capacity (i.e., are rival in consumption) – such as physical, financial, and human capital. It is the scarcity of these latter types of capital resources that drives both competition for funding and prestige and resource allocation decisions. As discussed below, to some extent, the rivalrousness of the system puts pressure on universities to optimize the system for commercial outputs because the appropriable benefits (revenues) generated by such outputs may provide the resources necessary to sustain the system. (More on this dynamic below.)

University science and technology research systems – like road systems, basic research, the Internet, and many other infrastructures – are socially valuable primarily because of the productive activity they facilitate downstream (Frischmann, 2005). In other words, the value created by these research systems is only realized when the research-related outputs are used downstream; essentially, the "value added" is embedded in the outputs. Accordingly, to fully understand the social demand for this type of infrastructure and to assess how well demand signals "manifest" upstream, it is necessary to evaluate the output markets in terms of the nature of the outputs produced, the extent to which such outputs generate (non)observable and (non)appropriable value, and the manner in which value is distributed (e.g., is value realized only by consumers or are there external benefits to nonconsumers) (Frischmann, 2005).

Most university science and technology research systems can be classified as *mixed* commercial, public, and social infrastructure that enable the downstream production of a wide variety of private, public, and non-market goods. As a general matter, university science and technology research systems do not directly yield private goods for commercial markets (except to the extent that one takes the view that human capital outputs constitute rival goods consumed in the labor market), although these systems generate human and intellectual capital that may be used externally to produce such goods.

University science and technology research systems produce a wide array of public and non-markets goods that generate (or have the potential to generate) significant positive externalities. This should not be a controversial point. It is important to realize, however, that the human and intellectual capital outputs of these systems have varying potentials to yield positive externalities (and, conversely, appropriable benefits). This variance can be understood in a few ways. For a moment, put aside human capital outputs and focus on intellectual capital outputs – research results that are pure public goods. The research results may vary in terms of their genericness-specificity with respect to applications downstream – that is, they may vary along the basic to applied continuum. The research results also may vary in terms of the classes of applications – for example, commercial, private goods production or noncommercial research. Both types of variance affect the potential for positive externalities (and appropriable benefits).

Human capital outputs also may exhibit variance in the potential to generate positive externalities. To see how, consider the various production processes within the university science and technology research system that "produce" human capital outputs – specifically, research, education, training, and socialization.

As a general matter, most universities do not allocate their infrastructural capital on the basis of commercial prospects in output markets. As Auerswald and Branscomb (2003) note, researchers tend to allocate their resources according to their "*interest* in the question posed" which "contrast[s] sharply with a decision rule based on commercial potential."[15] Consequently, the range of outputs from university science and technology research systems has not historically been weighted more heavily toward commercial research. Of course, that is not to say that universities have not made significant strides in the realm of commercial research, but rather commercial applications have not generally been a central objective or priority. Put another way, industry demand for commercializable research has not driven universities' resource allocation decisions.

By the same token, historically, government funding has not been directed explicitly toward specific commercial ends; if it were, the justification for government intervention into the market would be quite weak (Frischmann, 2000). Yet, at times, government funding has yielded research with commercial applications, and, as the history behind the Bayh-Dole Act tells us, such research (allegedly) was underutilized. To solve this problem of underutilized government-funded research, intellectual property took on a new role, to which I now turn.

4. THE ROLE OF PATENTS IN THE UNIVERSITY RESEARCH CONTEXT

There are many competing theories, justifications, and explanations for the existence of intellectual property law. The dominant economic justification for patents outside the university research context is that granting patents over inventions provides the necessary incentive for private investment in creating the inventions in the first place; call this the *reward theory*. Information resources face the well-known supply-side problem, common to public goods: the inability to (cheaply) exclude competitors and nonpaying consumers (free-riders) presents a risk to investors perceived *ex ante* (prior to production of the good), which *may* lead to undersupply[16] (Lemley, 2005). Essentially, in the absence of patent law, there would be a significant underinvestment in invention because of the risk that competitors would appropriate the value of the invention. Granting inventors patents lessens the costs of exclusion, raises the costs of free-riding, encourages licensing, and, as a result, makes a greater portion of the surplus generated by the invention appropriable by the inventor.

In the university research context, patents have these same effects, but where research is funded by government, the economic justification is quite different.[17] Simply put, awarding patents for government funded research is premised on the notion that patents are necessary to facilitate post-patent research, development, and commercialization (Kieff, 2001); call this the *commercialization theory*. That is, in the absence of patents, government-funded research results would languish underutilized – underdeveloped and undercommercialized – because (1) the researchers and their host institutions lacked the incentives and capacity to further develop and commercialize the research or to transfer the research results to industry, and (2) even if transfer was feasible, industry lacked sufficient incentives to invest in development and commercialization without the exclusivity made available by patents in the form of exclusive licenses. Elsewhere I have questioned the strength of these arguments and argued that the classes of research results for which these arguments justify patents may be quite limited. Rather than rehash the arguments and counterarguments, which as noted in the introduction are the subject of continued debate, let me instead assume for purposes of argument that the federal policy of allowing federally funded researchers to patent the research results is warranted. After all, as also noted earlier, the law only encourages and enables, but does not require, university patenting and participation in commercialization.

Most analyses of the role of patents in the university research context focus on the exclusivity of patents: that is, *the benefits of exclusivity* – increased appropriation of surplus; increased technology transfer, licensing, and related transactions; increased commercialization; and so on; and *the costs of exclusivity* – deadweight losses, increased transaction costs, patent thickets, and so on. It is important to keep in mind that the benefits and costs of exclusivity are felt differently by different constituencies within a university and thus may lead to internal conflicts.

Exclusivity is a supply-side concern that is relevant to assessing how well markets will function.[18] Patents improve exclusion and consequently the supply-side functioning of markets for university research results as well as those markets further downstream for derivative commercial end-products. Both the reward and commercialization theories of patent law take patent-enabled exclusivity as the relevant *means* for fixing a supply-side problem – essentially, the undersupply of private investment in the production of patentable subject matter or in the development and commercialization of patentable subject matter that would occur in the absence of patent-enabled exclusivity.

Both theories take as a given that the market mechanism will best aggregate information regarding demand for such investment. Put in a slightly different way, the argument is that private investment into the production, development, and commercialization of patentable subject matter will be allocated efficiently on the basis of expected returns in downstream commercial markets, so long as patents are available to provide the necessary exclusivity. This seems to make sense, so long as we are talking about allocation of private profit-driven investment. But what if investment is not entirely private?

What if demand for research-related outputs and the allocation of infrastructural capital to the production of such outputs is not determined accurately by the market mechanism on the basis of expected returns in downstream commercial markets? What if demand is assessed more efficiently by non-market processes – involving government, non-profits, or community organizations, for example (Frischmann, 2005; Strandburg, 2005)? What if we are talking about public or community investment rather than private investment?

As noted above, university science and technology research systems are mixed infrastructure that produce a mix of outputs, some of which may have commercial application, many of which do not. How, if at all, does the availability of patents in the university research context affect demand for university science and technology research systems?

In *An Economic Theory of Infrastructure and Commons Management* (Frischmann, 2005), I explain the concept of demand manifestation, which basically concerns how well consumer demand for infrastructure-dependent outputs translates into demand for infrastructure in the upstream market. Markets may under-represent social demand for infrastructure – a failure to accurately manifest demand – where output producers fail to observe or appropriate value in output markets. Put another way, the market mechanism exhibits a predictable bias in favor of outputs that generate observable and appropriable benefits; to the extent that infrastructure access or infrastructure capital is scarce, relying on the market mechanism to indicate demand for access or capital may lead to undersupply of socially desired outputs – specifically, public goods and non-market goods that yield positive externalities.

In the past, universities had not directed their resources toward the production of commercial outputs for a variety of reasons – public interest missions, an explicit focus on education of citizenry, the "ivory tower" metaphor and the ideal of insulation from market or government influence, and so on. Another important reason is that universities had not always been able to appropriate the benefits of commercially viable research in the absence of patent protection.

Arguably, the obstacles that patents were introduced to overcome – insufficient incentives and capacity to develop and commercialize research results – may have acted as an important buffer between the university science and technology research system and the marketplace. This is not to say that universities and industry did not interact. To the contrary, as David Mowery (2005) demonstrates, universities and industry have a long history of interactions[19] (Mowery, 2005 – this volume). Clearly, the buffer has been permeable over time, but (arguably) it may have been sufficient to insulate system management and resource allocation decisions from the demands of downstream commercial markets.

Although universities were vertically integrated in the sense that they produced both the infrastructure and the outputs, the infrastructure remained generic and the outputs remained mixed because the appropriability of surplus downstream was not a driving factor in the allocation of infrastructural capital. Introducing patents into the system, along with a host of other initiatives aimed at tightening the relationship between universities and industry, may change the dynamic in a relatively predictable manner.

Demand for university-produced commercial research manifests in market-driven transactions made possible by patents (e.g., licenses) and critically, through other university–industry relationships, such an industry sponsorship of research. This creates a demand-pull that, at the margins, may lead to the creeping optimization of the infrastructure. This is similar to the current debate over the end-to-end architecture of the Internet, although the optimization question is much more explicit and immediate in that context. In a realm of limited, scarce resources and robust competition for prestige, students, and funding, university decisions[20] about how to allocate upstream infrastructure capital to downstream production may be biased toward output markets that generate appropriable returns at the expense of those that generate positive externalities.[21]

As I argue at greater length in *An Economic Theory of Infrastructure and Commons Management* (2005), the market mechanism exhibits a bias for outputs that generate observable and appropriable benefits at the expense of outputs that generate positive externalities. This is not surprising because the whole point of relying on exclusivity – whether provided by traditional property rights or patents – and the market is to enable private appropriation and discourage externalities (Lemley, 2005). The problem with relying on the market mechanism is that potential positive externalities may remain unrealized if they cannot be easily valued and appropriated by those that produce them, even though society as a whole may be better off if those potential externalities were actually produced (Frischmann, 2005).

The market mechanism exhibits other biases as well. For instance, because private discount rates tend to be higher than social discount rates, markets tend to be biased toward the short term. Among other things, the divergence between private and social discount rates can lead to overinvestment in applied research and commensurate underinvestment in basic research.[22] Further, incumbent market actors may act strategically to preserve their market positions or to control the direction of innovation. These two biases introduce further dynamic complications associated with path dependence and the costs of changing directions once a path has been taken.

As noted previously, university science and technology research systems are inputs into the production of a wide variety of research-related outputs that are used externally and internally to produce value downstream (which may actually involve internal cycling for continued use in the university science and technology research system). There is a real risk that the biases of the market mechanism will "work their way upstream" and infect/affect university science and technology research systems. The most obvious manner in which this dynamic can be expected to operate is simply by way of upstream resource allocation – in a world of scarce resources (particularly, physical, human, and financial capital), it should not be surprising to see an emerging preference for self-supportive activities that yield appropriable benefits that are fed back into the system.

Thus, introducing patents into the university research context is not solely about introducing exclusivity (with its benefits and costs) to fix a supply-side problem – underutilization, underdevelopment, and undercommercialization of research results. Introducing patents into the university research context is also (if not primarily) about manifesting market-driven demand for university-produced research and more subtly for the infrastructural capital aggregated within university science and technology research systems.

This should not be surprising. As it has become more clear that innovation is the engine driving the economy, we should expect pressure to optimize various institutions to support innovation policy.[23] Should universities be optimized to supply innovation?[24] I think not, at least not as a matter of general public policy. As a general matter, I agree with Richard Florida's argument (1999) that an inordinate focus on innovation "misses the larger economic picture."

> Universities have been naively viewed as "engines" of innovation that pump out new ideas that can be translated into commercial innovations and regional growth. This has led to overly mechanistic national and regional policies that seek to commercialize those ideas and transfer them to the private sector. Although there is nothing wrong with policies that encourage joint research, this view misses the larger economic picture: *Universities are far more important as the nation's primary source of knowledge creation and talent. Smart people are the most critical resource to any economy, and especially to the rapidly growing knowledge-based economy on which the U.S. future rests.*

5. THE UNIVERSITY'S CHOICE

Some seem to believe that university commercialization is simply inevitable. In *Capitalizing Knowledge*, for example, Etzkowitz, Healey, and Webster (1998) claims that the "function of the university" has "irrevocably changed," that "[t]here is likely no return to an earlier era," and that "the university is changing its organization and ideology to accommodate its new role in economic development." Not only do I disagree, but I find such assertions somewhat hyperbolic and misleading.[25] Universities, like any other organization, must adapt and evolve with changing economic and social conditions, but each university must determine its own "ideology" and mission and decide on the extent to which it should participate in commercialization, entrepreneurship, and economic development.

As noted earlier, the U.S. government has made an explicit policy decision to allow funded entities to obtain patents and thereby has encouraged participation in the commercialization of federally funded research. Nonetheless, universities still must decide on the extent to which they wish to participate in the commercialization process. As a general matter, universities are not required by law to create technology transfer offices, delay or withhold publication of research results, patent research results, issue exclusive licenses, or be entrepreneurs. The Bayh-Dole Act enables universities to participate in the commercialization process, but it does not obligate or constrain them to pursue any particular strategy with respect to federally funded research. Universities remain in the driver's seat and may decide which road to take and at what speed.

There is no uniform answer for universities to the commercialization question. The extent to which universities should actively participate in patenting and commercializing research and to which a university research system should be directed toward patentable research outputs will vary considerably across universities. Some universities may have sufficient resources to resist pressure to optimize the university science and technology research system for commercial outputs; other universities may not. Some universities may in fact prefer to optimize, perhaps because of a particular university mission, a vision of the university role in the modern economy, or strategic reasons related to faculty recruitment, student recruitment, prestige, or public image. In the end, with respect to patent policy, technology transfer, commercialization, and entrepreneurship, universities have choices and face competing incentives. How to proceed depends upon the particular university's objectives for its science and technology research system. (As Don Siegel suggested at the Conference, universities must determine what their objectives are and then make strategic decisions about their degree and form of participation.)

Perhaps idealistically, I envision robust competition among universities operating on different models and pursuing different strategies, missions, and ideologies. Some universities may support mixed infrastructures while actively engaging in the commercialization process. (I suspect that the major, elite research universities fall into this camp.) Other universities may need to choose whether to optimize their science and technology research systems for commercial research outputs or to sustain a mixed infrastructure. In the various markets that universities compete (for faculty, students, government funds, etc.), different strategies may be successful.

That is, it may be the case that faculty, students, or funding agencies may look (dis)favorably on optimization. (I suspect that middle-tier and perhaps lower-tier universities fall into this camp.) I cannot offer broad prescriptions for universities regarding what strategy to pursue, but I do think it is critical that each university carefully evaluates its strategy in light of the demand-side considerations I have noted in this chapter.

Those universities that wish to preserve the integrity of their research systems as mixed infrastructure and to resist the pressure to evolve (or optimize) into commercial infrastructure need to affirmatively take steps to manage conflicts of interests, to insulate upstream decisions regarding infrastructural capital allocation (i.e., decisions that impact the allocation of the five types of aggregated capital resources to particular types of productive activities) from the demands of the marketplace, and ultimately to minimize (or eliminate) any dependence upon commercial revenues for sustaining the research system. Those universities that wish to optimize their research systems for commercial outputs should do so explicitly with a full awareness of the risks and rewards.

6. A FEW WORDS ON TECHNOLOGY TRANSFER AND ENTREPRENEURSHIP

Let me return to the overarching theme of the Conference, the relationship between patents, university technology transfer, and university entrepreneurship. Universities may execute a variety of different strategies for promoting entrepreneurship. Different strategies coincide with different degrees of participation in the commercialization process. Universities can be entrepreneurs, support entrepreneurs, and educate entrepreneurs. The basic point is that universities need not be commercial entrepreneurs in order to teach entrepreneurship or provide students with entrepreneurial opportunities and experience.

An active, entrepreneurial university may offer hands-on, practical training in entrepreneurship for students in the fields of business, science, and technology. The collective efforts necessary to commercialize university research internally require close collaboration among participants in the university science and technology research system and with university faculty, students, and administrators in other parts of the university. An interdisciplinary collective entrepreneurship program within a university setting may provide an excellent environment for commercializing research and educating entrepreneurs. Moreover, as Gary Libecap pointed out at the Conference, universities may even mitigate some of the commercialization pressures discussed in this chapter through the development of entrepreneurship education, training, and skill development.

Universities may opt to be less entrepreneurial and yet still be involved in the commercialization process. For example, universities may leave the post-patent efforts to licensees or spin-off companies – external investors, and entrepreneurs. Of course, the need to coordinate the efforts of scientists, technologists, innovators, investors, and entrepreneurs still provides ample opportunities for hands-on, practical training for entrepreneurship students.

Finally, it is worth emphasizing that entrepreneurship need not involve commercialization of technology. Universities that decide not to make commercialization a priority and instead aim to sustain their science and technology research systems as mixed infrastructure may nonetheless advance entrepreneurship education. To the extent that it is critical for universities to offer a practical/clinical component within their entrepreneurship education programs, it seems to me that those universities that decide not to focus on the commercialization of their research output may structure their programs around (1) open source, community-based enterprise projects and (2) externships with local businesses. Furthermore, as Tom Byers indicated at the Conference, even universities (like Stanford) that have pursued commercialization of research actively need not explicitly link entrepreneurship education with technology transfer.

7. CONCLUSION

The issues surrounding commercialization of university research systems are quite similar to those surrounding the commercialization of other mixed infrastructure, such as the Internet. Mixed infrastructure are similar in terms of the manner in which they generate social value and in terms of the significant pressures they face to evolve into commercial infrastructures. In some cases, such as the Internet, technological design creates a buffer that resists optimization and protects the generic nature of the infrastructure. In the case of university research systems, traditional buffers between universities and the market seem to be eroding. In this chapter, I have argued that this ought to be of significant concern to universities and society more generally because it may lead to a creeping systemic optimization of university research systems for commercializable outputs – a slow and subtle shift in the allocation of infrastructure resources, priorities, relationships, norms, and so on – dictated by the demands of downstream commercial markets. I have not argued that commercialization of research results is inherently bad or undesirable. To the contrary, such commercialization ought to be pursued when possible. It is the commercialization of university science and technology research systems – the upstream infrastructure – with which I am concerned. Nor have I argued that universities ought not participate in commercialization. On the contrary, I suggest some should. In the end, I believe universities face difficult questions about the degree to which and manner in which they participate in the commercialization process. As I noted in the introduction, to grapple with these questions, universities should step back from their immediate context, compare their situation with that of other industries and social contexts, reflect on their role in society, and proceed carefully.

NOTES

1. My teaching focuses primarily on the law while my research focuses primarily on the intersections of law, economics, science, technology, and culture.

2. In this chapter, I do not delve into the literature on institutional resource allocation, which focuses on the allocation of resources among university departments (Thomas, Slaughter, & Volk, 2001). I may do so in future work, however.

3. In his book, *MIT and the Rise of Entrepreneurial Science*, Henry Etzkowitz (2002) suggests that "reorient[ing] the universities toward a commercial role was not intervention in the sense of specific government measures requiring targeting of particular areas of R&D for support, as in Japan, or requiring enterprises and research institutes to make research contracts with each other, as in the Eastern European socialist model. Instead, incentives were built into the research-funding system to move universities closer to industry, in their motivation and structure" (Etzkowitz, 2002, p. 125). Etzkowitz is reassured that the government is not overtly intervening into academia, but fails to appreciate fully the risks of industry intervention, which I discuss below.

4. The distinction between basic and applied research can be understood by looking to the variance of the application estimate. A larger (smaller) variance in the distribution corresponds to a basic (applied) innovation, representing a wider (narrower) range of potential applications and hence greater (less) uncertainty to a specific application. [The] distinction between basic and applied research is not dependent upon the applications themselves, i.e., whether the innovation will be used to produce a public or private good. Instead, the distinction rests on the range of potential applications and the corresponding uncertainty with regard to specific applications." *Id.* at 365 (footnotes omitted).

5. This section of the paper borrows heavily from my Minnesota Law Review article (Frischmann, 2005).

6. Infrastructure resources vary in their capacity to accommodate multiple users, and this variance in capacity differentiates nonrival (infinite capacity) resources from partially (non)rival (finite but renewable capacity) resources. For nonrival resources, such as basic research, the marginal costs of allowing an additional person to access and use the resource are zero. For partially (non)rival resources, the cost-benefit analysis is more complicated because of the possibility of congestion. See below.

7. There is some similarity between non-market goods and merit goods. While non-market goods are not provided for by the market, merit goods are partially provided by the market. Merit goods are considered so beneficial to the public that any deficiency in market provision will be made up for with public provision. For example, education could be provided exclusively by the private sector. However, this would leave many children without access to education and cause a subsequent host of social problems when these children do not have the necessary skills to become productive members of society. Therefore, education is a good whose social merit has been recognized, and is therefore often provided by both the public and private sectors to insure more widespread consumption (Musgrave, 1959).

8. Consider, for example, a flower garden. A person who plants flowers in his front yard creates the potential for positive externalities that may be realized by those who walk by and appreciate their beauty. The view of the flowers is nonrival; consumption by one person does not deplete the view (or beauty) available for the other to consume. Consumption depends upon access, however, and the realization of potential externalities depends upon whether the homeowner builds an effective fence (i.e., one that would obstruct the view from the sidewalk). If the homeowner builds an effective fence, then the door has been closed and the potential for externalities remains untapped. If, on the other hand, the homeowner does not build such a fence, then people who pass by obtain access to the view, consume it, and realize external benefits.

9. With respect to the third point regarding supply of commercial infrastructure, there is significant disagreement among economists about the need for competitive input markets and the need for government intervention into various input markets. The thrust of the arguments made in that debate concern incentives, the presence of natural monopolies, strategic behavior by monopolists (infrastructure providers), and the effectiveness of government institutions, and generally focus on supply-side issues without challenging the first two points made above.

10. Of course, these resources also produce other important outputs as well, e.g., educated citizens.

11. Florida (1999) focuses on the importance of attracting and aggregating human capital within the university science and technology system as a means of improving its performance. He notes that universities must attract the ''top talent,'' referring to academic research professors, in order to attract the top graduate students. Florida (1999) emphasizes the need to shift our myopic focus on research results (e.g., university derived invention) to human capital, in terms of both human capital outputs and human capital as a component of infrastructural capital.

12. The intellectual capital category is meant to capture the full range of intangible products of the human intellect, regardless of whether the product has been fixated in a tangible medium (i.e., written down) and regardless of whether any particular entity claims ownership of the intellectual good. Intellectual capital often

overlaps significantly with human capital. For example, the idea residing in the mind of a professor is an intellectual resource while the professor is a human capital resource.

13. I recognize that the term "capital outputs" seems like an oxymoron, but it is not. It is important to realize, however, that capital goods are produced and thus are outputs of a production process, especially when evaluating streams of cumulative input–output relationships.

14. It is important to realize that socialization is an important aspect of the university science and technology research system. Students are prepared for entry into the research community, for example, by gaining familiarity with professional norms and ethics and forming relationships with members of the community. Most undergraduate or graduate students have limited real-world experience and very little (if any) experience in dealing with professionals *as a member of the professional community*. In law school, for example, we place a significant emphasis on the fact that students will be entering a profession, that they will be members of the bar, and that a host of ethical and even less formal community norms apply to members. The law school experience, in part, consists of a socialization process that prepares the students for professional membership. A very similar dynamic exists within the university research setting, although it is less explicit and less formal than in the law school setting (Strandburg, 2005). Strandburg (2005) explores the relationships between community norms and academic scientists' individual references.

15. Further, they note: "A fundamental challenge involved in taking a project from invention to innovation is accomplishing the shift from decisions based on the criterion of 'interestingness' to one based on the criterion of commercial value."

16. For a certain subset of patentable subject matter, trade secrecy or other mechanisms may provide sufficient means for appropriating surplus to attract private investment into production. For this subset, patents may be justified for a variety of reasons associated with disclosure (Strandburg, 2004).

17. I am concerned in this chapter with government-funded research. Of course, a significant amount of university research is funded through other means.

18. Excludability is relevant to a supply-side analysis of whether markets will work efficiently. (Low cost) exclusion is one key to a well-functioning market. If one can (cheaply) exclude others from consuming a resource, one can demand payment as a condition for access. If one cannot (cheaply) exclude others from consuming a resource, then the market may fail to satisfy consumer demand for the resource (undersupply) because suppliers will not be able to recoup their costs from consumers. Simply put, a producer of a good needs must exclude you from consuming the good it has produced if it wishes to charge you for access and consumption. Further, a producer of a good needs to be able to charge you for access if it wishes to recover its costs. If the costs of exclusion are high, then producers must either sink these additional costs and charge higher fees, or run the risk that consumers will "free ride" (i.e., consume the good without paying). Either route may lead to market failure. Thus, if market provision of a resource is desirable but the costs of exclusion are too high, then government intervention to "fix" the market may be appropriate.

19. Mowery shows that the trend of increased patenting behavior by universities occurred prior to 1980 and the passage of Bayh-Dole. He also suggests that while the relationship between universities and industry may have evolved (been transformed) in the past few decades, transformation should not be attributed to the Bayh-Dole Act itself (Mowery, 2005 – this volume).

20. A critical question to consider is who allocates these resources. Kathy Strandburg's (2005) paper focuses on the preferences of basic researchers and the differences between homo economicus and homo scientificus. I wonder (1) whether basic researchers are making allocation decisions (I think, no), and (2) whether it is a question of nature vs. nurture – will scientists evolve? Will changes in the environment lead to slow subtle changes in the species? Etc.

21. As discussed at the Conference, an empirical study of the allocation of infrastructure capital resources of the types identified above is needed. The datasets that would be useful include, inter alia, time spent by faculty and graduate students on different types of projects; factors in hiring, promotion and tenure of faculty; and allocation of physical capital such as labs and equipment to general purpose or dedicated commercial projects.

22. This bias influences decisions about many infrastructure resources. It can lead to overconsumption of environmental resources in the present without due regard to the costs for future generations, or to technological optimization of the Internet in favor of existing or reasonably foreseeable applications to the potential detriment of yet-to-be-developed applications.

23. In fact, innovation theory drives similar optimization debates in other infrastructure industries (Frischmann, 2005) (similar pressure to optimize the Internet infrastructure).

24. If so, how? That is, assuming that promoting innovation were our sole policy objective, it is not clear what the optimal role of universities would be. The current trend reflects one of many possibilities. Specifically, the current trend envisions universities as active participants in the post-patent commercialization process, and critically, in the part of the process that bridges the gap between invention and innovation. Bridging this gap is critical to the commercialization process and, as Auerswald and Branscomb (2003) have argued, a bridge may be collectively built by university researchers, entrepreneurs, venture capitalists, and other interested parties in a sort of collective entrepreneurship. Of course, building bridges consumes resources. Perhaps universities would better serve innovation policy by focusing further upstream on the wide variety of inputs necessary for innovation, including both intellectual and human capital.

25. Similarly, in *Entrepreneurial Science: The Second Academic Revolution*, Henry Etzkowitz and Andrew Webster claim that "universities are undergoing a 'second revolution.'" I suppose I might be willing to agree if I also were willing to conclude that the broader commercialization, privatization, and deregulation movement were part of an inevitable revolution as well. But I do not. Universities (and society more generally) should seriously evaluate such developments (and attendant claims of inevitable revolution) and not succumb to the dominant economic mindset without question. See Croissant and Restivo (2001). ("From the early 1980s through the present, commercialization of research has been a consensus policy: Not a natural

"evolution" of research and development practices, but a conscious reprioritization by a broad coalition of actors.")

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PROS AND CONS OF FACULTY PARTICIPATION IN LICENSING

Jerry G. Thursby and Marie C. Thursby

ABSTRACT

In this chapter we provide a general overview of the university licensing process and its dramatic growth over the past decade. We then discuss the role faculty play in commercialization through the licensing process. Concerns have been voiced in recent years over the possibility that the recent growth in university licensing suggests that the traditional role of faculty in the generation of "basic" research results – as well, possibly, as their role in "open science" – has been compromised. We discuss the available evidence for this downside to faculty licensing. Finally, we consider several impediments to the licensing process.

1. INTRODUCTION

The importance of university research for industrial innovation is widely accepted – so much so that any changes in the research environment tend to spark controversy. The recent increase in university licensing is no exception. Since 1980, the Bayh-Dole Act has allowed U.S. universities to own and license results from federally funded research. License-related activity

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has increased dramatically in the last decade and has prompted recent Congressional review of the Act. Central to the debate is faculty behavior. Proponents of licensing argue that without the incentives it provides, neither faculty nor companies would undertake the development needed for many results of federally funded research to be transferred to industry. Critics claim that publication would be sufficient for transfer and, more importantly, that potential financial returns from licensing divert faculty from more basic to applied research.

Much of our own research on university industry technology transfer examines these conflicting aspects of faculty participation in licensing. In this chapter we review this line of research, focusing first on the pro side – that is, the apparent need for faculty involvement, not only in recognizing when their research has commercial potential, but also in development toward commercialization. We then discuss the con side – the extent to which faculty involvement with licensing compromises a traditional research agenda. Finally, we consider several impediments to the licensing process involving faculty.

In Section 2, we provide a general overview of the university licensing process and its dramatic growth over the past decade. In Section 3, we discuss the role faculty play in commercialization through the licensing process. In Section 4, we turn to a discussion of concerns voiced over the possibility that the recent growth in university licensing suggests that the traditional role of faculty in the generation of "basic" research results – as well, possibly, as their role in "open science" – has been compromised. Finally, in Section 5, we consider several impediments to the licensing process.

Throughout this chapter we cite results from two surveys we conducted. The first is a survey of 112 industry-based licensing executives of companies that either licensed-in university inventions or sponsored university research. Details on the survey are found in Appendix A. The second is a survey of technology licensing professionals in the technology transfer offices (TTOs) of 62 U.S. universities. Details on the survey are found in Appendix B.

2. UNIVERSITY LICENSING: A DESCRIPTIVE VIEW

2.1. The License Process

The license process begins with a faculty member reporting a discovery that she believes has commercial potential. This report, or disclosure, is made to the university's TTO and provides information on the invention and inventors, funding sources, potential licensees, and barriers to patent potential, such as prior publication.

It is important to realize that invention disclosures represent a subset of university research with commercial potential. The TTO personnel interviewed in our university survey indicated that they think less than half of all faculty inventions with commercial potential are disclosed to their office (Thursby, Jensen, & Thursby, 2001). In some cases, faculty may not realize the commercial potential of their ideas. But often they do not disclose inventions because they are unwilling to risk delaying publication in the patent and license process. In our industry survey we found that 27% of university licenses include clauses that allow for deletion of information, and 44% allow for publication delays (Thursby & Thursby, 2003). The average publication delay is nearly 4 months, and some firms can ask for as much as a year's delay.

Faculty who specialize in basic research may not disclose because they are unwilling to spend time on the applied research and development that is often needed for businesses to be interested in licensing university inventions.[1] Finally, some faculty may refuse to disclose for "philosophical" reasons related to their notions of the proper role of academic scientists and engineers. Thus, for a variety of reasons, the TTO personnel we interviewed indicated that one of their major challenges was obtaining faculty disclosures.

Once an invention is disclosed, the TTO evaluates patent and commercial potential. From our earlier survey, it is clear that many universities apply for patents only when they expect to find licensees easily. Mowery and Ziedonis (2002) note that 6 years after disclosure, slightly more than 20% of disclosures at Stanford and the University of California system have patents. Of course, many inventions, such as copyrightable software and reagent materials, are not eligible for patent protection. If it is believed that the invention has commercial potential, the TTO then attempts to find a licensee. We note that the process of finding a licensee is quite varied, with faculty often directly involved in finding licensees (see below). Further, the research leading to the discovery may have been funded by a firm that has right of first examination of inventions resulting from the research. In addition, firms often actively seek products and processes from universities.

2.2. Invention Characteristics

According to our university survey, disclosures tend to be concentrated in science (22% on average), engineering (29%), and medicine (33%).

Respondents claim that only 40% of disclosures lead to licenses, and less than half of these ever generate income. In the 2000 Association of University Technology Managers (AUTM) survey, 163 institutions reported 19,385 active licenses; of these, only 8,531 (44%) had generated licensing income in that year. In our survey, we asked for the percentage of total licensing income generated by the top five income generating licenses. The average for the 53 responding institutions was 76%.

These statistics are hardly surprising since university inventions tend to be embryonic. Respondents to both our university and industry surveys noted that, respectively, 88% and 84% of licensed university inventions require further development and that, respectively, 45% and 44% of licensed inventions are no more than a "proof of concept" at the time of license (Thursby et al., 2001; Jensen & Thursby, 2001; Thursby & Thursby, 2002). The firms noted that for such inventions, faculty cooperate in further development more than 40% of the time. Only 7% of licensed-in technologies were deemed ready for practical or commercial use.

The business survey also provides evidence on the failure rate of university inventions licensed-in. Forty-two percent of the firms that licensed-in university inventions indicated that these inventions had a higher failure than non-university licensed-in technologies, while only 11% reported a lower rate.[2] Those who noted a higher failure rate reported, on average, that 48% of their university licenses were for technologies that were only a proof of concept; all others reported only 31% to be in a proof of concept stage (these percentages are significantly different at a 5% level). Further, the correlation between the reported failure rate and the fraction of licenses that are in a proof of concept stage is 0.31 (significant at a 1% level) while the correlation with the fraction that are ready for practical or commercial use is −0.23 (significant at the 10% level).

On average, 47% of the time that an invention failed, the reason given was failure of the technology, and 26% of the time the reason was the need for a longer time to market than had been expected. Not surprisingly, these reasons are more closely associated with early than with late-stage technologies. We also found that that 18% of the time respondents felt that a faculty failure was associated with failure of the licensed technology.

The survey also provided information on the licensee's use of the inventions licensed-in. Fifty-two percent of the university inventions licensed-in were used in new product development, and only 9% were used for process improvement. Twenty-four percent of the licenses were for research tools, and 18% were for platform or core technologies. Given concerns that firms license inventions not to develop them but to prevent rivals from doing so, it is interesting that few respondents indicated that the licenses were to prevent a rival from licensing the technology. The latter follows, we believe, from the fact that university technologies are so embryonic that few firms show interest in a given technology. In our survey of university TTOs (Jensen & Thursby, 2001; Thursby et al., 2001) we asked about the frequency of bidding on a technology by more than one firm. Forty-four percent said this occurred rarely or never, and 51% indicated it only occurred sometimes. Since it is rare that more than one firm shows an interest in a particular technology, it should follow that few firms license-in order to prevent a rival from licensing that technology.

We compared the purpose of university technologies with the fraction of university licenses in various stages of development. Of particular note is the relationship between technologies for process improvement and stage of development. Process improvement is negatively and significantly related to proof of concept (−0.178, significant at the 10% level) while it is positively and significantly related both to manufacturing feasibility known (0.324, significant at the 1% level) and ready for practical or commercial use (0.18, significant at the 10% level). In other words, process improvement tends to be late stage. Other purposes of university inventions are not correlated with stage of development.

Finally, we asked about problems significant enough to prevent the firm from licensing early stage technologies. The most important reason relates to the firm's market niche – this is cited by 51% of the respondents. The next two major reasons relate to funding problems; internal funding problems are cited as being of greater importance (29%) than are external funding problems (10%). We considered whether external funding problems were cited by small companies more often than for large companies. We used an employee size of 100 as our cut point, but we found no significant difference. The final choices given to respondents relate to either necessary scientific expertise from either in-house staff or from faculty, and neither issue was of substantial importance to our respondents.

2.3. Growth in Licensing

Annually since 1991, the AUTM has collected license data from universities. For the 84 U.S. institutions responding to the AUTM survey in both 1991 and 2000, the number of inventions disclosed by faculty increased 84%, the number of new patent applications filed increased 238%, the number of license and option agreements executed rose to 161%, and royalties increased more than 520% (in real terms). In 2000, 168 U.S. institutions reported 12,075 invention disclosures, 4,049 licenses executed, and 6,135 new patent applications. Further, 165 institutions reported $169 million in cashed-in equity and $1.3 billion in income.[3]

3. THE ROLE OF FACULTY

3.1. Overview

Faculty are arguably the most critical element in the commercialization of university–industry licensing. Without faculty there would be no university inventions to license. To end here any discussion of their role in licensing, however, would be shortsighted, as recent research points to faculty involvement well beyond simply disclosing research, with faculty often identifying licensees and working with licensees in further development (see, e.g., Agrawal & Henderson, 2001; Colyvas et al., 2002; Jensen & Thursby, 2001; Lowe, 2002; Thursby et al., 2001; Thursby & Thursby, 2002).

Understanding the nature of this involvement is important for understanding how technology is transferred through licensing, in addition to more controversial issues, such as the importance of licensing in the transfer process. Some critics of university licensing argue that licensing is unnecessary. The argument follows that if the faculty disseminate their research through publication, the staff of R&D-intensive companies can pick up and use inventions without licensing. But to the extent that faculty know-how is important in development, a simple reading of the relevant literature is not always sufficient for commercialization of university research.

It is not surprising, therefore, that the role of faculty has been the focus of recent research on university-to-industry technology transfer. Thursby et al. (2001) provides evidence from our university survey to suggest that the majority of inventions licensed are so embryonic that successful commercialization depends critically on faculty participation in further development. Jensen and Thursby (2001) examine the incentive problems associated with obtaining faculty participation. If faculty have a taste for academic research, as is suggested by Levin and Stephan (1991), Jensen and Thursby (2003), and Jensen, Thursby, and Thursby (2003), then license payments tied to commercial success, such as royalties or equity, are important to attract them to work on commercial development. Thursby, Thursby and Dechaneaux (2004) provides additional evidence that milestone payments are important in providing incentives for faculty to continue with development efforts after a license is signed.[4] Lach and Schankerman (2003) provide empirical support for the view that faculty disclosure of inventions is positively related to their share of license revenue from their inventions.

3.2. Faculty Involvement

As noted earlier, recent research on university licensing shows that faculty are often involved in the license process well beyond disclosure. Respondents to our survey of university TTOs estimated that 71% of the inventions they licensed could not be successfully commercialized without faculty cooperation in further development. In this section we discuss this role, and the faculty role in identifying potential licensees.

3.2.1. Identifying Licensees

Jansen and Dillon (1999) report a substantial role for faculty in providing leads to the TTO regarding potential licensees. They report that 56% of the primary leads for over 1,100 licenses, executed at five universities and one national lab, were inventors. This is consistent with evidence from our business survey as to how licensing firms found university inventions of interest. Using a 5-point Likert scale, we asked respondents about the importance of six methods for identifying university technologies. The questions and responses are found in Table 1. A "Don't know" category was included in our question but is excluded from the table. Note a similarity in responses across the questions concerning publications, patent searches, and presentations at professional meetings; at any conventional level of significance the responses are not significantly different, however, each is significantly different from each of the remaining three responses. Further, responses to "Marketing efforts …" and "canvass universities …" are not significantly different at conventional levels of significance.

What stands out is the extreme importance of personal contacts between the firms' R&D staff and university personnel. These responses are significantly different at all conventional levels from the responses for each of the other sources. Since the most likely university contacts are faculty inventors, this result underscores the central role that faculty, who are the ones most familiar with the technology, play in the transfer of technology *after* an invention is made. We argue that this pivotal role of the faculty follows in large part because of the embryonic nature of most university technologies; the potential markets for embryonic technologies are unclear, as are the identities of firms that might profit from licensing those inventions.

Table 1. Industry Sources for University Licenses.

	Extremely Important	2	3	4	Not Important
Journal publications	19.6	31.4	31.4	13.7	3.9
Patent searches	24.0	33.0	24.0	10.0	9.0
Presentations at professional meetings	13.1	37.4	31.3	16.2	2.0
Marketing efforts by the university's technology transfer office	12.0	15.0	23.0	26.0	24.0
Personal contacts between our R&D staff and university personnel	45.7	31.4	14.3	2.9	5.7
Our licensing staff routinely canvass universities	9.3	19.6	16.5	24.7	29.9

We can characterize the results in Table 1 as suggesting that mechanisms for identifying technologies fall into three categories: (1) reading journal publications, making patent searches, and attending scientific presentations, which are indirect efforts in that they do not involve any personal contact with university personnel; (2) direct efforts either by the university TTO via marketing, or firms via routine canvassing, and (3) one-on-one approaches based on personnel contacts. The latter efforts are the most important, with indirect efforts second in importance.

3.2.2. Faculty Involvement and Stage of Development

The common reason stated for faculty involvement in further development is the early stage in which most university inventions are licensed (Colyvas et al., 2002; Jensen & Thursby, 2001; Thursby et al., 2001). In our industry survey we were able to investigate this in more detail by asking respondents the percentage of time that faculty are involved in further development for licensed inventions in each stage of development at the time of license. For technologies in the earliest stages of development, respondents indicated frequent faculty involvement. For technologies that are only a proof of concept, or for which a lab scale prototype is available, faculty are used 55% and 54% of the time, respectively. Faculty are used much less frequently in later stage technologies. For technologies which are ready for use, or for which manufacturing feasibility is known, respondents indicated that faculty were used 15% of the time (same for both stages).

We asked respondents who viewed faculty as important for further development why they viewed them as such. The most important reason given is specialized knowledge of faculty (66%), whereas only 17% noted that faculty development was cheaper than in-house development.

When faculty are used for further development of the technology, firms either use sponsored research agreements or consulting arrangements. Forty-six percent of the time sponsored research is used, whereas consulting is used 63% of the time. Finally, when a decision is made not to license-in a technology, a firm might nonetheless decide to sign a sponsored research agreement for further development of the technology. We find that signing a sponsored research agreement in lieu of a license is a common practice, particularly for early stage technologies. When technologies are only a proof of concept, firms sponsor research 21% of the time. For lab scale prototypes the response was 23%.

4. THE DOWNSIDE TO FACULTY INVOLVEMENT IN COMMERCIALIZATION

In Section 2.3 we note the dramatic growth in university licensing over the last decade, and in Section 3.2 we discuss the role faculty play in the process beyond their inventive activity. This increase in licensing, along with the need for faculty input, has led to controversy over whether faculty have been diverted from their primary duties in education and basic research. As evidence we note the cover story of the March 2000 *Atlantic Monthly* magazine, which made reference to the "kept university." As well, the National Academy's Committee on Science, Technology and Economic Policy has asked whether licensing has gone too far in diverting faculty. In this section we cite three sources of evidence that shed light on this issue. The first is evidence from our industry survey on their perspective as to whether growth in licensing has stemmed from faculty changing the nature of their research, or whether it has followed from greater willingness of universities to engage in licensing. In the second we formally model university licensing as a multi-stage process (as discussed in our background discussion of the licensing process in Section 2.1). Using the AUTM data within this formal model allows us to use non-survey data to ask about the sources of licensing growth. Finally, we consider the research and disclosure behavior of 3,342 faculty at six major research university over a period of up to 17 years. With that data we can make a comparison of the research behavior of those who do not engage in commercialization via disclosures with those who do engage in the process.

4.1. Survey Evidence on Sources of Growth in University Licensing

In our survey of industry licensing executives we sought to uncover reasons behind the growth in university licensing. We started with a question as to whether contractual agreements (license, option, and/or research agreements) with universities had increased, decreased, or stayed about the same over the 5-year period preceding our survey (1993–1997). Of the 106 answering this question, 50% indicated an increase, while only 16% indicated a decrease. The remaining 34% said there had been no change in contractual agreements. For those indicating an increase, license agreements had increased by 86% in 1997, compared to the average of the preceding 4 years, and research funding to universities doubled. On average, each of these firms executed 13 licenses per year over the period 1993–1997 and provided $13.2 million in sponsored research with U.S. universities.

We then asked respondents whether there were reasons for the changes. Since so few firms indicate a decrease (only 17 firms), we concentrate on the firms that noted increasing contractual arrangements. Respondents were given five reasons for increasing contracts (in addition to an "other" category) and were asked to indicate importance using a 5-point Likert scale from "Extremely important," which we coded as a 1, to "Not important," which we coded as a 5; a "Don't know" response was permitted. Results are in Table 2. The first three reasons relate to university characteristics, including the nature of faculty research, while the last two relate to changes in corporate R&D. What stands out is the greater importance attached to university receptivity than either costs or faculty research orientation: three times as many respondents recorded a 1 for "universities' receptivity" as recorded a 1 for "costs" or for "faculty orientation." Further, a change in "reliance on external R&D" is more important than either "costs" or "faculty orientation." Of course, the firms' "reliance on external R&D" could change for reasons other than internal factors; for example, it could relate to university factors. To examine this possibility, we computed the simple correlation between individual respondent answers to the "reliance on external R&D" question and the "costs," "faculty orientation," and "universities' receptivity" responses. The only significant correlation is between R&D and "costs;" the correlation is 0.49, suggesting that to the extent

Table 2. Reasons for Increased Contacts.

	Extremely Important	2	3	4	Not Important
Cost of university research	10.9	19.6	30.4	10.9	28.3
Faculty research is more oriented toward the needs of business	10.6	21.3	27.7	19.1	21.3
A change in universities' receptivity to licensing and/or research agreements	29.2	27.1	20.8	10.4	12.5
A change in our unit's reliance on external R&D	20.8	37.5	10.4	14.6	16.7
A change in the amount of basic research conducted by our unit	18.4	22.4	20.4	14.3	24.5

reliance on external R&D is related to university characteristics, it is the cost of university research that is important.

Our results indicate that the major cause of increased university licensing – at least from the perspective of industry – lies with university receptivity rather than faculty research orientation. Nonetheless, one can argue that the number who noted the importance of a change in faculty orientation signals a problem. For more on this issue see Thursby and Thursby (2002).

4.2. A Production Analysis of the Sources of Growth in University Licensing

In Thursby and Thursby (2002) we consider further this issue of the sources of growth in university licensing by estimating a three-stage production process of outputs related to inputs. This process mirrors the one outlined in Section 2.1. The first stage is one in which disclosures are generated. Inputs to this stage are the number of university licensing professionals and faculty, research funding, and what we call the "propensity," or willingness of faculty to be engaged in the licensing process.[5] Once an invention has been disclosed, the university then makes a determination whether to patent. The inputs to this patenting stage include the disclosures from the first stage, the number of university licensing professionals, the quality of the faculty, and the "propensity" of the university's central administration to engage in licensing via the patenting process. The final stage of the process is the one in which a license is signed. Inputs to this stage are the disclosures and patents from the first two stages, the number of university licensing professionals, the quality of the university's faculty, and the "propensity" of the licensing professionals in finding licensees. This latter propensity is both a measure of the effectiveness of the university technology professionals, and the willingness of industry to sign contracts.

In each of the three stages all variables are observable, with the exception of the three propensities. The data on faculty size and quality are from the National Research Council (NRC, 1995), and the remainder are from the annual AUTM surveys. Our approach is to estimate the three stages of the production process over the years 1994–1998. The estimation process allows us to measure that portion of growth that can be attributed to changes in the observable inputs. All other growth, the "residual" growth, is attributed to changes in the three propensities. That is, we estimate growth in each of the three stages *after* removing the effects of changes in the observable data. These residual growth rates are the growth rates in the propensity of faculty to engage in licensing, the propensity of university central administrations to engage in licensing, and the propensity of the licensing professionals and market demand in generating licenses.

After accounting for growth rates in observable inputs, the growth rate in disclosures is only 2.7% per year, while the nominal or raw growth rate, that is, before accounting for changes in observable inputs, is 7.1%. For patents the comparable figures are 12.1% and 17.1%, while for licenses the figures are −0.173% and 8.4%. These growth rates support the survey results in that the bulk of growth seems to be coming from the central administrations of universities.

4.3. Have Faculty been Diverted from Their Traditional Roles?

The preceding two sections suggest that the primary source of growth in university licensing has not been the faculty; rather, the primary source can be traced to central administrations. Nonetheless, there can still be concerns that, whatever the source of growth, the need for faculty beyond the invention stage may well signal a diversion of faculty from their traditional role in basic research. In this section we review evidence in Thursby and Thursby (2007) on the research, demographic, and disclosure profile of a group of 3,342 faculty scientists and engineers at six major universities:

Cornell University, MIT, University of Pennsylvania, Purdue University, Texas A&M University, and University of Wisconsin-Madison. With this data we can compare research profiles of those who actively engage in commercial activity via disclosure with those who appear to have remained in more traditional faculty tracks.

First, we note that our choice of universities is not random. Given our interest in the effect of licensing on faculty research, it is important to select major research universities with substantial licensing activity. All of the universities in the sample are among the top 50 universities in terms of total research expenditures, licenses executed, and invention disclosures, as reported in the 2001 AUTM survey. All but one of the universities are above the averages of the top 50.

Our measure of faculty interest in licensing is invention disclosures as opposed to licenses executed. While disclosures and licenses are not independent, we believe the former is more representative of faculty interest and the latter more representative of commercial quality. That is, a license disclosure simply indicates that an inventor has a research result that she believes has commercial potential. While all universities in the sample require their employees file such disclosures, this is hardly enforceable. As we noted in Section 2.1, faculty may not disclose for a variety of reasons. While a disclosure signals a willingness to be involved with licensing, it need not indicate that the research was motivated by the desire to license. Curiosity-driven research can often lead to commercially applicable results by accident. In their interviews with MIT mechanical engineering faculty, Agrawal and Henderson (2002) found that most conducted research with the primary goal of publishing.

The faculty we study are from the list of science and engineering faculty in Ph.D. granting departments given in the 1995 NRC report. We exclude faculty not listed in such departments, thus medical school faculty are excluded unless they also hold appointments in Ph.D. granting departments. Departments also are excluded if one could not reasonably expect disclosure activity (for example, we exclude astronomy).

The TTO of each university supplied us with the names of disclosing faculty and dates of disclosure. Four universities provided disclosure information from 1983 to 1999, and the others provided information from 1983 to 1996 and from 1987 to 1999.[6] Matching these files with the NRC list provides a sample composed of multiple years of disclosure or non-disclosure activity for faculty of our universities. We have information on dates of hire and departure, if applicable, so that the final sample includes the faculty when they were actually at the respective universities.[7] In our sample we have 3,342 faculty and 45,889 observations, where an observation consists of a person/year.

Thus, for each faculty member in our sample, we know whether she disclosed, and if so, how often, in each year that she was on the faculty of her respective university during the period made available by her TTO. Of the 45,889 observations, 3,241 (7.1%) represent disclosures in a particular year by a faculty member. This is our measure of faculty *interest* in licensing activity. From here forward, we use disclosure to indicate that a faculty member has disclosed at least once in a given year.

Given the concern that academics have become too commercial, the portion of faculty expressing interest in licensing is remarkably low. Of the 3,342 faculty, 2,145 (64.2%) never disclosed an invention, 495 (14.8%) disclosed in only one year, and 254 (7.6%) disclosed in only two of the years they were included in the sample. Only 67 faculty (2.0%) disclosed in eight or more of the years they were in the sample. Across the six universities, the fraction of faculty who never disclosed ranges from 53.9% to 72.2%. This, of course, does not tell us which faculty members disclosed: for example, was it the most productive in terms of publication? More to the point, simple counts reveal nothing about changes in the nature of the research conducted by the 35.8% who disclosed.

Our data show a dramatic increase in disclosure activity from 1983 until the mid 1990s, at which time activity leveled off with 10–11% of a year's observations being disclosures. In 1983, the likelihood that a faculty member disclosed was only 0.95%, as compared with over 10% by 1996. Earlier we noted that only about 20% of the faculty disclose in more than one year in our sample. Here we find that, in the latter years, about one in 10 faculty are disclosing in a given year. Thus, while disclosure activity has increased, it tends to be concentrated in a few faculty. Contrary to the notion that disclosures may come at the expense of, or accompany a decline in publications, publications per faculty in our sample more than doubled over the period of our study. Assuming that a publication in 1983 reflects the same research productivity as it does in 1999, the increased disclosure activity may in fact reflect increased research activity. Of course, publication counts tell us nothing about the nature of research. If, as feared, research has become more applied, it may well be the case that applied research, in general, leads to higher numbers of publications for the same research effort.

To examine the nature of research, we map each faculty member's journal publications into Narin, Pinski and Gee (1976) classification of the 'basicness' of journals.[8] This classification characterizes journals by their influence

Table 3. Percent of Basic Research.

Percent	% of Sample	% Who Disclose
No basic	26.14	11.34
<33	1.26	15.65
33–67	7.62	18.90
67–100	64.98	8.92

on other research. As discussed by Narin et al. (1976), basic journals are cited more by applied journals than vice versa, so that journals are considered to be basic if they tend to be heavily cited by other journals. For example, if journal A is heavily cited by journal B, but B does not tend to be cited by A, then A is said to be a more basic journal than is B. Advantages of the Narin classification are not only its measure of influence, but also ease of extending the measure to a large number of journals and articles. The ratings are on a 5-point scale, and we classify as basic only publications in the top basic category, which covers about 62% of all ranked journal publications. Only about a third of the publications could be rated, but we found no systematic change over time in the number of publications that could be rated. In a regression of the fraction of rated publications (where we drop observations with no publications, rated or otherwise) on a set of indicator variables for the year of the observation, we found an R^2 of only 0.0016, and very few significance differences in the coefficients of early versus later years.

In order to relate basic publications and disclosure activity we dropped from our sample all faculty who did not have any publications in journals rated by Narin (1976). This leaves a sample of 11,667 observations. We then tabulated the fraction of basic publications with disclosure activity, and results are in Table 3. The likelihood that a faculty member discloses initially increases with the fraction of basic publications, and then decrease. Those whose research is in the midrange (33–67%) have the highest probability of disclosure (18.9%). We then looked at the fraction of total publications that were basic. In doing so we assume that the fraction of total publications that are basic is the same as the fraction of rated publications that are basic. The number of basic publications per faculty member by year is then computed and presented in the second column of Table 4. In the third column, we present the number of total publications per faculty member by year. While these averages have varied over the 17 years, the two columns are very closely related. The simple correlation between these two

Table 4. Basic Publications by Year.

Year	Basic Publications/ Faculty	All Publications/ Faculty	Ratio: Column 3/Column 4
1983	2.08	7.24	0.287
1984	2.19	6.93	0.317
1985	1.93	6.50	0.297
1986	1.72	6.14	0.280
1987	1.65	6.10	0.270
1988	1.77	6.14	0.288
1989	1.61	5.91	0.272
1990	1.58	5.96	0.265
1991	1.44	5.66	0.254
1992	1.74	6.25	0.278
1993	1.74	6.43	0.271
1994	1.84	6.69	0.275
1995	1.83	6.92	0.265
1996	1.92	7.45	0.258
1997	2.12	8.02	0.265
1998	2.17	8.62	0.252
1999	2.08	8.70	0.240

columns is 0.85. The implication is that there is little or no change in the relation between total publications and the percent that are basic publications.

5. IMPEDIMENTS TO LICENSING

5.1. Different Objectives

For industry profits are the ultimate objective of any undertaking. Within universities, however, the objectives of commercialization differ across different stakeholders within the university.[9] The stakeholders most important in licensing include faculty inventors, the university central administration, and the TTO. In our university survey we asked about importance of a number of possible measures of success in licensing for each of these three groups. We asked respondents to indicate the importance, as they see it, of the following measures of success for each stakeholder group: (1) royalties/ license fees generated, (2) sponsored research funds, (3) number of licenses/ options signed, (4) number of patents awarded, and (5) number of inventions

Table 5. Measures of Success: Percent of Respondents Who Indicated "Extremely Important".

	Technology Transfer Office	Faculty	Central Administration
Royalties/license fees generated	70.5	41.0	69.4
Sponsored research funds	34.4	75.4	48.4
Number of licenses/options signed	49.2	11.5	24.2
Number of patents awarded	16.4	16.7	14.5
Number of inventions commercialized	60.7	36.1	32.8

commercialized. We used a 3-point scale of "not very important," "moderately important," and "extremely important." Respondents were also given an opportunity to indicate that an outcome was "not applicable." Results for the case "extremely important" can be found in Table 5. Note that measures of importance vary substantially across the three groups. About 70% of the TTOs indicate that they and their central administrations view royalty income as extremely important, whereas, in their view, only about 49% of faculty share that view. Faculty consider sponsored research funds of greatest value. Note, finally, that TTOs value the signing of a license and the commercialization of an invention much more so than do other stakeholders. In discussions with university licensing professionals we learned that they view the commercialization of inventions as a measure of compliance with the Bayh-Dole Act. It is clear that while income is important, it is only one of multiple university objectives in licensing.

In what way are these differing objectives an impediment to commercialization of university technologies? In Jensen et al. (2003) we develop a model and provide evidence that this multiplicity of objectives is a problem. The TTO finds and executes licenses, but it must act as the agent of the central administration, which set the terms of its employment. It also acts as an agent of faculty inventors, who provide the necessary inventions. With income as the primary objective of the central administration, but interests of the faculty more varied, the TTO must perform a balancing act to satisfy both parties. Recall our discussion in Section 2.1 regarding the difficulties of obtaining faculty cooperation in disclosing inventions. To the extent that the TTO must conform to the wishes of the central administration, and to the extent that these wishes do not match those of the faculty, the problem of obtaining disclosures from faculty inventors, who may already be skeptical of licensing, becomes more difficult. Indeed, it is not uncommon to hear from faculty that their TTO professionals are not cooperative.[10]

5.2. Moral Hazard

In Section 3.1 we noted the importance of faculty cooperation in further development of an invention after a license is signed. This presents a moral hazard problem to the extent that faculty might prefer their research to development of a licensed technology. In Section 3.1 we noted the work of Jensen and Thursby (2001) and Thursby et al. (2004) regarding the problem of providing sufficient incentives to overcome the moral hazard problem – faculty might not be willing to provide that development assistance. In this section we review some of that work.

Jensen and Thursby (2001) assert that contracts which include either payments tied to commercial success, such as royalties based on sales (running royalties) or an equity position, can solve the moral hazard problem, since payment is contingent on successful development. Thursby et al. (2004) argue most university inventions are embryonic and, if successfully commercialized, may be years from yielding revenues. That university inventions might not be successful is evident from our business survey, in which respondents reported that around 50% of all university licensed inventions fail because they do not meet the need anticipated at the time the license is signed. Since the inventions are risky and years away from potential revenue, they conclude that royalties and equity might not provide a sufficiently strong incentive for faculty to cooperate. In our business survey we asked about the importance of various payment terms for faculty who are critical in development and those who are not critical in further development. We include in payment terms running royalties, equity, and milestone payments. Milestone payments are payments contingent upon reaching a technical milestone. For example, if the invention is a drug or a medical device, a milestone might be reached when the invention begins phase one trials. Such contingencies based on technical success, as opposed to commercial success, can both shorten the time to a payout and reduce the risk that the faculty inventor never receives a payout. Our survey provides some clear results: running royalties are not used by firms to solve the moral hazard problem, whereas milestone payments are regarded as an important tool in this regard. Results on equity were weakly supportive of the use of equity to solve the moral hazard problem.

Thursby et al. (2004) note that the moral hazard problem can also be addressed by consulting contracts between the firm and the faculty inventor. In our industry survey we find that consulting contracts are used 58.7% of the time when faculty input is necessary for further development. However, there is substantial variation across firms in the use of such contracts. Some firms report that they never use consulting, while others report that consulting contracts are used 100% of the time. Thursby et al. (2004) construct an econometric model that relates the percent of the time a firm uses consulting to the size of the firm, their average distance from the major universities with which they contract, the extent to which they also use sponsored research to obtain faculty cooperation, measures of the typical stage of development of licensed university contracts, and, finally, a measure of the moral hazard problem perceived to be faced by the firm. They find a positive and significant relationship between the use of consulting and the firm's perception of the severity of the moral hazard problem.

6. CONCLUSION

Much of our own research on university industry technology transfer has examined both the role of faculty in licensing, and conflicting aspects of that participation. In this chapter we review this line of research, focusing first on the pro side – that is, the apparent need for faculty involvement, not only in recognizing when their research has commercial potential, but also in development toward commercialization. We then discuss the con side – the extent to which faculty involvement with licensing compromises their traditional research agenda. We then consider several faculty impediments to the licensing process.

Overall, faculty participation is crucial for many technologies. This role follows largely from the fact that university inventions are typically very embryonic. Such inventions usually require further development, and faculty play an important role because of their specialized knowledge of the invention. Further, finding potential licensees for such inventions can be difficult, and our university survey showed that rarely does more than one firm express interest in an invention (Jensen & Thursby, 2001). Faculty play a role in identifying licensees.

This participation is not without pitfalls and impediments. It has been suggested that recent increases in licensing, and, consequently, in faculty participation, signals a change in the direction of faculty research. We find that reasons for the increase in licensing lie less with changes in faculty research, and more with changes in the interests of university central administrations. Further, there is little, if any, evidence to date to suggest changes in faculty research in response to licensing possibilities. Impediments to ease of transfer via licensing include differing objectives of the three principal university stakeholders in the licensing process – central administrations, technology transfer professionals, and faculty – as well as the moral hazard problem of faculty not delivering on needed aid in development.

7. FUTURE DIRECTIONS

There are many issues that remain to be studied further. We are looking more deeply into the issue of the diversion of faculty from their traditional role in basic research. In particular, we note above that our work examines the publication records of faculty who disclose versus those who do not disclose, and the records of faculty before and after they begin to engage in the licensing process. In the future we plan to consider citation counts and sources of funding.

In Thursby et al. (2004) we consider the role of consulting in solving the moral hazard problem. Consulting, however, plays a much larger role in the transfer of knowledge beyond its use in license contracts. Currently, we are engaged in a broader study of consulting. In that work we are looking at patents with university faculty inventors. For such patents in the 1990s, we find that around 35% are not assigned to the faculty member's university. In discussions with university licensing professionals and industry research executives we learned that these patents are generally the result of consulting arrangements between the faculty and the firms to which the patents are assigned. This allows us to map the type of faculty and firm most likely to engage in consulting that can result in a patent.

Finally, if we take together all of the results reported in this chapter, it suggests challenges for entrepreneurship education. Our results, particularly those pertaining to disclosure, suggest a clear need for science and engineering faculty to understand a variety of issues in technology commercialization. Faculty cannot be expected to disclose inventions with commercial potential without some awareness of the market potential for practical applications of their work. This, of course, requires some knowledge of business, legal, and regulatory factors well beyond the domain of science and engineering disciplines. As discussed in another paper in this conference

(Thursby, 2005), introducing these issues to science and engineering curricula can be tricky, and, particularly at the graduate level, require a balance of the need to broaden technical education with the need to maintain technical rigor.

NOTES

1. See Mansfield (1995) and Zucker, Darby, and Brewer (1998) regarding the extent to which faculty do both types of work and, in fact, view applied work as complementary to their basic research agenda.

2. We asked for the percent of licensed-in agreements with universities that were not successful; by not successful we mean the technology did not fit the need anticipated at the time of the license – as an example, it did not reach the royalty stage.

3. This does not include sponsored research money tied to an executed license which is usually about 20% of the amount that is paid directly as license income.

4. We discuss the issue of moral hazard in more detail in Section 5.2.

5. Recall our discussion in Section 2.1 regarding the issue of faculty interest in the commercialization process.

6. We started with 1983 so as to be well past the date of passage of the Bayh-Dole Act of 1980. Universities supplied us with data as far back as disclosure information could easily be retrieved. The 1997 end was for Purdue University. Purdue was the basis for our pilot study in this project and that pilot was initiated in 1998, hence we only collected data through 1997.

7. For many of the faculty we could not find the arrival and departure dates. However, for some of these we were able to confirm that they were on the faculty in a given year, even if we do not know arrival or departure dates, so they did not have to be dropped from the sample.

8. This classification has been updated regularly since 1976.

9. For more on the multiplicity of university objectives see Thursby and Kemp (2002)

10. As an example, in a private conversation with an administrator of a major research university we were told that faculty regularly (and against university regulations) attempted to commercialize their inventions without using the TTO. The reason given was dissatisfaction with the TTO.

11. More complete details on the survey can be found in Thursby and Thursby (2004).

12. Further details of the survey can be found in Jensen and Thursby (2001) and Thursby et al. (2002).

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APPENDIX A. INDUSTRY SURVEY DESIGN[11]

The sample was drawn from the mailing list of Licensing Executive Society, Inc. (U.S.A. and Canada) (LES). We phoned companies with multiple entries to ensure a single response from each suitable business unit and to identify the most appropriate respondent. Further calls allowed us to eliminate those that do not license-in technology from any source and those no longer in business. This left us with 1,385 business units in the sample, and 300 responded (21.7% response rate); 112 indicated that they had licensed-in university technologies, and 188 indicated that their licenses were from other sources, though 61 of the latter had sponsored university research.

Of the 112 firms that licensed-in university technologies, 104 gave information on the number of their license agreements with universities. These 104 respondents had 417 licenses in 1997, which represents approximately 15% of the total reported by AUTM. Seventy-one respondents reported $307 million of support, which is approximately 17% of the comparable AUTM figure of $1,786 million for 1997. If the firms with missing sponsored research expenditures had the same average research expenditure as the 71 usable responses, then our 114 respondents account for about 28% of all industry research support at U.S. universities. Seventy-nine firms listed the primary universities with whom they licensed during the preceding 5 years, and 64 listed the primary universities with whom they sponsored research. Eighty-five universities are mentioned (many are mentioned by a number of firms) and they cover most of the major U.S. research universities; based on the 1997 AUTM survey, they represent 35 of the top 50 industry supported universities and 40 of the top 50 licensing universities. It is reasonable to conclude that our sample represents a substantial portion of all industry/university contractual agreements of the recent past.

Finally, the employment profile of our respondents who license-in from universities is similar to that reported by AUTM for 1998. In the AUTM survey, 64% of all university licenses were to startups or existing firms with fewer than 500 employees. About two thirds of our sample of firms have fewer than 500 employees, and less than half the respondents are responding for business units with no more than 100 employees. Sixty-three percent of those who actively license-in from universities had no more than $1,000,000 in revenues in 1997.

APPENDIX B. UNIVERSITY INDUSTRY SURVEY DESIGN[12]

The university survey was sent to the technology transfer offices of the top 135 U.S. universities in terms of licensing revenue as reported in the 1996 AUTM survey, and 62 responded. The majority of universities responding were public, and of the public universities responding, 62% were land-grant institutions. Private universities accounted for 37% of the responses. Average industry sponsored research for universities in the sample was $16.9 million in 1996, and federally sponsored research was $149.6 million. The average technology office in the sample reported 26.3 licenses executed, 92.3 inventions disclosures, 30.1 new patent applications, and $4.2 million in income for 1996. Compared to the 131 U.S. universities that responded to the 1996 AUTM survey, the respondents to our survey represent 68% of industry sponsored research, 75% of federally sponsored research, 71% of royalty income, 74% of the licenses executed, 70% of the invention disclosures, and 48% of the new patent applications.

INTRODUCING TECHNOLOGY ENTREPRENEURSHIP TO GRADUATE EDUCATION: AN INTEGRATIVE APPROACH

Marie C. Thursby

ABSTRACT

University inventions are increasingly transferred to industry by market mechanisms involving licensing and start-up ventures. This chapter explores the ways in which entrepreneurship education can benefit the professionals involved in this process. We focus on graduate education since the professions typically involved require one or more graduate degrees, such as the Doctor of Philosophy in the case of scientists and engineers or professional degrees such as the Master of Business Administration or Doctor of Jurisprudence in the case of business professionals or attorneys. Introducing entrepreneurship education to graduate programs presents a challenge since graduate education is highly structured. We present a model that preserves the in-depth disciplinary structure of degree programs while bringing Ph.D. students in science and engineering together with MBA and JD students to explore the interface of technology, business, and legal issues in commercialization of the science and engineering student's research.

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1. INTRODUCTION

University discoveries and inventions are increasingly becoming the engine of entrepreneurship and technological advance for start up and established companies. The process of discovery and technology transfer involves the efforts of a variety of professionals: inventors, who typically are scientists and engineers; technology transfer professionals who evaluate inventions in terms of commercial potential and develop business models for commercialization; attorneys involved in various aspects of intellectual property protection; and industry personnel scouting for inventions of potential use. While the skills needed by these professionals vary, some requirements are common. At some point, all of them need to be able to identify market opportunities for inventions. As is apparent from growing public policy concerns, it is also important that those involved with business and intellectual property strategy understand the implications of their decisions, not only for potential success of current inventions, but also for the freedom of future scientists and engineers to build on these inventions (Rai & Eisenberg, 2003; Thursby & Thursby, 2003). For all, communication and networking skills are important.

In this chapter, we explore the ways in which entrepreneurship education can benefit the professionals involved in university industry technology transfer. We focus on graduate education since the professions involved typically require one or more graduate degrees, such as the Doctor of Philosophy (Ph.D.) in the case of scientists and engineers, or professional degrees, such as the Master of Business Administration (MBA) or Doctor of Jurisprudence (JD) in the case of business professionals or attorneys. Introducing entrepreneurship education to graduate programs presents a challenge because graduate programs are typically highly structured and allow little latitude for coursework outside the primary discipline. This is particularly true in the case of doctoral programs in which research training is the primary focus.[1] We argue that while standard courses have little appeal, integrative programs, in which students "add on" experiential entrepreneurship modules that complement their core in-depth degree work, can add substantial value.

To illustrate, we describe a new program in technology commercialization and innovation at Georgia Institute of Technology and Emory University. This program, Technological Innovation: Generating Economic Results (TI:GER®), brings Ph.D. students in Science and Engineering from Georgia Tech together with Georgia Tech MBA students and Emory JD students to examine issues related to the commercial potential of the Ph.D. students' thesis research. Supported by a curriculum that focuses on the technical, legal, and business issues involved with moving fundamental research to the marketplace, this program leverages Ph.D. research while creating an on-campus internship in technology commercialization for the MBA and JD students. As we will argue, this integrative approach not only addresses the need for these students to understand issues in technology commercialization, but also can enhance the research agenda itself.

In Section 2, we discuss the need to introduce aspects of technology entrepreneurship into graduate education. We argue that programs of this type address broader needs than simply improving university industry technology transfer, also improving the abilities of targeted students to compete for and work effectively in their careers. In Section 3, we describe the TI:GER® objectives, curriculum, and team structure. In Section 4, we discuss key differences between TI:GER® and other approaches to introducing entrepreneurship to graduate programs for science, engineering, law, and business students.

2. NEED FOR AN INTEGRATED APPROACH

2.1. Science and Engineering Ph.D. Students

Why is it important for doctoral students in science and engineering to understand business and legal issues that must be addressed for industrial application of their research? The answer for many, particularly those preparing for academic careers in fields with little direct application in industry, is that it isn't. However, two factors suggest that this may be a shrinking portion of doctoral students. First, particularly in the life sciences, the lines between basic and applied research have become blurred, so that many research topics lie in what is known as Pasteur's Quadrant, where basic or fundamental research has direct (albeit with significant subsequent testing and development) applicability for solving industrial problems (Stokes, 1997). Second, well over half of doctoral students in the past decade have sought immediate employment in industry (National Science Foundation, 2002). Both factors suggest a need for integrative programs such as TI:GER®.

Regardless of their career goals, it can be argued that students whose research lies in Pasteur's Quadrant need to be able to recognize when the research has commercial potential. Indeed, the first step in the direct transfer of academic research to industry is the disclosure of inventions believed to have commercial potential. Recent empirical evidence on disclosure in U.S. universities suggests that only a fraction of inventions with commercial potential are disclosed (Jensen, Thursby, & Thursby, 2003; Thursby & Thursby (2002, 2007)). This is hardly surprising, since most academic research is sufficiently basic that the translation of results into downstream applications is not obvious early on. In fact, many university inventions have a variety of applications (Shane, 2000). For precisely these reasons, one can argue for educational efforts to assist students and faculty in recognizing potential market applications of their work.

For students pursuing industrial careers, there are even more compelling reasons to be aware of the business and legal issues involved in technology commercialization. These students need to be able to move from a primarily disciplinary environment in doctoral training to an environment in which research is ultimately justified in terms of its contribution to the business (Greene, Hardy, & Smith, 1995). Thus, even those who work on the bench need to understand what motivates market-driven (as opposed to curiosity-driven) research. Moreover, many graduates find that upward mobility in business requires their taking on management functions, which prove quite difficult without some knowledge of business and legal issues, as well as communication skills well beyond those typically acquired in doctoral programs. Indeed, a study by the National Academies Government-University-Industry Research Roundtable (GUIRR) indicates that while U.S.-educated scientists and engineers are well trained in the conduct of research, they lack skills in management, communication, and team-based problem solving that are critical to decision making in innovation-related careers (National Academy Press, 1991). This study, along with several others, maintains that this severely limits career options (Armstrong, 1994; Committee on Science, Engineering, and Public Policy (COSEPUP), 1995).

2.2. Students in Professional Degree Programs: MBA and JD

Here, as above, we argue that while there is a clear need for students with future careers in technology transfer to understand the issues involved in technology commercialization, there are also compelling reasons for most students in professional programs to understand the interplay of business, law, and science. This is surely the case for business students with aspirations for employment in companies which either conduct or in-source research and development (R&D). Personal discussions with industrial advisors for the TI:GER® program reveals that recruiting business graduates with knowledge and experience in technology commercialization is a priority for such companies. This is not surprising given survey results on the most critical needs of R&D intensive companies. The Industrial Research Institute surveys its membership yearly (225 firms) regarding their toughest problems in R&D. The *Survey* routinely lists "managing R&D for business growth," "integration of R&D and business strategy," and "making innovation happen" among the top five problems in R&D (Industrial Research Institute).

The case for law student participation in programs such as TI:GER® relates to a need for them to understand scientific and business principles. An important problem facing the legal profession today is that many cases and decisions require some knowledge of scientific and market principles as well as legal principles (Breyer, 1998, 2000; Greene, 2001). Moreover, many patent cases hinge more on scientific or technical issues than on market phenomena. It is because of these issues that Justice Breyer encouraged the National Academies to create the science, technology, and law program to promote research on issues at this interface (National Research Council, 2004).

Spanning this interface is particularly important for students interested in becoming patent attorneys. With the court's extension of patent rights to types of inventions that were previously considered unpatentable, such as gene sequences, software, and business methods, there has been growing concern over the quality of patents (Bagley, 2003a, b, 2001; Levin & Levin, 2002). Much of the problem stems from the fact that without prior patentability, there is little prior art in these areas to assist patent examiners in judging the novelty and non-obviousness of inventions (Sampat, 2004a, b). There are no easy solutions to this problem, and in fact there have been resulting calls for reform of the patent system (Cohen et al., 2003; Cohen & Merrill, 2004). We argue that multidisciplinary education, which introduces law students to business and scientific principles, can only improve the ability of future examiners to address these concerns.

Bagley, Associate Professor of Law and a TI:GER® faculty member, provides another perspective. She argues that more in-house and outside legal counsel will need to advise their companies on intellectual property issues than ever before because of the pervasiveness of intellectual property that can be protected, not only by patents, but also by copyright and trademark (e.g., sounds, colors, scents, dilution) and the financial ramifications of failing to properly protect it (e.g., Rembrandts in the Attic, developing and leveraging IP portfolios). She notes that many banks are developing business method patent portfolios for defensive purposes. To provide effective advice and counsel, these lawyers need to understand how intellectual property is created, how to nurture environments in which it can thrive, and how to create legal structures to facilitate its exploitation.

Finally, Bagley suggests that the growing number of start-ups and small businesses that may not be able to afford large law firm fees will create opportunities for niche legal practices catering to the needs of such companies. While integrative graduate education is no substitute for law firm experience, it may allow attorneys interested in such a practice to carve out niches in traditional firms or allow them to create their own shops more quickly.

Just as the GUIRR and COSEPUP studies reported a need for doctoral students to gain experience in team-based problem solving, there is a need for both MBA and JD students with innovation-related career objectives to have experience working with scientists and engineers (as well as each other). Exposure to Ph.D. students in science and engineering requires professional students to figure out how to talk to researchers (and the importance of asking the right questions along the way), to understand their motivations, to understand the nature of the research process with its dead ends, stops and starts, and how laws and business organizations impact whether that research reaches its full potential.

Finally, it is important to recognize that while cross-functional teams are often employed in industry to improve innovation, their performance is often reported to be less than anticipated. Why this is the case and ways to improve performance is a burgeoning research area (Gerwin & Barrowman, 2002; Randel & Jaussi, 2003). To this point, we suggest that students with multidisciplinary team experience in their graduate education may well have a competitive advantage early in their careers.

3. THE TI:GER® PROGRAM IN TECHNOLOGY ENTREPRENEURSHIP

3.1. Overview and Program Goals

Formally, TI:GER® is a 2-year certificate program that focuses on the technical, legal, and business issues involved with moving fundamental research to the marketplace. As shown in Fig. 1, students participate in the program while continuing as full-time students in their respective degree programs.

The program has four goals, the first being to graduate technically proficient science and engineering Ph.D.s with the skills and multidisciplinary perspective needed to succeed in innovation-related careers – be it as

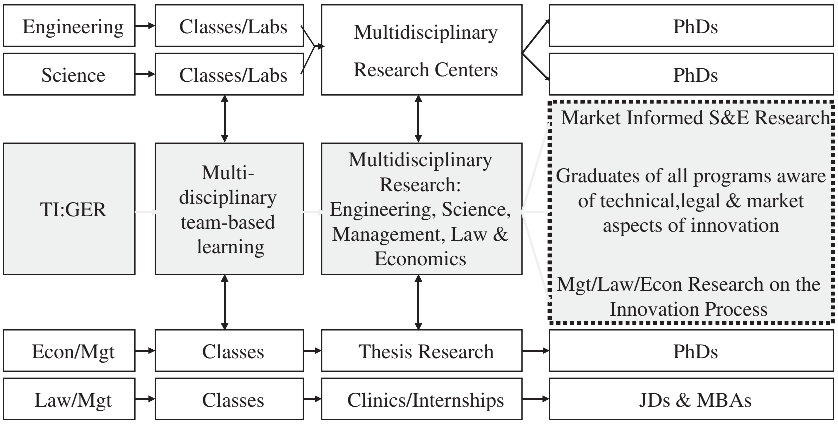


Fig. 1. TI:GER vis a vis Traditional Graduate Programs.

academics, entrepreneurs in small companies or intrapreneurs in corporate labs. Throughout the program, engineering doctoral students collaborate with MBA and JD students to examine technical, business, and legal factors that will influence potential market applications of the Ph.D. student's thesis research. The idea is to involve these students in collaborative, multidisciplinary projects of mutual benefit without sacrificing the rigor and in-depth education of their respective degree programs.

Thus, a second goal of the program is to produce thesis research of scientific merit and market relevance. The idea is for doctoral students to consider market implications of thesis research early on, allowing them to refine their research ideas in light of market, legal, and regulatory issues involved in potential applications researched by the MBA and JD students.

The third goal of the program is to expose MBA and JD students with career goals in technology transfer, R&D management, or patent or intellectual property law to the challenges in fundamental research and its commercialization. A fourth goal is to encourage Ph.D. students in Management at Georgia Tech and Economics at Emory University, who serve as teaching assistants in the program, to focus their thesis research on innovation issues. In this section, we discuss program aspects that address the first three goals, leaving discussion of the fourth goal in Section 5.

Central to the program are team-based projects centered around the Ph.D. students' research. Note the intent is not to divert the Ph.D. students from fundamental research, but to expand their knowledge of the legal and management tools used by businesses to capture value from research and development. Potential benefits from team collaboration are an increased probability that Ph.D. research results will impact industry, as well as *learning by doing* in commercialization. Similarly, the MBA and JD students are not diverted from their regular program, but gain hands-on, clinical experience in a technical research environment. Thus, all of the students are given first-hand experience in the challenges of multidisciplinary teamwork and behavioral aspects of project management.

3.2. Team Model

Fig. 2 illustrates the composition of TI:GER® teams as well as the nature of team collaboration. Team participants include law, economics, and management faculty, the Ph.D., MBA, and JD students, along with a program director with industry experience in commercialization, and economics and management doctoral students who serve as teaching assistants. This section presents a stylized view of team collaboration over the 2 year period.

The Ph.D. students ideally enter the program as they are beginning their thesis research. The best way to understand this collaborative model is to compare it to traditional science and engineering research, in which students and advisors consider primarily technical issues in determining the students' research agenda. Initially the students formulate hypotheses based on the current knowledge base and potential contributions to the engineering literature. As the research proceeds toward proof of concept, the focus turns to testing and validation, and once a lab-scale prototype is developed, issues of scale-up become important.

In the TI:GER® teams, market and legal issues are considered as early as the hypothesis formation stage. At this stage, the science and engineering students' primary responsibility is to communicate the technical challenges of their research as well as its expected scientific merit. JD students are responsible for directing patent searches, and to identify prior art is, of course, contingent on effective communication by the Ph.D. students. MBA students take primary responsibility for market research. For some thesis topics, market research is well defined, but for others the science and engineering research may lead to platform technologies capable of impacting a variety of markets that cannot be identified ex ante. Initial market forecasts for most topics therefore consider a number of emerging markets. Thus, in contrast to thesis research driven by science and engineering merit alone, the

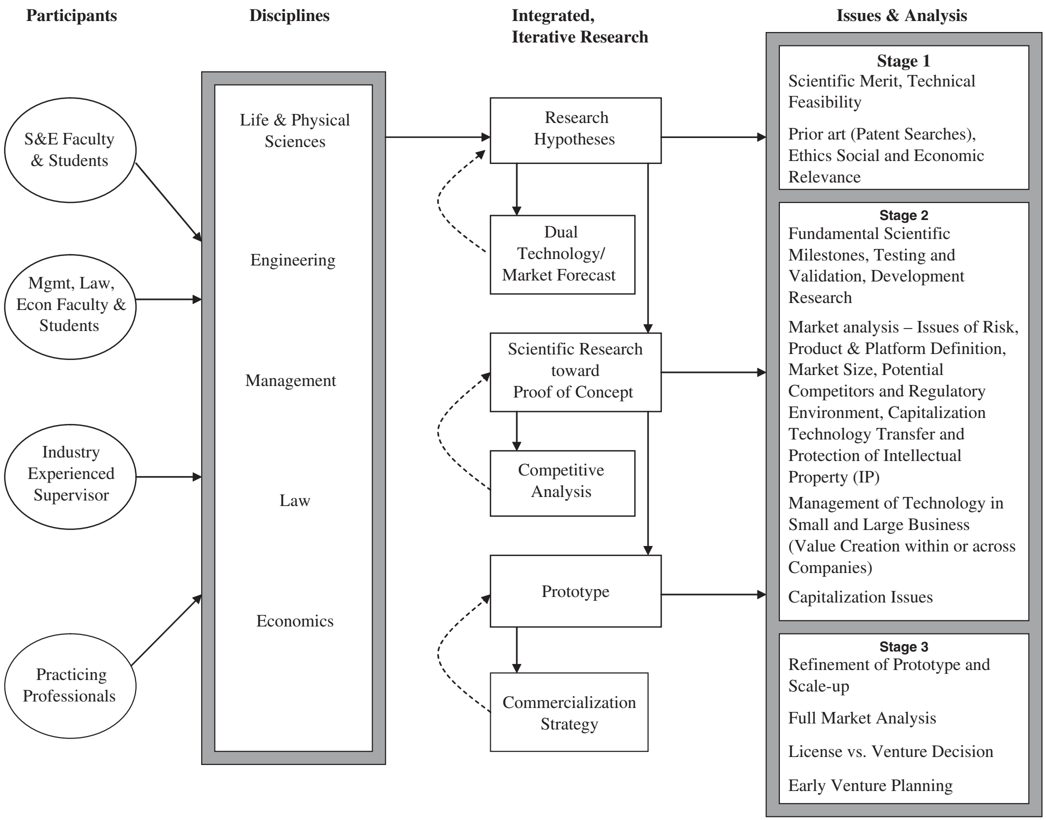


Fig. 2. Team Model.

TI:GER® model creates a mechanism for students to explore societal impacts of their research.

As research progresses toward proof of concept and lab-scale prototype, the Ph.D. student is responsible for drafting an invention disclosure. Market analysis focuses on practical issues as to how basic research is transferred to industry. Issues addressed may include manufacturing feasibility and cost, sales, recycling and other ethical issues, regulations and approvals affecting market potential, intellectual property protection, as well as strategies to facilitate industrial application (e.g., exclusive or non-exclusive license, start-up ventures). In cases where students are interested in a start-up venture, the legal and financial aspects of business organization become important.

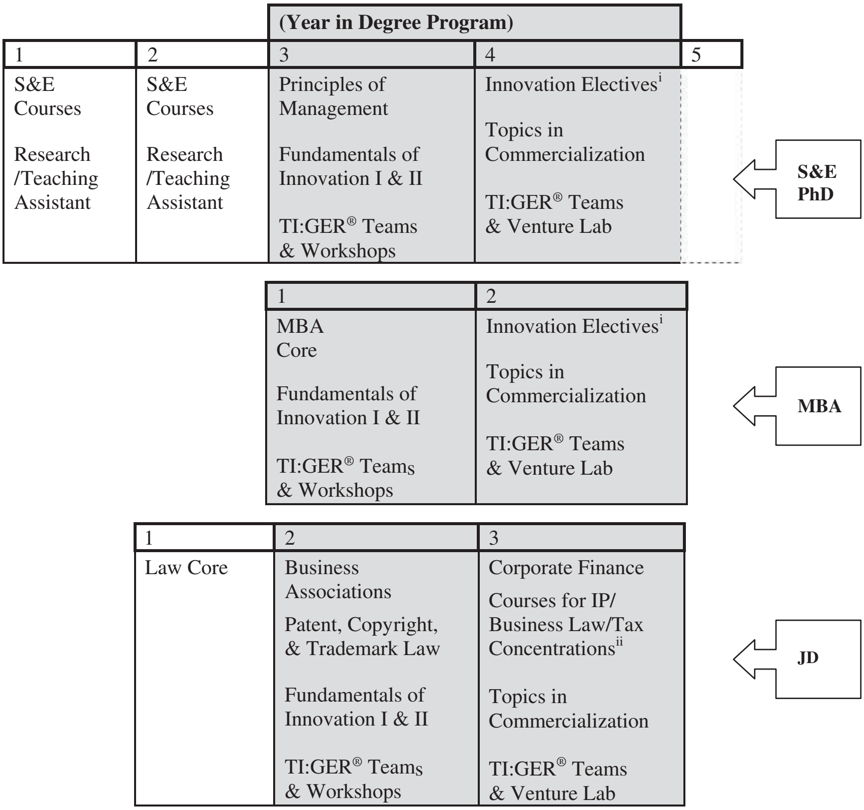
3.3. Program Structure

As noted above, TI:GER® is a 2-year program. As shown in Fig. 3, the science and engineering students are admitted as they begin their thesis research, which for most students is the second or third year of their Ph.D. program. The MBA is a 2-year degree, so that students are recruited as a part of the regular MBA recruitment process. The JD is a 3-year degree, and students enter the TI:GER® program in the beginning of their second year.

In their first year, students take fundamentals of innovation I and II (FOI-I and II), which are open only to TI:GER® students, and cover a variety of topics in a typical sequence of activities in technology commercialization. Abbreviated syllabi for these courses are attached in the appendix.

Topics in the first semester (FOI-I) include general issues in university–industry technology transfer, an introduction to experimental research methods in science and engineering, identification of entrepreneurial opportunities in technological environments, the importance of balanced teams in technology commercialization, the legal and economic factors in protection of intellectual property, and an introduction to capabilities needed to succeed in particular industries. The class includes team and individual assignments. As shown in the appendix, the major team deliverables are (i) an intellectual property assignment, which includes an invention disclosure and prior art search for the doctoral students' research, and (ii) a preliminary industry analysis relevant to commercial application of that research.

The second course covers topics such as licensing versus venturing, market analysis, entrepreneurial finance including a real options framework, business association (and securities) law. The key team deliverable for this class is a commercialization plan for technology based on the Ph.D.



		(Year in Degree Program)		
1	2	3	4	5
S&E Courses Research /Teaching Assistant	S&E Courses Research /Teaching Assistant	Principles of Management Fundamentals of Innovation I & II TI:GER® Teams & Workshops	Innovation Electives[i] Topics in Commercialization TI:GER® Teams & Venture Lab	

S&E PhD

1	2
MBA Core Fundamentals of Innovation I & II TI:GER® Teams & Workshops	Innovation Electives[i] Topics in Commercialization TI:GER® Teams & Venture Lab

MBA

1	2	3
Law Core	Business Associations Patent, Copyright, & Trademark Law Fundamentals of Innovation I & II TI:GER® Teams & Workshops	Corporate Finance Courses for IP/ Business Law/Tax Concentrations[ii] Topics in Commercialization TI:GER® Teams & Venture Lab

JD

Fig. 3. TI:GER® Student Participation.

Note: (i) Entrepreneurial Finance, Legal Issues in Technology Transfer, Organizational Entrepreneurship, Special Topics in Technology Mapping, Technology Venture Creation. (ii) Patent Prosecution, Patent Litigation, Intellectual Property Licensing, International Intellectual Property, Bioethics & Public Health Law, Computer Law, Corporate Practice, Food & Drug Law, Franchise Law. IP Licensing Federal Income Tax (3 courses: Individual, Corporations, and Partnerships).

student's research. Various faculty members from Georgia Tech, including the College of Management, and the Emory School of Law teach the TI:GER® innovation course modules and are frequently supported by outside speakers. Speakers include the leadership of the Georgia Tech Office of Technology Licensing (OTL), patent and technology attorneys, venture capitalists, and technology entrepreneurs.

The core second year course, Topics in Commercialization, is a capstone course that is structured much like a consulting course. Teams work to evaluate business opportunities and help develop business plans and strategic licensing plans for early-stage technologies being developed in the Georgia Tech incubator. This work gives students more hands-on experience, not only in the process of technology commercialization, but also in consulting with small businesses. Depending on the progress (or lack thereof) of the Ph.D. student's research, students either develop a business plan for technology based on this research or write a case study of their team experience.

In addition to TI:GER® courses, the science and engineering students are required to take a course in principles of management for engineers. All Ph.D. students at Georgia Tech must specify a minor and TI:GER® science and engineering students can use the TI:GER® courses for that minor. The MBA students are required to take a series of program-relevant electives, such as Entrepreneurial Finance, Legal Issues in Technology Transfer, or Organizational Entrepreneurship. Similarly, the JD students are required to take program-relevant electives such as Business Associations, Patent Law, Copyright Law, Trademark Law and Corporate Finance. The TI:GER® experience, plus these courses, will provide them with a degree concentration in either Intellectual Property or Technology Law. There are currently 64 students enrolled in the program, including 16 Ph.D. students in science and engineering, 29 JD students, and 16 MBA students.[2] The Ph.D. students come from mechanical engineering, biomedical engineering, electrical and computer engineering, industrial engineering, and chemistry. Current research topics include circuit design for concurrent search for many patterns in large datasets, use of nuclear magnetic resonance in treating insulin-dependent diabetes, use of microsensors for early cancer detection, construction of micro and nano structures for cell cultures, development of microneedles for drug delivery, structure–function relationships of articular cartilage in shear, and high-speed digital packaging and mixed signal system design.

4. BENCHMARKING

The TI:GER® program is designed to answer the call by the Committee on Science, Engineering, and Public Policy for programs that provide innovative multidisciplinary experiences for science and engineering students without interfering with those aspects of their degree programs that are exceptional. The most novel and, we feel, compelling feature of TI:GER® is the team-based approach centered on the science and engineering students' research. The program neither dilutes the rigor of their doctoral program nor diverts them from their research. Rather, it is designed to enhance the potential for industrial application of their research and to expand their career opportunities by giving them first-hand experience dealing with the types of professionals they will work with in industry.

There are, of course, other approaches to introducing Ph.D. students to business and other multidisciplinary team issues. A recent NSF (National Science Foundation)-funded survey of 1,727 engineering faculty reveals that the most common way to introduce Ph.D. students to industrial research and development issues is through sponsored research, which usually involves "demonstrating how existing knowledge could be synthesized and as solving a specific technical problem" for industry (Morgan, Strickland, & Kannankutty, 1997). Such problems are often too incremental (as opposed to fundamental) for thesis research. Industry contact was noted in fewer than 20% of the responses, so that students are unlikely to have been exposed to how businesses determine their research agenda or protect the related intellectual property. By contrast, our approach is to introduce students to these issues within the context of their own fundamental research.

Another approach is for engineering Ph.D. students to pursue dual degrees, an option that necessarily extends the length of their program. Still another is for them to earn management degrees once they work in industry, but the opportunity cost of such an approach is high.[3]

There is a growing trend for entrepreneurship programs to offer courses and degree concentrations tailored to the needs of engineering students. For the past 8 years Stanford University has offered a Roundtable on Entrepreneurship Education for engineers. As shown on their website, many of the more than 100 universities attended offer courses in entrepreneurship for engineers at the graduate level.

Similarly, many universities offer multidisciplinary courses in new venture creation and product design. These courses often involve interaction of student teams with a university technology transfer office to simulate the commercialization of "real" technologies. Some of these courses allow enrollment by law students as well as business and engineering students. An example at University of Michigan is Finance 745: Idea to Initial Public Offering in 14 Weeks. There are also a growing number of joint degree programs in business and law, such as the JD/MBA at Emory. There are high-technology law clinics at DePaul College of Law, Syracuse University, and the University of California at Berkeley.

This semester, a new course will be introduced at Harvard, titled Commercializing Science and High Technology. The course applies the integrative concept of TI:GER® in that it is designed for engineering graduate students (Ph.D. and masters), MBA students, and medical students, many of whom are pursuing a Masters in Clinical Health. Topics covered include issues in commercialization from the perspective of company labs and universities, as well as norms of open science. Cross disciplinary teams of students will examine commercialization issues for Harvard technologies. Original cases have been developed, including one that focuses on the dilemma faced by a TI:GER® doctoral student who is committed both to her research career and forming a company to facilitate the commercial application of her work.

The key difference, we believe, in the TI:GER® model and the bulk of these programs is the integration of technical, business, and legal aspects of innovation in a research-oriented program. The program closest in spirit is the "Innovation Realization Lab" at Purdue University, which teams science and engineering Ph.D. students with MBAs to examine market implications of science and engineering students' research.[4] The major difference, of course, between the two programs is the legal component, which we feel is important. While intellectual property is a core topic in both programs and both utilize guest speakers from the legal community, the legal component of TI:GER is more extensive, as law faculty are part of our core faculty and JD students are team members. We believe the participation of JD students significantly increase student benefits from the program. Not only does it expose engineering and MBA students to an additional dimension of multidisciplinary interaction, but the program also reaches a new group of students. The intellectual property track for the law students will give them a competitive advantage in practicing intellectual property law and sitting for both the law exam and the patent examiner's exam. The latter meets an important national need as patent examiner and intellectual property attorneys increasingly need to understand both technical and business issues.

5. STUDENT RESEARCH ON TECHNOLOGY ENTREPRENEURSHIP: ECONOMICS AND MANAGEMENT PH.D.S

As mentioned in Section 3.1, there are also doctoral students in economics from Emory University and management from Georgia Tech who participate in the program. Their participation is for a full 2 years. In the first year, they serve as teaching assistants in fundamentals of innovation I and

II. Based on successful performance and an interest in conducting their thesis research on issues related to technology commercialization and entrepreneurship, they are eligible for dissertation research support. The benefits to these students from participation include:

- team participation designed to enhance their understanding of the technology commercialization process and provide them with multidisciplinary teaching experience which they can carry into their career;
- observations from the team projects and access to industry partners will introduce them to unsolved problems that would not be apparent from the usual literature searches;
- research support for dissertations on related topics and exposure to other academics and journal editors through an annual doctoral workshop sponsored by TI:GER®.

To date, two economics and two management students have participated. Their research topics include strategic alliances in biotechnology in relation to pharmaceutical pipelines, limited copyright protection and industry structure, market strategy formulation and technology commercialization, and a behavioral model of venture capital investment.

6. CHALLENGES

We believe the integrative concept behind TI:GER® is a compelling approach for introducing entrepreneurship to graduate education. It offers students the normal activities associated with graduate study in their discipline merged efficiently with a curriculum on the technical, legal, and business issues involved with moving fundamental research to the marketplace. It leverages Ph.D. research while creating an on-campus internship in technology commercialization for the MBA and JD students. We argue that this integrative approach not only addresses the need for these students to understand issues in technology commercialization but also enhances the research agenda itself.

There are a variety of challenges to developing integrative programs. These range from the mundane (but real) logistic challenges of cross-campus collaboration, to more fundamental issues such as availability of resources, including funding and materials. Funding is currently provided by the National Science Foundation, the Alan and Mildred Peterson Foundation, and the National Collegiate Inventors and Innovators Alliance. In the long term, sustainable funding will be an issue. Another challenge is that teaching materials that focus on commercialization of early stage research are scarce. There is a need for more case writing, such as the Infovision Case being developed by Lee Fleming and myself, which focuses on the intellectual property, startup versus license, and research challenges faced by one of the TI:GER® Ph.D. students.

NOTES

1. A common complaint is that doctoral training is "a mile deep and a micron wide," which leaves graduates unprepared for careers that necessitate an understanding of issues at the interface of business and science (Stevenson, Thursby, & Steuterman, 2002).
2. One Ph.D. student in economics from Emory and two Ph.D. students in Management from Georgia Tech are enrolled as teaching assistants.
3. Among the Masters programs designed for engineers is the NSF-funded Global Innovation Program at the Georgia Institute of Technology. The November 9, 1998, issue of *The Scientist* highlights a number of MBA programs jointly sponsored by engineering and management schools, stating, "Anyway you look at it, taking on an MBA degree course is a major commitment."
4. Thursby was the founding director of the Innovation Realization Lab so similarities are not surprising.

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Sampat, B. (2004b). *Genomic patenting by academic researchers: Bad for science?* Mimeo.

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Stevenson, W., Thursby, M., & Steuterman, R.J. (2002). Ph.D. research in an entrepreneurial environment: A new model for graduate education in science and engineering.

Stokes, D. (1997). *Pasteur's quadrant*. Washington, DC: Brookings.

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Thursby, J., & Thursby, M. (2007). Patterns of research and licensing activity of science and engineering faculty. In: R. Ehrenberg & P. Stephan (Eds), *Science and the University*. University of Wisconsin Press, forthcoming.

APPENDIX. COURSE SYLLABI AND ASSIGNMENTS

I. **Fundamentals of Innovation I**
Intellectual Property Assignment
Industry Analysis Team Assignment
II. **Fundamentals of Innovation II**
Commercialization Plan Assignment

I. TECHNOLOGICAL INNOVATION: GENERATING ECONOMIC RESULTS (TI:GER®) SEMINAR ON THE FUNDAMENTALS OF INNOVATION I ABBREVIATED SYLLABUS

Faculty

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COURSE OVERVIEW

Technological innovation, is not simply invention, but a process that includes all of the steps from the decision to conduct research and the identification of opportunities and paths for that research to contribute to society through commercial application and diffusion to its ultimate impact and consequences. (This is Everett Rogers' definition of innovation which can be found in his classic book, Rogers, E. (1995) *The Diffusion of Innovation.* New York: The Free Press, 1995. Another useful reference in this regard is

Kline, S. J. and Rosenberg, N. (1986). "An Overview of Innovation," in *The Positive Sum Strategy.* Washington, D.C.: National Academy of Sciences.) This is the first of a two-course sequence on various techniques and approaches needed to understand the innovation process. Issues explored will include patterns of technological change, the identification of market and technological opportunities, competitive market analysis, the process of technology commercialization, appropriability and intellectual property protection, and methods of valuing new technology.

This is not a course in entrepreneurship or managing product or process development per se. The primary focus is on the acquisition of a set of tools that are critical for capturing value from new technology, be it in a university setting, large or small company. These tools can provide a framework for the types of problems that will be addressed in your TI:GER® teams.

In the Fall Semester, Fundamentals of Innovation I will focus on:

1. Identifying and evaluating business opportunities for technological innovation;
2. Learning forms of intellectual property protection and writing patent claims;
3. Identifying the capabilities and resources necessary to succeed in a particular industry;
4. Learning to work in a multidisciplinary team.

In the Spring, Fundamentals of Innovation II will focus on identifying the value proposition of a potential product based on the technology, identifying potential markets, valuing the technology at various stages of research, evaluating legal structures for feasible business opportunities, understanding the business impact of legal decisions, and developing a commercialization plan.

These two courses will provide the academic core to the student's first year in the Technological Innovation: Generating Economic Results (TI:GER®) program. Students will take each course as a "community of participants" and will participate in innovation teams. Innovation teams will comprise the Ph.D. candidates, MBA, and JD students, and will be formed within the first month of the fall semester. These teams will participate in in-class activities and team problem-solving exercises to obtain an understanding of the technology commercialization process. The research that will drive the innovation teams will be provided by the Ph.D. candidates and their advisors.

INNOVATION TEAM STRUCTURE AND PERFORMANCE EXPECTATIONS

Each innovation team will comprise a Ph.D. candidate, an MBA, and two JDs. The teams will remain intact for the entire 2-year TI:GER experience. Teams are expected to set their own priorities and "commercialization agendas" within the context and schedules determined by the Fundamentals of Innovation course.

Each team should develop shared patterns of understanding. Teams are expected to work through and develop its own set of positive team dynamics and work rules. Just as in an actual commercialization setting, each team is expected to leverage its mix of disciplinary skills and learn from each other. Teams will learn about four important factors for developing team climate for innovation during the Fall TI:GER® Retreat on September 10.

Each TI:GER® team will meet on a fixed scheduled basis with the TI:GER® Program Director in order to give an update on team activities and to receive any needed direction on specific team activities. These meetings can be conducted on either the Tech or Emory campus, and if necessary students can join the meeting remotely via speakerphone. Teams that do not meet as scheduled will be penalized in terms of the overall course evaluation. Meeting times will begin in October after Fall Break.

SCHEDULE OF CLASSES AND READINGS (READINGS SHOULD BE COMPLETED BEFORE CLASS INDICATED)

8/24 Orientation

This class will be devoted to an overview, including patterns of technological innovation, the role of universities in the innovation process, and the legal context within which university inventions are currently commercialized (the Bayh–Dole Act).

Technology profiles for the Ph.D. students' research will be distributed, and a local attorney will discuss confidentiality requirements for class participation.

8/31 The Existence and Recognition of Opportunity and 3 Lab Visits

Shane, 2004. Academic Entrepreneurship. Chapter 1 (Introduction **-Skim**).

Shane, 2000. "Prior knowledge and the discovery of entrepreneurial opportunities," Organizational Science 11, 448–469.

9/7 Lab Visits – Teammate recommendation sheets due at end of visits

9/10 Retreat – Emory Law School, 5th Floor Library
team building activities
Guest Speaker: Patrick Hatfield
Guest Speaker: Marcia Rorke

Marcia Rorke's discussion will draw from her monograph with David Lu, *From Invention to Innovation*. In this monograph they develop an Innovation Process Map which illustrates the relationships between technical, market, and business organizational steps in the technology commercialization process – along with the key skill requirements needed at the various process stages. The map is segmented into 4 stages of innovation: Research (Idea to Engineering Application), Innovation (product definition to engineering prototype); Entrepreneurial (prototype to production); and Managerial (production/major market penetration). The map and its relevance to this course will be one of the primary topics for the retreat. Since the Ph.D. research that will drive our innovation teams is in early stage, virtually all of the course assignments, and much of the course focus, will be in the Research or Innovation stages of the map.

9/14 More on Identifying Opportunities, Licensing and Spinoffs

Shane, 2004. Academic Entrepreneurship. Chapter 6 (The types of technologies that lead to university spinoffs)

Shane, 2001. "Technology opportunities and new firm creation." Management Science: 47(2), 205–220 **(Skim).**

Case: Three Dimensional Printing (UVA-ENT-0006)

Guest Speaker: Dr. George Harker, Director, Georgia Tech Office of Technology Licensing and Assistant Vice Provost-Economic Development/Technology Ventures

9/21 Introduction to IP – Patents, Trademarks, Trade Secrets, Copyrights

The Legal Protection of Intellectual Property, Harvard Business School Publishing, no. 9, 898–230 (1998).

“Intellectual Property and Strategy,” Harvard Business School Publishing no. 9, 704–493 (2004).

9/28 Patent Searching Training

Chapter 6 of “Patent It Yourself” by David Pressman, 10th ed., (Nolo Press) (2004).

10/5 Markum vs. CVD

CVD, Inc. vs. A.S. Markham Corp, (Case by Michael J. Robers and Ennis Walton)

10/12 Patent Drafting I

10/26 Patent Drafting II

11/2 How Useful are Patents?

Cohen, W.M., Nelson, R.R., Walsh, J.P. (2000) “Protecting Their Intellectual Assets: Appropriability Conditions and Why US Manufacturing Firms Patent (Or Not),” NBER Working Paper Series, National Bureau of Economic Research

Teece, D.J. (1998) “Capturing Value from Knowledge Assets: The New Economy, Markets for know-How and Intangible Assets.” California Management Review 40(3), pp. 55–57.

11/9 Strategy: Competitive Advantage/Five Forces Analyses

Thompson & Strickland, Strategic Management Concepts and Cases, (14th ed) Chapter 3 (Industry & Competitive Analysis) and Chapter 4 (Company situation Analysis)

11/16 Guest speaker: David Ku – working with the Food and Drug Administration

11/23 Patterns of Technological Change

Shane, 2004. Academic Entrepreneurship, Chapter 7 (The industries where spinoffs occur)

Henderson & Clark,1990. Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms, ASQ, Vol. 35, pp. 9–30.

Utterback, J.M. and Afuah, A.N. 1998, "The Dynamic 'Diamond': A Technological Innovation Perspective." in Economic Innovation New Technology, 1998,Vol.6, pp. 183-199 **(Skim).**

11/30 Public Policy

Thursby, J.G. & Thursby, M.C. University Licensing and the Bayh-Dole Act, Science, vol. 301, August 22, 2003, p. 1052

Thursby, J.G., Jensen, R. & Thursby, M.C., 2000, Objectives, Characteristics and Outcomes of University Licensing: A Survey of Major U.S. Universities.

Monday, December 6, by 5pm: Industry Analysis and 2nd Team Analysis due

INDUSTRY ANALYSIS TEAM ASSIGNMENT

Each team should identify an industry (using the NAICS code) that is relevant to an application of the team's technology. In a 10–12 page paper, please describe the application in some detail and what customer need this application addresses (2–3 paragraphs or so). After that introduction to your industry analysis, answer the following points/questions in order to demonstrate how your team is strategically thinking about the competitive environment surrounding that particular application of the technology.

1) Identify four dominant economic features of the industry and explain how these features affect the industry.
2) Identify the major competitive forces that industry members are facing and describe the strength of each force.
3) What market positions do industry competitors occupy – who is strongly positioned, who is not?
4) What strategic moves are competitors likely to make within the next year?
5) What forces are driving changes in the industry, and what impact will these changes have on competitive intensity and industry profitability?

TI:GER FUNDAMENTALS OF INNOVATION I: PATENT SEARCH AND ANALYSIS TEAM PROJECT

Fall 2004

The purpose of this is to help the project team assess whether to move ahead with efforts to patent the subject invention or to focus efforts in a different direction. Patent attorneys routinely order searches for clients (some conduct the searches themselves) and report on the results. More and more inventors are learning the importance of conducting a search before engaging the costly services of a patent attorney, and business managers who are thoroughly familiar with the nature of and patent protection prospects for an invention can better contribute to and lead the team effort to achieve commercial success. The chapter from "Patent It Yourself" also contains 14 specific reasons for conducting a patent search, all of which are relevant. This project has three components:

1. **Invention Disclosure**: Handed out last week, an invention disclosure (ID) is to be prepared by each Ph.D. student and distributed to his team members. The team should discuss the disclosure to ensure all members understand the nature of the invention and any related drawings. The Ph.D. student may need to modify the ID after this team discussion. The ID is to be handed along with the other project documents.
2. **Prior Art Search**: Each member of the team is to be involved in searching the prior art for the ID. **You are not allowed to use Nerac for this project.** The team members will decide amongst themselves how to share and divide the search responsibilities. Each team member is to record on a Patent Search Worksheet where he or she searched (e.g. Japanese patent abstracts in Lexis–Nexis database), how he or she searched, giving specific Boolean or natural language search requests, and what he or she found. Use as many worksheets as needed and submit all worksheets (do not retain copies) with the other project documents. There is no set minimum or maximum number of references required; the searching portion of the grade will be largely based on quality and thoroughness, not quantity.
3. **Search and Analysis Summary Letter**: Each team will produce a letter drafted by the patent JD student. The patent JD student is responsible for getting information from the other team members on the scope of each person's search and the most relevant patents and other documents. In practice, the patent attorney would receive a search report from a patent searcher, analyze it, and convey results to the client. This is not a patentability opinion;

> this is just a summary letter. The letters should be addressed to Professor Bagley and should be 1-2 pages in length; the sample on page 6/14 of the chapter handout can be used as a guide. As the sample letter shows, an in-depth analysis of each reference is not required; however, the letter should point out particularly relevant patents and should briefly mention why they are perceived as relevant or what aspect of the reference merits particular attention. Copies of the five most relevant references should be submitted with the summary letter.
>
> JD students: do not state an ultimate conclusion regarding the patentability of the invention. Rather, conclude with a statement such as "the contemplated invention may require further consideration before moving forward with the patenting process: if you think some of the references may prove problematic. If you have a particularly damaging reference or negative comments, do not put those in writing. Always convey those orally to the client, otherwise the written statements may come back to haunt both you and the client. At the top of each letter (and each page) should be a heading in boldface type **"Attorney Client Privilege – Attorney Work Product."**
>
> Each JD student will be provided with a diskette for use in preparing the summary letter. **No copies of the letter should be retained or kept on any student's hard drive; all drafts and the final summary letter should be on the diskette that is turned in to Professor Bagley (however, a hardcopy of the letter should be turned in as well).**

At the conclusion of the project, the team should designate a person (a JD student might be a logical choice) **to turn in the following to Professor Bagley by 5:00 p.m. on November 2, 2004:**

- **One ID**;
- **One set of search worksheets from each team member**;
- **One search and analysis summary letter with the most relevant references attached,**
- **One diskette on which the summary letter has been created**.

This is a team assignment, so assess your team members' strengths and maximize them to the team's advantage. The patent JD students are not responsible for doing all of the summarizing of the search, just for putting together the summary letter. Properly apportioning the work will allow each person to obtain a beneficial learning experience.

ATTORNEY CLIENT PRIVILEGE
ATTORNEY WORK PRODUCT

PATENT SEARCH WORKSHEET

Sheet ___ of ___

Inventor: ____________________________

Brief Description of Invention:

____
____

Search Strategy:

Database/Source Searched	Search Requested (i.e. Boolean String, Natural Language, Number of Items retrieved)	Fruitful (Y/N)

Relevant Patents, Abstracts, and other Publications:

Patent/App #	Date (m/d/y)	Inventor (Assignee)	Comments

Patent Searcher: ___________________________________ Date____________________

II. TECHNOLOGICAL INNOVATION: GENERATING ECONOMIC RESULTS (TI:GER$^{\circledR}$) SEMINAR ON THE FUNDAMENTALS OF INNOVATION II SPRING 2005 SYLLABUS

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COURSE OVERVIEW

The Seminar on the Fundamentals of Innovation II is the second of a two-course sequence focusing on the concepts and needed to understand the technology commercialization process. In the Spring semester, the course is focused on:

1) Making the new venture or licensing decision.
2) Building on the industry analysis and intellectual property assignments from fall semester by developing market strategies.
3) Developing valuation strategies and understanding the impact of legal decisions in business structuring.
4) Building rapport in multidisciplinary teams.
5) Writing a commercialization Plan.

Students are also encouraged to "keep current" on general topics of innovation and technology commercialization. Excellent business-oriented web sites that provide free content (sometimes just excerpts of articles are free) helpful in individual development, class preparation, and team activities include Forbes at www.forbes.com, Fortune at www.fortune.com, Business

Week at www.businessweek.com, Business 2.0 at www.business20.com, and www.researchoninnovation.org.

The TI:GER® Program Director will meet any students who received lower than expected evaluations from their team members in the Fall team evaluation exercise to discuss improvement. **Each TI:GER team will meet with the TI:GER® Program Director** in order to give an update on team activities and to receive any needed direction on specific team activities. These meetings can be conducted on either the Tech or Emory campus, and if necessary students can join the meeting remotely via speakerphone. Teams that do not meet as scheduled will be penalized in terms of the overall course evaluation. We will also have two **Tell It Like It Is Workshops** which will help facilitate communication and learning among the teams as teams work on different projects. More details on the format of these workshops will be presented in the class. There will be a **marketing strategies assignment, an in-class valuation assignment** and you will be asked to **attend two Impact speaker series or Tech Law series talks** and provide a one page write-up about what you learned. The final project will be developing and presenting a **Commercialization Plan** for your team's technology.

SCHEDULE OF CLASSES AND READINGS

1/11 Making the Venture/Licensing Decision

1/18 The Commercialization Plan – Macro and Micro Level Considerations

Chapter 1, The New Business Road Test, John W. Mullins, London Business School, 2003.

Making the Licensing Decision, Marcia Rorke.

1/25 Tell It Like It is (each team gives project updates)

2/1 Market Strategies – Case/Discussion

Partington, M. (1996). New Product Development at Cannon, HBS, 9, 396–247

Hertenstein, J. (2004) Endius Inc: Alternatives for Developing a New Medical Device

2/8 Team Meetings

2/15 Tell It Like It Is (on Team Work)

2/22 **Guest Speaker: James Vlazny, President, Licensing International, Inc. "Trends in Pharma/BioTech Licensing"**

2/22Market Strategies Assignment Due

3/1 **Corporate Finance**
Chapter 3, Valuing firm Output, Corporate Finance: principles and practice, William J. Carney.

3/8 **More Corporate Finance**

3/29 **Entrepreneurial Finance**
Harvard Case No. 9, 201–023, Merck & Co.: Evaluating a Drug Licensing Opportunity, 2000
See other readings in course pack.

4/5 **Corporations and Securities Issues**

Chapter 3 Forming the Corporation, Business Associations, 4th Ed. Larry E. Ribstein, Petter V. Letsou, 2003
4/12 **New Harvard Case (Case to be distributed in class.)**

Lee Fleming and M. Thursby, *Infovision*

4/19 **Presentations of Commercialization Plan – Poster Session Industry Advisory Board Meeting**
4/26 **Strategic Planning for second year of TI:GER**

4/26 Written Commercialization Plans due

COMMERCIALIZATION PLAN OUTLINE

I. Executive Summary (1–2 pages)
II. Project Summary (2–3 pages)
  A. Project Description
  B. Project management
  C. Technology/supplier dependencies
III. Internal Factors – Application analysis (technology robustness, potential spinoffs, target industries, rationale for choosing these industries) (2–3 pages)
IV. External Factors/Application Deployment Issues (20–25 pages)
  A. Industry Analysis
  B. Product Definition
  C. Market Analysis

D. Partner Assessment (if appropriate)
E. Intellectual property
F. Commercial deployment analysis (for partners)
G. Deployment risk analysis (for partners)
H. Immediate next steps

AN INTEGRATED MODEL OF UNIVERSITY TECHNOLOGY COMMERCIALIZATION AND ENTREPRENEURSHIP EDUCATION

Arthur A. Boni and S. Thomas Emerson

ABSTRACT

We examine the challenges of commercialization of university-developed technology and the synergistic relationship of the university's technology transfer office with business-school-based entrepreneurship education programs. We postulate that business schools can effectively augment the university technology transfer office in developing and growing successful startups, through catalyzing the process of startup creation and by actively assisting in the formation of multi-disciplinary leadership teams for spinout companies. The assistance of the business school's alumni and entrepreneur networks can also be leveraged for both mentoring and investment. The challenges of an effective program include securing early marketing input, building effective leadership teams, negotiating the terms of technology licenses, and developing the enthusiasm and cooperation of faculty researchers. At Carnegie Mellon, we have developed an integrated entrepreneurship education program focused on opportunity recognition and strategy development, team building and leadership

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University Entrepreneurship and Technology Transfer: Process, Design, and Intellectual Property
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development, and resource acquisition and allocation. Our program actively assists in launching and supporting the resulting spinout companies by connecting entrepreneurs with value-added investors, support networks, and partners. In addition, we monitor and mentor the spinout companies through their startup and growth stages. Our program includes an aggressive cross-campus initiative in which we teach entrepreneurship courses in the science, engineering, and computer science schools (in addition to the business school) and conduct seminar series to reach faculty and graduate students within those areas of the university. We are aided in the program by the enlightened technology transfer policies that Carnegie Mellon adopted in 2001. The rationale and objectives of those policies are explained in a lengthy appendix. We illustrate the effectiveness of the model through discussion of three recent spinout companies. We conclude that university entrepreneurship education programs can significantly enhance the effectiveness of university technology transfer programs. To optimize that result, the entrepreneurship education program should extend beyond the walls of the business school and should actively assist in the creation of well thought-out business plans and the formation of well-balanced leadership teams actively monitored and mentored by the business school and its alumni and entrepreneur networks. Additionally, it is necessary to tailor the program to the specific character and needs of the region.

1. CHALLENGES OF COMMERCIALIZING TECHNOLOGIES AND NEW COMPANY FORMATION IN A UNIVERSITY SETTING

The intellectual capital and property developed by our nation's universities are often heralded as a significant resource for the introduction of new and innovative products and services to the country's economy. Beginning in 1980 with the passage of the landmark Bayh-Dole Act, universities began in earnest to build their technology transfer activities to protect the university intellectual property, transfer it to industrial partners via licensing to existing companies, or to stimulate new business creation via startup companies (another part of the Bayh-Dole legislation stimulated the initiation of the Small Business Innovation Research (SBIR) program at the federal government level). The Association of University Technology Managers (AUTM) publishes annual reports that highlight the very significant impact that the nation's universities have had in both of these areas. Full information can be found at www.autm.net. In Pittsburgh, the base of sponsored research at Carnegie Mellon University, the University of Pittsburgh, and the UPMC Health System collectively exceeds $750 million annually. AUTM annual reports that provide benchmarks suggest that this base of research should produce approximately 8 to 10 companies annually, and that has been observed in the Pittsburgh region in the late 1990s and the first few years of the 21st century.

While AUTM statistics provide good benchmarks for the university-based startup initiation process, it must be recognized that it is a necessary condition for a startup company to execute on a potential commercially viable opportunity including the following essential components: development of the opportunity (identification of a compelling customer-driven market need, development of a market strategy, articulation of a value proposition); acquisition of resources necessary to compete in the marketplace in light of competition; and development of a world-class leadership team – in addition to executing a license with the university. While many of the technology-based spin-offs from universities are potentially viable, the lack of market-driven, entrepreneurial leaders is often rate limiting. We postulate that the business school can effectively augment the university technology transfer office in developing and growing successful startups. MBA entrepreneurship programs often have potential leaders with some level of industry experience who can provide the appropriate market perspective to develop these opportunities as part of their MBA curriculum as described herein. Furthermore, alumni networks include entrepreneurs who are seeking "serial experiences." In this chapter, we use Carnegie Mellon University as an example of this approach. The objective would be to accelerate both the pace and probability of success of university-based startups. We have found that suitable performance metrics do not exist for such a model, and this could become the subject of a future research study in entrepreneurship. The University of Washington is currently beginning such a study of management teams in startup company teams (ref. Corey Phelps, University of Washington, private communication, 2004). Also, Gary Cadenhead, at the University of Texas, has been tracking winners of their Moot Corp. competition (ref. *No Longer Moot – The Premier New Venture Competition from Idea to Impact*, Gary M. Cadenhead, Ph.D., 2002, Remoir).

Developing an effective and integrated model for university-based technology commercialization includes challenges and actions that must be taken at the university level (and this is a university-wide effort), within public institutions in the community, and within the business community as illustrated in Fig. 1. We illustrate this model from our own institution and

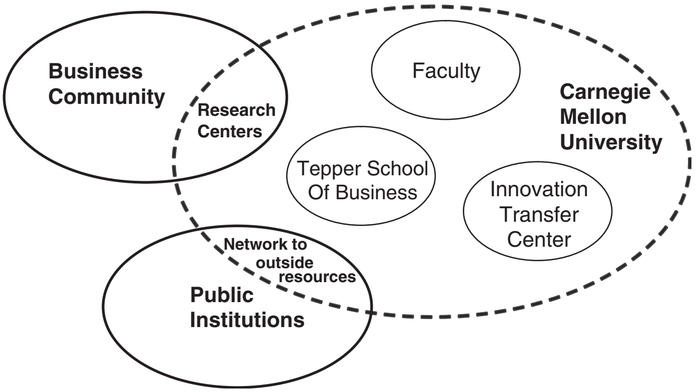

Fig. 1. Effective Program Begins with Acknowledging All Stakeholders.

region, and suggest that those in other regions should extend the concept to the conditions applicable in their own universities and communities. Within the Carnegie Mellon University community we include faculty, students, and administrators, along with the technology transfer office (officially named the Innovation Transfer Center); the business community (the extended network that includes the venture capital and angel investors, the entrepreneur service providers – incubators, law firms, accounting firms); and the public institutions (economic development organizations, technology councils) that support entrepreneurs in the community.

Within the university community, challenges include:

- Early marketing input: Most often, university faculty and student researchers focus principally on the technology and not the market. It is important to create an environment where solutions for real problems in the market are identified early, and innovative technologies can then be used to provide solutions for the market.
- Team Building: Faculty and student researchers are often ill equipped to lead company spin-offs, and conflict of interest and commitment are prevalent. Therefore, the spin-off is challenged with an inexperienced and incomplete management team.
- Delays and complexity of the licensing process: Faculty and their commercialization partners can be understandably frustrated by lengthy negotiations, time delays, and inflexible licensing terms.

Community-wide challenges include the existence and close linkages between the university and the community:

- Economic development groups supporting pre-seed investments to advance technology development, market development, and intellectual property (IP) development appropriate for protection of products to be introduced into the marketplace.
- Receptive and active investor groups and networks (angels, early-stage venture capitalists (VCs), later-stage VCs). Without adequate and "value-added" investors, the fledgling venture often fails due to lack of adequate resources.
- The lack of an adequate pool of successful entrepreneurs in the community, which makes the team building issue very difficult. This situation exacerbates the funding of early-stage ventures and also leads to less than desirable success in the commercialization process.
- Incubators are neither a necessary nor a sufficient condition for success of early-stage companies; however, in many cases the existence of an incubator to provide space, facilities, and counseling to early-stage companies does in fact stimulate successful transition from the startup to emerging company stage. The incubator therefore may become an asset at the company stage (seed or startup) where resources are often lacking or are too expensive.

2. BUSINESS SCHOOL ENTREPRENEURSHIP CENTER COMPLEMENT TO TECHNOLOGY TRANSFER EFFORTS

The role of the technology transfer office is to work with faculty to develop IP and licensing strategies. While there is an effort to commercialize technologies via startup companies, most universities approach this via faculty and community efforts, and the technology transfer office plays a supportive but important role. There simply isn't enough time to promote company formation actively. Financial incentives associated with company formation are often less than for licensing to existing companies.

The role of the entrepreneurship education program is to educate and support entrepreneurs in the university environment and to build bridges to the outside community. Mature entrepreneurship centers such as the Donald H. Jones Center (DJC) for Entrepreneurship within the Tepper

School of Business at Carnegie Mellon University are ideally suited to partner with the technology transfer office. As noted, technology transfer at Carnegie Mellon resides in the Innovation Transfer Center (ITC).

At the DJC, we have a multi-fold strategy consisting of:

1. Integrated curriculum development at the MBA, undergraduate, and community level that is focused on:
   - Opportunity recognition and strategy development
   - Team building and leadership development
   - Resource acquisition and allocation
2. Launching and supporting entrepreneurial companies with well-balanced and qualified teams of entrepreneurs.
3. Connecting entrepreneurs with value-added investors, support networks, and partners.
4. Ongoing monitoring and mentoring of spinout companies during their startup and emerging growth stages.

Our teaching program provides the necessary skill sets for entrepreneurs and utilizes experiential learning to impact the ability of the entrepreneur to anticipate failure modes at all stages of the company life cycle. David Morgenthaler, founder of Morgenthaler Ventures, provided us with some interesting statistics on over 200 companies in their venture capital investment portfolio (private communication, 2004). As illustrated in Fig. 2, the failure modes for venture-backed companies are as follows: the first and least often encountered failure mode is technology – 10% of the failures, i.e. the technology is not able to perform at the necessary level, not able to transit from the laboratory into commercial practice accounts, or fails to be scaled up at all or not economically to commercial levels. Market factors

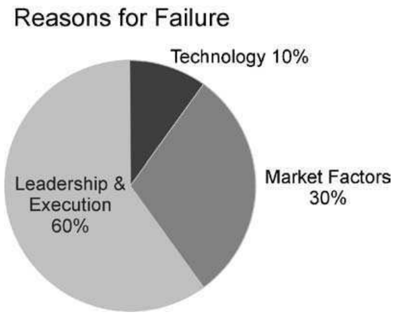

Fig. 2. Common Failure Modes.

account for 30% of the failures, i.e. the market did not develop, competition was too great, or failure to access sales channels, etc. Standing out is that 60% of the failures result from the failure of the leadership team to execute the business plan. While the Morgenthaler portfolio analysis represents just one data point, it certainly reflects our experience (we are in the process of gathering a broader range of data from contacts in our venture capital network). This will be the subject for another publication at a later date.

The constituency and audience includes students (graduate, undergraduate, researchers, and MBAs), the research faculty, and to a certain extent the administration that must be receptive to creating and maintaining an entrepreneurial culture and policies. Additionally, direct links to centers of excellence are developed in the university including schools, colleges, institutes, research centers, etc.

We have found it important to develop programs and interfaces to link our teaching faculty directly with the key internal constituencies. Examples include:

- Seminars and lecture series across the campus
- Entrepreneurship courses in the business school and in each school or college
- Business plan competitions – internal and intercollegiate
- "Boot camps"

We also actively expose our students to visiting entrepreneurs (regional and beyond), venture capitalists, and lawyers (corporate and IP) very regularly.

Launching and supporting new ventures is supported by the capstone of our teaching program, which is a team-created business plan with validation by local, national, and international business plan competitions. These plans are also validated by outside entrepreneurs in our network. Our program at the Tepper School of Business is described in more detail in the next section.

3. OVERVIEW OF THE TEPPER SCHOOL OF BUSINESS PROGRAM VIA THE DONALD H. JONES CENTER FOR ENTREPRENEURSHIP

We describe below the three major initiatives focused on the University, all tied either directly or indirectly with the ITC:

Program Overview: While Carnegie Mellon has realized numerous successes in the area of entrepreneurship education, much more can be done. In fact, in response to many student and faculty requests to access entrepreneurship education more directly and in a manner more targeted to their specific interests, the DJC launched a two-pronged initiative last year to bring entrepreneurship education to a much wider audience and to impact the success rate of technology commercialization, company formation, and successful growth.

- Launched an MBA course in the fall of 2003 entitled *Technology Commercialization Workshop*, a one-semester course. The workshop provides student participants with hands-on experience in initiating and developing a technology-based firm. Participants are 2nd year MBA students who work in New Business Teams (NBT), each assigned an early stage invention and an experienced entrepreneur-mentor. The technologies are prescreened for commercial potential by the course professor who develops a portfolio from the ITC and from local companies, inventors, universities, and economic development organizations that fund early-stage technology development. Each team identifies and quantifies potential markets for the technology, assesses capital requirements, and develops a commercialization strategy and business plan required to advance to an initial funding round.

This course links our MBA students with technologists on campus and in the community to commercialize technology. During the academic year 2003–2004, the NASDAQ Educational Foundation provided a seed grant that has enabled development of curricula and facilitated the seed funding of select innovative projects. Following graduation in June 2004, three technology-based companies were launched from this program. They are: (1) EA Devices, Inc. (the EA Needle, energy assisted biopsy device for cancer diagnostics); (2) ClearCount Medical Solutions, Inc. (RFID-enabled operating room management of sponges and instruments); and (3) Biostics, Inc. (acoustic MEMS system for drug discovery and diagnostics of biological molecules for a variety of applications). Both EA Devices and ClearCount have received seed funding to initiate operations and commercialization, and Biostics is currently seeking funding. We describe these activities more fully in Section 4 as recent case studies.

In the current academic year, we have 14 MBA student teams working on commercialization strategies and plans for technologies from the School of Computer Science, Mellon College of Science, Carnegie Institute of Technology (the school of engineering), and from local companies. We have plans to extend the technology sourcing to other non-profit institutions and commercial organizations both regionally and nationally.

- Created an approach to bring the undergraduate and non-MBA entrepreneurship curriculum directly to the other six colleges and schools at Carnegie Mellon at the undergraduate and graduate levels. We piloted this program via a single course: *Technology-Based Entrepreneurship*, in 2003–2004. The program was highly successful and well received. We collaborated with faculty and deans from other schools on campus and this single course has been multiplied to *three* courses, tailored specifically for (1) engineering students, (2) computer science students, and (3) biology and other science students. These courses are now offered in their respective schools (as opposed to in the DJC) and bear the names *Introduction to Entrepreneurship for CIT* (which is CMU's engineering school), *Introduction to Entrepreneurship for Computer Scientists*, and *Introduction to Entrepreneurship for Mellon College of Science.*

The courses described above work in a complementary fashion with our curriculum as a much broader entrepreneurship curricula.

The purpose of the program described above is to reach out from the business school and to stimulate innovation and commercialization at Carnegie Mellon and to form teams of MBA and undergraduate business students with engineers and scientists.

We plan to augment team formation and to engage our broader network as such (see below).

Each team in these academic programs developed a business plan, and we organize and host internal business plan competitions on campus both at the undergraduate and graduate levels. These internal competitions provide students valuable experience in the stages of business planning and commercialization, and serve as "feeders" for participation in external competitions as described below. Teaching entrepreneurship "where the inventors and innovators are located" also drives the technology transfer pipeline with commercially viable ideas and opportunities that have been matched with market need prior to ITC direct involvement, i.e., we are attempting to provide a market perspective (market pull) rather than the technology push approach to technology innovation.

- Venture Competitions – business plan competitions with real world entrepreneurs and investors as judges.

As noted above, it is necessary for emerging entrepreneurs and their companies to develop business plans that can be used to attract adequate resources to commercialize their technologies and to create successful organizations. Resources include financial and business partners as well as funding for management teams. The business plan competition has become a common venue for refining and developing business plans and communication skills of teams and providing them with the opportunity of getting feedback and advice from potential investors (venture capitalists and angels) and entrepreneurs who have built successful companies.

We have found it useful to look at this process as a three-fold, time-sequenced evolution:

(1) Internal competitions at Carnegie Mellon (at both undergraduate and MBA level) to select the best of our annual portfolio of opportunities. (2) Intercollegiate competitions held nationally "to raise the bar" on the level of competition and to gain a national perspective from entrepreneurs and investors. (3) The McGinnis Venture Competition, our own international intercollegiate MBA/graduate competition to provide both an international perspective and level of competition that can showcase our program and provide opportunities for a broader range of our constituents (students, faculty, and administrators) to see the venture creation process first-hand and to interact with international teams. We also bring in qualified judges from outside our region so that local investment opportunities can become more visible on a national level, and investments from outside the region can be facilitated. The judges include successful entrepreneurs, venture capitalists, and angel investors.

Additionally, we have developed and are building on two major initiatives focused outside the university. These are developed to provide access to networks of entrepreneurs, investors, technologists, service providers, and partners for our emerging companies.

- Alumni-driven hubs in technology centers in the United States: Our initial focus is in Boston and Silicon Valley, where CMU has a large base of alumni who wish to remain engaged with and provide support to the university. These regions have a large concentration of successful entrepreneurs and investors and clusters of companies that may be partners for emerging companies in the Pittsburgh region. We plan to engage our alumni and their networks for the resources needed by our emerging companies, i.e. capital, technology, and entrepreneurial leadership. Further, many of our graduates wish to locate in these regions once they graduate, so access to networks in these regions is beneficial to them in launching their companies and careers. We are contemplating extending these networks to other technology/biotechnology centers with high concentrations of Carnegie Mellon alumni.

- Network building in the local community: The startup process requires an extensive network of support for entrepreneurs, including funding for very early-stage companies (pre-VC level). The Pittsburgh region has developed a cluster of state- and foundation-funded initiatives that focus on the pre-seed funding and entrepreneurial support in areas of technology (Innovation Works and Idea Foundry), life sciences (Pittsburgh Life Science Greenhouse), and digital chip and robotics technology (Pittsburgh Digital Greenhouse and the Robotics Foundry recently merged to form the Technology Collaborative). These organizations represent our partners via an alliance with the university to provide a smooth transition from the university and business school environment into emerging companies. It is possible via this network for emerging companies to access ~\$1–\$1.5 million of investment prior to angel and VC involvement. Typically, these investments are not "priced" and the investment comes in the form of a convertible note with warrants (or discounts) that are valued at the first round of institutional investment. In the following section, we will illustrate how this network has been leveraged in the last few years to launch companies successfully out of the Tepper School. Beyond this alliance, there are also several organized angel groups that participate once early development, marketing, and management milestones have been achieved. These include LifeSpan, Blue Tree Capital Group, LLC, the Western PA Adventure Capital Fund, Smithfield Partners, and others. These groups have sufficient capital to bridge a company from the university to institutional venture capital both locally (via our local networks) and nationally (via our Boston and Silicon Valley hub networks).

4. RECENT CASE STUDIES

4.1. PlexTronics, Inc.

PlexTronics began in our entrepreneurship classes. In the summer of 2001, Richard Pilston, a Ph.D. candidate in Chemistry from the Mellon College of Science, visited the DJC for Entrepreneurship. He believed the research he was doing in conductive polymers for his Ph.D. under Dr. Richard D. McCullough, Professor of Chemistry and Dean of the Mellon College of Science, was potentially of commercial value. He wanted to investigate how he could form a company to commercialize this technology after graduation. We suggested that he enroll in 45-886 Entrepreneurship, an introductory course at the graduate level in entrepreneurship. That fall, Pilston completed his Ph.D. and received an appointment as a post-doctoral fellow in the Mellon College of Science. While his status as a post doc caused him to drop our course officially, we permitted him to audit the course to completion and to audit the Entrepreneurship Project course in the spring.

The business plan Dr. Pilston prepared and honed in these courses proved quite attractive, and we began to actively assist in the formation of PlexTronics, Inc. in April 2002. Andrew Hannah, an Adjunct Professor in our entrepreneurship program at the Tepper School and a three-time serial entrepreneur, became interested in the project and agreed to serve as CEO of the company. One of us (Emerson) contributed some seed capital personally, recruited Eric Boughner, an MBA in the class of 2002, as the third founder, and began discussions on technology licensing with the ITC. A worldwide license to the technology was granted by the ITC to PlexTronics only 7 weeks after discussions began. Dr. McCullough agreed to contribute some seed capital and to serve on the company's Board of Directors. We also arranged for seed capital and board service from Mr. Robert J. Gariano, a Carnegie Mellon graduate, who had a highly successful career in the plastics manufacturing industry.

Today, PlexTronics, Inc. is housed in a local industrial park. The company employs 18 people and is capitalized above $6.5 million. The company has produced working light-emitting diodes and photo-voltaic cells using its proprietary polymers and is negotiating joint development agreements with leading companies in the conductive polymer field. They were named in the Innovation World "21 List" as one of the 21 companies best poised for growth in the 21st century. In October 2004, *Fast Company* magazine wrote an article about the company which said, "PlexTronics may be sitting on the 'next small thing." *Red Herring* described the company as a "nanotech start-up to watch." In addition, the Commonwealth of Pennsylvania has named the company as a "gazelle company," and has provided a benefit package totaling $785,000.

4.2. ClearCount Medical Solutions, Inc.

ClearCount Medical Solutions, Inc. was a 2004 spinout of our program. Steven Fleck and Gautam Gandhi, two of the founders of ClearCount, were second-year MBA students in our program. Fleck had worked during the summer of 2003 at CardiacAssist, a local medical device company, where he met James D. Fonger, M.D., a well-regarded cardiothoracic surgeon currently practicing at Lennox Hill Hospital in New York City. Dr. Fonger knew of an inventor (Dean Morris) who held U.S. patents covering the use of RFID technology to track surgical sponges and instruments in the operating room. Mr. Morris had been unsuccessful in raising capital to support a startup company that would commercialize these patents. Fleck and Gandhi enrolled in our Entrepreneurship course and Technology Commercialization Workshop in the fall of 2003 and used this idea as their course project.

By the spring of 2004 they had become enthusiastic about starting the company. They met with the inventor and reached an agreement to assign the patents to the company, contingent upon success in raising the required capital. They also met with industry leaders such as Johnson & Johnson, and with operating room nurses and surgeons to determine market acceptability. Using funds from our NASDAQ grant they completed a working prototype of the scanning device. Their business plan won the Rice University Business Plan Competition, and they placed second in the Global Moot Corp Competition.

Today, ClearCount Medical Solutions is located in Oxford Centre, Pittsburgh, PA. The company has commitments of capital exceeding $500,000. They have attracted support from Idea Foundry, Innovation Works, and the Pittsburgh Life Sciences Greenhouse – three local economic development organizations. In addition, they won a $100,000 SBIR grant to fund testing of their device at Stanford Medical School beginning in January 2005. The initial clinical demonstration on a limited patient subset was 100% successful.

4.3. EADevices, Inc.

EADevices, Inc. was another 2004 spinout of our program. In preparation for the inauguration of the Technology Commercialization Workshop course, the two of us visited a number of local companies during the summer of 2003 to see if they had technology or ideas that they were not using that could serve as the basis of student projects. Medrad, Inc., a local medical device company, contributed the idea of an energy-assisted biopsy needle for gathering tissue samples from lungs or other sensitive organs. A source of ultrasonic energy would be coupled to the needle to supply the cutting force, greatly reducing the pressure that would be required to penetrate the tumor.

This project was taken up by three students in the Technology Commercialization Workshop: Joshua Gerlick, a second-year MBA candidate, Yogesh Oka, a senior computer science major, and Mark O'Leary, an

M.S. candidate in mechanical engineering. Using funds from our NASDAQ grant they built a crude working prototype and tested it in simulated tissue (a grape suspended in Jell-O) and in animal tissue. Their business plan won the Global Moot Corp Competition in May 2004. The company is seeking investors to provide development and working capital. They have attracted interest from several local economic development organizations.

4.4. Biostics, Inc.

Biostics, Inc. was another 2004 spinout of our program. As part of its MEMS (Micro-Electronic Mechanical Systems) research program, Carnegie Mellon holds a patent portfolio in the production of tiny membranes on silicon. Biostics is the fourth company to be created to commercialize this technology for various applications.

Bryan Allinson, a second-year MBA candidate in 2004, worked with a research group in the chemical engineering department at the Carnegie Institute of Technology (Carnegie Mellon's engineering school) that was using the MEMS membrane technology to develop a group of sensitive biological sensors. Their research has the potential to serve as the basis of biological "lab-on-a-chip" and biosensor technology. Biostics was formed to develop and exploit this potential.

At this point, the company is negotiating a license of the technology from Carnegie Mellon University's ITC. It is seeking SBIR and other grants to support further research.

5. SUMMARY, CONCLUSIONS, AND ISSUES

There is a role for an effective partnership between entrepreneurship centers and technology transfer offices – each brings its own skill sets and expertise to facilitate effective commercialization of inventions.

Note that this partnership may work differently in major technology hubs and centers of entrepreneurial activity (e.g. Boston, Silicon Valley, San Diego, etc.) as opposed to smaller university-driven hubs like Pittsburgh, Philadelphia, Cleveland, etc. Entrepreneurial community networks bridging the university with the community are much more established or mature in well-developed centers such as Boston and Silicon Valley vs. regions such as Pittsburgh, which are in the "development stage." Therefore, in development stage regions it is more important for the technology transfer office and the business school to play a more proactive role in company formation. We have developed university-based programs to affect such a proactive role. Additionally, it has been necessary for the university itself to assist in the development of an entrepreneur support network in the community and in alumni hubs to facilitate funding and mentoring of very early-stage companies. Both Carnegie Mellon University and the University of Pittsburgh have actively engaged in the creation of Commonwealth of Pennsylvania and foundation-supported organizations such as Innovation Works (part of the statewide Ben Franklin Program), the Pittsburgh Life Science Greenhouse, the Pittsburgh Digital Greenhouse, and the Robotics Foundry. These organizations act as funding sources for early-stage companies with funds being used for early-stage technology and intellectual property development, for product prototyping, clinical testing and other activities that are difficult to fund via venture capital sources.

Despite these early-stage support networks, we have identified a number of challenges as we work with young, emerging companies in the university setting. These include the following:

- IP protection in a classroom/workshop format: In our courses, we work with students on developing technology commercialization strategies based on their own ideas, as well as disclosures from the university and the community. During the course of classroom discussions, there is often inventive material that evolves (shared ownership issues). Additionally, it is possible for these working groups to be considered as a public disclosure and thus potentially jeopardizing patenting. So, both non-disclosure (public forum) and inventive contribution to IP by team members and classmates has emerged as a concern. This is somewhat different from the working group in the technical setting, where these issues are somewhat different and can be treated by existing university policies and procedures. Therefore, we have developed confidentiality agreements for use in our classrooms where such issues may exist.
- Team building and leadership development: One of the most important aspects of company formation is building the founding team and advisory structure very early on. Also splitting of founder's equity and the equity structure is an important subset of this issue. It is much easier to do this correctly in the first place than to have to redo it later. Therefore, as soon as it becomes apparent that a company is going to be formed and spun off, we actively counsel the participants in this regard. Introduction is also made to competent counsel. Along similar lines, it is often necessary to work with emerging teams to identify qualified and experienced team

members, including CEOs, CTOs, and CFOs. These often come from our networks both locally and non-locally, including our alumni.

- Funding at early-stage gap level: It is our opinion that when dealing with very early-stage technology commercialization there is a necessity to have access to capital for prototyping, market and competitive research, patent searches, and similar activities. While we have developed alliances in the community to provide funding when companies have actually been formed, the pre-company stage that we deal with requires access to small amounts of capital to support the investment decision by these economic development groups. A grant from NASDAQ provided such capital for some of our recent spin-off companies. We are currently exploring the feasibility of creating a pool of funds to support future activities, and we are planning to make such investments as convertible notes so that the Entrepreneurship Center can benefit from the equity upside of these companies in the event that they are successful.
- Alignment of interest of all constituencies: As with any new venture, it is essential for an alignment of interests of the constituents, including founders, investors, company, etc. In the case of university-based spin-offs, it is important to recognize the interests of faculty, students, founders, and university administration as well as the business school. All parties need to support and benefit from the spin-off in the event of success, and to share in the risk in the event of problems (which almost always occur). In a university setting one must, of course, be very mindful of conflicts of interest for faculty as well as conflicts of commitment. These should be addressed by effective university policies (see below).
- Effective Technology Transfer Policies (CMU approach – see the appendix for details).

APPENDIX. OVERVIEW OF CARNEGIE MELLON UNIVERSITY'S TECHNOLOGY TRANSFER POLICIES

From 2000 through 2001, the President and Provost of Carnegie Mellon University charged the University Research Council (URC) to undertake a thorough examination of the University's technology transfer policies, with a view toward replacement or major modification of those policies. One of us (Emerson) was a member of the URC and participated in the revision of these policies. The idea was to create technology transfer policies that were simple, fair, clear, and fast. In addition, the new policies sought to align the interests of the university with economic development efforts within the Pittsburgh region, and to assist the university in attracting and retaining the highest caliber faculty researchers. The URC noted that the policies of many universities, by focusing on maximizing revenue to the university, place the university in an adversarial role with respect to faculty researchers who seek to commercialize the results of their research. The URC recommended a different approach in which the university becomes a partner with researchers in efforts to commercialize their research.

The final report of the URC was submitted to the President and the Provost on November 4, 2001. The authors were the members of the URC listed on the first page of the report. It represented a concerted effort of over nearly a 2-year period to create a model policy for streamlining innovation transfer from the university to the commercial marketplace. During 2002, Carnegie Mellon University substantially adopted and implemented the recommendations of the URC. To our knowledge, the URC report has never been published, although a PowerPoint presentation of portions of the report has been on the Carnegie Mellon website since that time.

While some of the discussion is specific to Carnegie Mellon and to Pittsburgh, we feel that the issues dealt with by the URC are broadly applicable to the research university setting. We include excerpts from the report here in the belief that the discussion will be relevant to others addressing issues related to technology transfer and commercialization of university research.

Carnegie Mellon University, University Research Council Excerpts from the Recommendations from Deliberations of 2000–2001 Academic Year

URC Members

Christina Gabriel, Vice Provost for Corp. Partnerships and Tech. Dev., Chair
Michael I. Shamos, Inst. for eCommerce & Language Technologies Inst., Vice Chair
Margaret Stanko, Faculty Senate, Executive Officer
S. Thomas Emerson, Donald H. Jones Center for Entrepreneurship
Kaigham J. Gabriel, Robotics Inst. & Electrical and Computer Engineering
Paul J. Hopper, Department of English
Anne R. Humphreys, Learning Systems Architecture Lab
Peter Lee, School of Computer Science
Thomas A. Longstaff, Software Engineering Institute
Jonathan S. Minden, Biological Sciences

Eric H. Nyberg 3rd, Heinz School & Language Technologies Institute
Henry R. Piehler, Materials Science and Engineering
Joel M. Smith, Office of Technology for Education
Craig M. Vogel, School of Design
Howard D. Wactlar, Vice Provost for Research Computing & Computer Science

ABSTRACT

The year 2000 marked the 20th anniversary of the passage of the landmark Bayh-Dole Act, which gave universities the right to own and commercialize inventions resulting from government sponsored research. It was also the seventh year of operation of Carnegie Mellon's Technology Transfer Office. The URC has spent the 2000–2001 academic year considering what has been learned during that time, both here at Carnegie Mellon and by other universities across the nation, about the commercialization of university innovations. Based on this analysis, the URC proposes a new approach for enabling innovation and innovation transfer at this university. It is designed to achieve much greater success by drawing upon Carnegie Mellon's distinctive culture, which stimulates and supports interdisciplinary, problem-solving creative activity. Through the formation of a new entity that the URC would call the "Innovation Network," Carnegie Mellon can strengthen its existing education, research, and service programs related to entrepreneurship and commercialization, link them with each other, and build a set of active connections with the university's external communities. In this way, the Carnegie Mellon University environment will become more attractive to the faculty, staff, and students who would be most likely to enhance the quality and reputation of the university's research and education programs.

The URC has also reviewed Carnegie Mellon's existing policies and procedures related to commercialization and technology transfer. The URC recommends several changes that would improve the university's performance in these areas and support the Innovation Network model.

I. EXECUTIVE SUMMARY

Carnegie Mellon is recognized nationally for its extraordinary success at innovation, problem solving, and interdisciplinary collaboration. The opportunity to work closely with experts in other fields is a key attraction for many of the outstanding faculty, staff, and students who choose to come to this university. Not only does this culture create an intellectually stimulating environment, but it is also conducive to generating commercially promising innovations that can contribute to economic growth, especially in the Pittsburgh region.

Given the strength and pervasiveness of this culture, there is an overwhelming sense among campus innovators and the Pittsburgh regional community that significant improvements should be possible in the commercialization process at Carnegie Mellon. The URC was charged "to develop a new vision for enhancing Carnegie Mellon's contributions to society through the commercialization of the results of certain research and education efforts, to evaluate the university's existing policies relevant to the innovation process, and to recommend modifications as necessary to align them with the new vision." In carrying out this charge, the URC solicited input from members of the university community as well as others in the region. Information and perspectives were also gathered from a range of sources in other parts of the country and the world.

The scope of the URC's deliberations did not extend to a broader consideration of corporate partnerships. University policies for industry affiliates or centers programs, the use of university labs by commercial firms, applied research and prototype development, etc., were not part of the discussions of this academic year. These issues will require in-depth consideration and may be taken up by the URC as a next step. The URC also did not make recommendations on issues of courseware ownership, technology for education, distance education, and the university's role in developing and marketing courseware. The URC believes this set of topics should also be considered carefully within the next 2 or 3 years.

This report describes the results of the URC's review and analysis of the university's policies and procedures for commercialization. It puts forward a proposal for Carnegie Mellon to create an "Innovation Network" that would encompass, or make connections to, all campus activities that enable innovation and innovation transfer. The Innovation Network would also build stronger links to relevant organizations and individuals outside the university. An important goal of this approach is to open the university's innovation transfer and commercialization process to active engagement by people and organizations who have quality assistance to offer and who have a stake in improving Carnegie Mellon's contributions to the regional economy and beyond. The network would also stimulate activities across the campus that enable innovation and strengthen Carnegie Mellon's distinctive entrepreneurial culture.

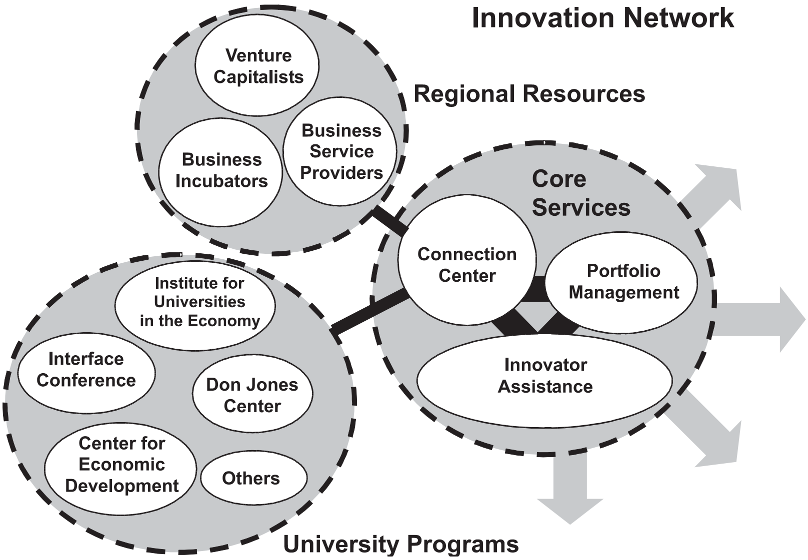

Fig. 3. A Schematic Representation of the Carnegie Mellon Innovation Network.

I. A. Innovation Network

A schematic representation of the Carnegie Mellon Innovation Network is shown in Fig. 3. The arrows emphasize that the overriding objective is to move innovations effectively from within the campus to the outside world. Commercialization assistance would be tailored to the needs of each innovator as a service to the campus community. The Connection Center would link innovators to university events and programs offering education and training, research, and benchmarking. It would also provide information about and introductions to resources that the region has to offer, such as the investor community and service providers for individual entrepreneurs or spin-off companies.

The current Technology Transfer Office (TTO) would cease to exist in its present form in this model, although many of its functions would continue to be carried out within the Innovation Network. Commercializable innovations at Carnegie Mellon often result from activities in the arts and humanities and therefore the current focus on "technology" needs to be broadened. In addition, the Innovation Network would enhance activities that stimulate innovation and facilitate its transfer, placing a particular emphasis on expanding promotion and marketing activities well beyond what the TTO can currently offer. These "enabling" functions would be separated from the administrative and regulatory functions that the university must perform by law to complete any licensing or commercial transaction. The most effective approach might be the creation of two entities within the Innovation Network, one to focus on assistance for innovators and entrepreneurs which might be called "innovator assistance" and one to handle administrative and regulatory functions as well as management of the university's intellectual property portfolio during the years after licensing agreements are signed. This latter set of functions could be called "portfolio management." The report offers a set of suggestions for how these activities could be structured, organized, managed, and evaluated. Finally, note that the URC has chosen to use the word "innovator" rather than the more narrowly construed "inventor" to describe an individual who creates a new concept with potential value for commercialization or other broad dissemination outside the university.

The Carnegie Mellon Innovation Network will provide:

- **Active assistance** tailored to an inexperienced innovator's needs.
- **Active facilitation of connections** to Carnegie Mellon alumni and regional resources for innovators.
- **A higher volume** of licensing activity, enabled by university policy changes and process improvements for innovation transfer.
- Space for spin-off company **incubation**.
- **Education initiatives** from the basics of the commercialization process to programs designed to stimulate entrepreneurship and an innovative campus culture.
- Rigorous **research** in the new Carnegie Mellon **Institute for Universities and the Economy**.
- **Evaluation** of progress and outcomes; **benchmarking** against programs in other universities and regions; **modification of programs** over time, based on evaluation and benchmarking results.
- A national leadership position through participation in national conferences and peer-reviewed publications.

I. B. Policy Recommendations

A commitment to enabling innovation and innovation transfer should be an integral part of the university's mission to benefit society. Commercialization assistance should be considered as a service that Carnegie Mellon needs to provide for its community of faculty, staff, and students.

In its licensing activity, the university's goal should be to maximize both financial and non-financial benefits over the long term from its relationship with each potential licensee. Procedures should be designed to be **simple, clear, fair, and fast**. That is, even from an inexperienced innovator's point of view, each step of the process and its rationale should be made easy to understand. There should be a sense that policies are applied consistently. Finally, decisions must be made without delay, recognizing that the commercial value of an innovation usually depends critically on the licensee's ability to bring a product to market more quickly than a competitor can do.

The URC proposes several changes in the IP Policy that will be necessary for this new, broader approach to be successful:

- Proceeds from the transfer of innovations should be shared by all creators, whether or not they have faculty status. In particular, the URC suggests a change that would enable staff members to be treated no differently from faculty researchers in this regard when they contribute in a similar way to open-ended research activities and the innovations that result.
- The university should demand a smaller percentage of equity in spin-off companies as well as of licensing revenues. The current 15% should be reduced to 5% , especially in those cases where the university elects not to invest its own resources in commercializing the innovation.
- In order to offer new and broader programs to encourage and enable innovation across the campus, the URC recommends that Carnegie Mellon change the algorithm that is currently in place for revenue sharing among innovators, their departments, and the university administration. The university should follow the example of other universities such as Stanford, by drawing a percentage of its gross proceeds from commercialization to pay for the more extensive core services that the Innovation Network would provide.

While the URC believes that the text of the policies addressing conflict of interest and conflict of commitment needs no modification, it may be necessary to change the oversight process to draw upon a new oversight mechanism, such as a standing or ad hoc committee, to advise the Provost rather than delegating authority entirely to the department head in many cases. At the suggestion of the Chair of the Faculty Senate, the URC also recommends that the university consult closely with faculty creators prior to making its decision about whether to commercialize their innovations, to ensure that any moral or ethical concerns are properly taken into account.

Finally, the URC recommends that all the policies and guidelines for commercialization procedures be simplified so that they are easier to understand and interpret by those who will need to follow them.

I. C. Vision

In interviews with individuals across the Carnegie Mellon campus and in the Pittsburgh regional community who have worked with the University's commercialization process, the URC heard a strong consensus that these constituencies continue to have significant concerns about the process. Central to the discontent is a sense that the university interacts with innovators as though it were in opposition to them, rather than showing enthusiasm for working toward a common goal. With the creation of the Innovation Network, the URC proposes a different process that emphasizes collaborative problem solving, and aims to put a new set of incentives in place to support this approach.

Vision: Carnegie Mellon should encourage the creation of innovations on campus and then to facilitate the timely and effective transfer of those innovations to the outside community. When commercialization would be the most effective mechanism for this transfer, the university needs to have policies, procedures and services in place, continually evaluated and modified as necessary over time, to ensure that the transfer proceeds smoothly and without unreasonable barriers or delays.

The new approach recommended here positions the university as **facilitator rather than adversary**. It draws upon and supports the university's **collaborative, entrepreneurial culture**. It puts stronger and more productive **campus-wide and regional connections** into place. As a result, the URC believes that the Innovation Network will enhance the university's reputation, make it easier for Carnegie Mellon to attract and retain world-class talent, and increase the probability that university innovations will lead to commercial success that will bring significant financial and other benefits to the university and play an important role in the revitalization of the Pittsburgh regional economy.

II. CARNEGIE MELLON INNOVATION NETWORK

Successful entrepreneurial economies thrive on the connections people make. The energy for creating and commercializing innovations is strongest when university researchers, investors, and business leaders can work together effectively as members of one community.

Carnegie Mellon intends to create an **Innovation Network** that will stimulate an innovative culture across the campus and enable the innovations created within the university to be transferred smoothly to benefit the community outside. Programs and services sponsored by the Innovation Network will be designed:

- to develop productive partnerships among and between faculty, staff, and students;
- to provide a comprehensive university resource for faculty, staff, and student innovators; and
- to facilitate a strong set of connections between university-based innovators and the investment and business community, particularly in the Pittsburgh region.

A primary goal of the Innovation Network will be to increase the level and effectiveness of the university's commercialization efforts.

Problem-focused, collaborative research is a distinguishing feature of the Carnegie Mellon culture. The opportunity to work in interdisciplinary teams is a key attraction for many of the outstanding faculty, staff, and students who choose to come to this university. Carnegie Mellon's interdisciplinary culture fosters an intellectually stimulating environment in technical fields as well as in the arts and humanities that often leads to the generation of commercially promising innovations. The purpose of the Innovation Network is to draw upon as well as support this creative, risk-taking culture and to improve the university's ability to contribute to the creation of broadly useful new products and processes as well as to economic growth, especially in the Pittsburgh region.

The Innovation Network will improve the understanding of innovation and innovation transfer across the campus and within the larger Carnegie Mellon and regional community with a coordinated set of new education, research, and innovator-assistance initiatives. For example, students, faculty, and staff will have a single point of entry that will enable them to know where to go and whom to ask for help with the development and transfer of their own innovations. Alumni will know how to contribute as mentors or investors for companies spinning out of the university. Members of the university community will be able to share the experiences they have had in entrepreneurship and technology development with their students and colleagues. And investors and the business community will find it easier to navigate university processes and administration to build new and expanded enterprises based on university innovations. The Carnegie Mellon Innovation Network will provide:

- **Active assistance** tailored to an inexperienced innovator's needs – the Network will provide assistance to the innovator for developing an effective presentation of a new concept, determining an appropriate commercialization avenue (*e.g.* licensing or new enterprise formation), developing a business and marketing plan, and pursuing financial and other resources to carry out the plan. Guidance for innovators will draw upon the expertise of a broad network of individuals, thus developing high-quality packaging for Carnegie Mellon innovations before they are presented to potential licensees or investors.
- **Active facilitation of connections** to Carnegie Mellon alumni and regional resources for innovators – a "Connection Center" will develop a network within and beyond the campus to provide connections to investors, business service providers, attorneys, technology and business mentors, candidates for key management positions in spin-off firms, *etc.* In the business commercialization process, the university will allow innovators to choose service providers either inside or outside the university for all innovation transfer functions except those for which the university is required by law to be the sole provider of the service.
- **A higher volume** of licensing activity, enabled by university policy changes and process improvements for innovation transfer. For example, experienced innovators may choose to have minimal university involvement and thereby reduce royalties and equity owed. Templates for legal documents will be simplified and clarified to reduce negotiation delay. Time to make decisions on university innovation investments will be reduced by involving more experienced reviewers in frequent, real-time decision meetings.
- Some space may be made available (*e.g.* in the Pittsburgh Technology Center facility) for spin-off company **incubation**, especially when collaborations with Carnegie Mellon research groups continue.
- **Education initiatives** – the Network will provide access to:
  education and training in the basics of commercialization;
  courses that bring an entrepreneur's perspective into the classroom;
  faculty-to-faculty courses to stimulate interdisciplinary collaboration.
  courses that focus on the "how-tos" of developing a commercial product, bridging the tension between promotion and production, and product innovation;
  expanded entrepreneurship programs for graduate and undergraduate

non-business majors and regional entrepreneurs; and entrepreneurship-focused campus events.

- Participation in the new Carnegie Mellon **Institute for Universities and the Economy** – rigorous **research** on entrepreneurship and the innovation process, technology policy, industry sector evolution, and regional economic development. The institute will evaluate and promote the regional and national economic impacts of university research and training through multi-disciplinary research, support of educational programs and university policies designed to advance the economic impact of universities, and support of public policy concerned with regional development. For some studies, the institute would use Carnegie Mellon and the Pittsburgh regional entrepreneurial community as a test bed.
- **Evaluation** of Innovation Network progress and outcomes; **benchmarking** against programs in other universities and regions; **modification of programs** over time, based on evaluation and benchmarking results.
- A national leadership position through participation in national conferences and peer-reviewed publication.

III. REQUIREMENTS FOR CREATING THE INNOVATION NETWORK

The Innovation Network will be managed as a loose federation of interconnected entities overseen by the university Provost. A director of the Innovation Network will be appointed to manage the core services and their connections to university programs and community resources. A key responsibility of the director will be to facilitate discussion and action, promote and foster synergies between and among all stakeholders, and communicate progress to all stakeholders.

Although technology patenting and licensing, along with some marketing and business incubation functions, are currently handled within Carnegie Mellon's existing Technology Transfer Office, the Innovation Network will address these functions in a different way while also offering the other new activities and services listed above. It is important to note that the Innovation Network will highlight "enabling" functions – related to the identification, articulation, and promotion of an innovation – and separate them from functions which concentrate on protection of IP rights, satisfying regulatory requirements, and negotiating certain clauses in legal documents. Emphasizing the "enabling" functions will be a significant change from current university practice and may require additional staff and resources dedicated to these tasks.

Some of the new and enhanced activities that the Innovation Network will need to develop are listed below:

- **Connection Center**: The Connection Center constitutes the heart of the Innovation Network. Its goal is to strengthen the interpersonal network that links innovators with campus and community resources such as investors, technology and business advisors, and professional service providers. It will also link them to each other and to the community of Carnegie Mellon alumni and friends so that more experienced innovators can mentor less experienced ones. It will provide basic information and a link to deeper educational resources on campus and in the community, so that even novice innovators will quickly be able to learn the processes they will need to follow for transfer of their innovation and to make informed choices at each step along the way. With quality screening and guidance from Innovation Network staff, the Connection Center will also enable innovators to seek and evaluate service providers from the community using a "food court"-style forum, with space for meetings, information in pamphlet and book form, and a database and web presence. Over time, as this network grows, this Connection Center hub will become a well-known regional community presence, and will become more and more valuable to campus-based innovators at several stages of the commercialization process.
- **Mentor–Investor Community Database**: The Innovation Network will draw upon a large number of experienced innovators, entrepreneurs, and technology and business professionals who have connections to Carnegie Mellon. Many faculty, staff, and alumni across the nation have expressed the desire to participate in the process as mentors, investors, and consultants to contribute to the success of less experienced innovators and support the university. A database of these contacts will be created, and the dedicated time of a key staff member will be provided within the Connection Center to build and maintain relationships and to broker appropriate connections with innovators.
- **Market Research**: Innovators often cannot predict the most promising commercial application for their innovation, and may not have sufficient knowledge of the targeted industry sector to be able to present a compelling case for investment or licensing. The Innovation Network will develop or purchase professional market studies relevant to each innovation and for classes of related innovations. In addition, a strategy for

making connections to key individuals in key companies in the sector of interest will be developed in each case. The Innovation Network will have several commercialization specialists on its staff, chosen for their deep knowledge about technologies and industry sectors representing the university's strongest target application areas. Ideally, they will also have their own well-developed networks of connections based on their personal experience in those sectors. These specialists will be able to interpret market data in light of this knowledge and provide a dramatic improvement in the university's ability to commercialize its innovations effectively.

- **Enabling Faculty Participation**: Many Carnegie Mellon faculty have extensive experience with innovation and commercialization. Sharing that knowledge with students who will themselves often become entrepreneurs, or acting as mentors to other faculty, contributes to the success of individual innovators as well as to the health of the entrepreneurial culture on campus and in the community. However, the departments where "commercializable" innovations are most likely to emerge, and where faculty are most likely to have experiences to share, also tend to be the same departments where demand for courses is high and faculty teaching loads are large. Funding to enable those departments to support a small surplus of faculty lines would enable some faculty to teach courses to potential collaborators in other fields, to serve on innovation review committees or as mentors for university innovators, or to take a leave of absence to pursue a short-term entrepreneurial activity in the Pittsburgh community. For example, starting in the fall term, 2001, a faculty researcher in the biological sciences will teach a course to a group of interested faculty colleagues in other research fields. This **"Foundations to Frontiers" course** will first teach basic introductory concepts in the instructor's field, and then present several unsolved research problems that are the current "grand challenge" issues in the field. Once basic concepts are understood, experts in other fields will be more likely to see the contributions their specialized expertise could make toward solving the grand challenges collaboratively.
- **Expansion of Entrepreneurship Courses and Training**: The DJC for Entrepreneurship within the Graduate School of Industrial Administration (currently the Tepper School of Business) is expanding its course offerings in entrepreneurship, and several of the other schools on campus are developing programs in entrepreneurship for non-business majors. Investment is needed to meet the demand for entrepreneurship education from both undergraduate and graduate students majoring in other disciplines.

Additional sections of existing classes at the business school will be offered to interested students, with an intense short-course offered first to provide the essentials of the required background. All of the class sections will include both business and non-business majors, so that students will mix and work with each other on team projects, promoting cross-fertilization. The university would also like to scale up its offerings in entrepreneurship education for executives from regional companies, which can be focused on the needs and interests of particular industry sectors. Finally, staff from the sponsored research and technology transfer offices would like to expand the training they offer to members of the Carnegie Mellon community who do not already have substantive experience with the university's policies and procedures for patenting, licensing, and new venture formation.

- **Incubation Space**: Carnegie Mellon's Pittsburgh Technology Center building offers high-quality space where spin-off companies could be located adjacent to labs where their research collaborators work. However, the facility's costs are high relative to the cost of incubator space elsewhere in the region, particularly outside the city limits. A subsidy to help defray these additional costs would enable new, high-growth companies to work more closely with university researchers while they are in the early phases of development, when such collaboration is most critical to their success.
- **Campus and Community Links; Events**: The Innovation Network will sponsor events on campus (such as an "Innovation Fortnight," which a member of the URC proposed as an annual 2-week period of innovation-focused seminars and conferences, and the annual student-run "Interface" technology-business conference) that are designed to encourage greater understanding of innovation and foster a culture of entrepreneurship across the campus and in connection with the regional community. In addition, Carnegie Mellon will participate more fully in related programs sponsored by other regional organizations, such as the educational programs of the National Foundation for Teaching Entrepreneurship, the Pittsburgh regional EnterPrize business plan competition, and Leadership Pittsburgh.

IV. OPERATIONAL SUGGESTIONS FOR INNOVATION TRANSFER PROCESS

Carnegie Mellon's goal for innovation transfer is to enable university-generated innovations to find an appropriate path out of the university for

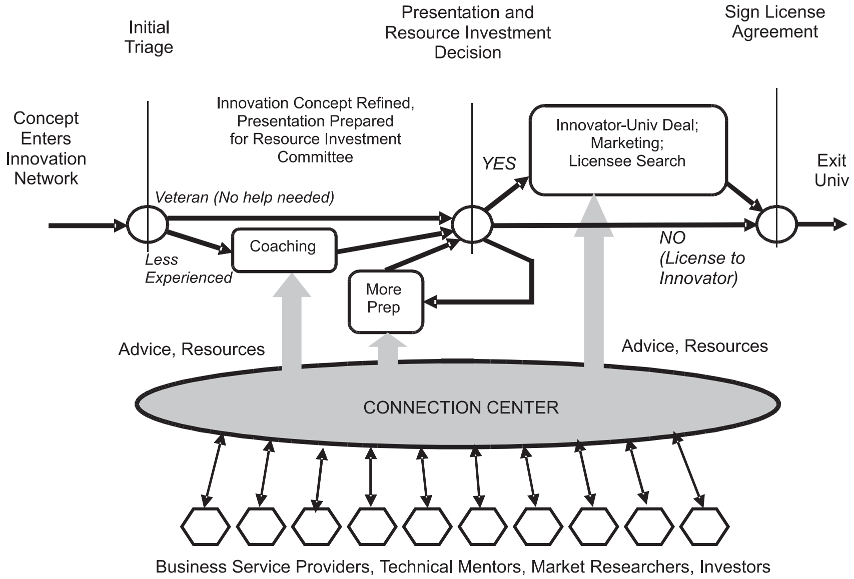

Fig. 4. The Path Followed by an Innovation through the Innovation Transfer Process.

broader use in society, and to offer services to innovators as needed so that this transfer will be effective in each case. To do this, the Innovation Network must provide a process that draws upon a variety of resources, both from within the university and from the community.

Innovation transfer may be described as a packaging and marketing function. A concept, idea, or invention must be shaped and articulated, or ‘‘packaged,’’ so that it can be presented effectively to those constituencies, or markets, that might find it of value to them. Therefore, the university's focus should be on guiding innovators as necessary to develop a convincing case for the worth of their innovation to potential markets, making a decision about whether to invest university resources, and then seeking and closing a deal with an appropriate licensee outside the university to complete development and dissemination of the innovation and its derivative products and processes.

The path followed by an innovation through this process is depicted in Fig. 4. An innovator or group of innovators, who may include faculty, staff, or students, present a rough description of their innovation, concept, or idea to a front-door gatekeeper, labeled as the "initial triage" point in the figure. The gatekeeper determines what level and character of guidance the innovators will need to develop their concept and make the case for university investment.

If help is needed, it could take a variety of forms. The gatekeeper would assign a "coach" to the innovators to provide this help by drawing upon university and community resources. Coaches would be responsible for providing guidance well matched to an innovator's level of experience. This guidance might include such things as preliminary market research and connections to mentors outside the university. The coach would also work with the innovators as they prepare their case to ask the university to invest its resources in patenting, marketing, and other tasks required to commercialize the innovation. Each innovation is different and will likely require a different level of attention during this initial pre-decision phase, although only nominal university resources other than staff time will be used.

If no help is needed in this phase, which would likely be the case when the innovators are experienced veterans, then no coach is assigned.

Key to the success of this process will be the quality and timeliness of the investment decisions that the university must make for each innovation. The director of the Innovation Network, reporting to the Provost, would be responsible for these university resource allocation decisions. To advise the director, the URC proposes the formation of a standing Resource Investment Committee. This group would be composed of faculty, staff, alumni, and others who have been properly screened and who agree to confidentiality. In order to conduct a fair and expert evaluation of the potential of each innovation, a range of area expertise will be required among the committee members. In addition, it may be necessary to draw upon individuals outside the university in particular cases. The committee would meet as often as necessary (probably weekly) and would be larger than necessary so that meetings could be scheduled even in the absence of several committee members. With help needed from Innovation Network coaches, innovators would make carefully constructed presentations in real time to the committee and would provide backup information in writing. The committee would evaluate the innovation based on this material and make an investment recommendation in each case to the director of the Innovation Network.

If a decision is made to invest, the committee would also recommend a list of action items to be accomplished with university and community resources for the next phase, which would likely include intellectual property protection, active marketing, and negotiation with potential licensees. The university's investment would cover patenting costs, market research services and other business services contracted to outside firms, travel, and so on.

The final step in the transfer process, after a licensee is identified and negotiation underway, is to draw up the formal license agreement. It is at this point that the Innovation Network's Portfolio Management function first becomes involved. Portfolio Management would be responsible for coordinating the final stages of negotiation, ensuring consistency with university policy, and appropriate signatures. In the following years while the license agreement is in effect, Portfolio Management would also assume responsibility for monitoring compliance of the licensee to the terms of the agreement, verifying that milestones have been achieved, invoicing for royalty payments, and watching over the university's intellectual property portfolio to take appropriate action in cases of patent violation.

The Innovation Network's Connection Center plays a role at several stages of the process. Connections to service providers, mentors, and investors will become more effective over time as the network gains experience and becomes known to the broader Carnegie Mellon community. It will be especially valuable, for example, for campus innovators to engage the interest of alumni who have skills, experience, or financial resources to offer. An important collateral objective of the Innovation Network is to deepen and strengthen the bonds between the university and its alumni, industry partners, and organizations in the Pittsburgh regional community. The Connection Center offers a means toward that end.

As organizations responsible for providing services to the university community, the Innovator Assistance and Portfolio Management functions, in particular, ought to take advantage of best practices that have become common in customer service industries. For example, staff in these offices should be using one of the standard commercially available information systems to track the progress and timing of each innovation transfer as well as relationships with all of their "customers" on campus and outside. To evaluate and shape the Innovation Transfer process over time, the URC recommends that the Innovation Network develop a set of quantitative and descriptive metrics that can be tracked and monitored. For example, these could include the number of concepts that enter the front door, the number of presentations made to the Resource Investment Committee, the time elapsed between various checkpoints in the process, the number of marketing interactions, and the number of concepts successfully licensed during a given interval. Taken in the aggregate along with the measures of royalty income published by the AUTM, a set of carefully defined metrics could enable the university to use principles of continuous improvement to build greater effectiveness over time and provide quantitative data to be used in making staffing and investment decisions.

A rough estimate based on current levels of activity at the university indicates that the following staff would be necessary to support the director of the Innovation Network in managing this process effectively:

- 1 gatekeeper at the front door (this position may rotate with other functions)
- 3 coaches
- 2 marketing specialists
- 2 licensing officers
- 1 administrative assistant
- 1 financial manager

Finally, in order to offer new and broader programs to encourage and enable innovation across the campus, the URC recommends that Carnegie Mellon change the algorithm that is currently in place for revenue sharing among innovators, their departments and the university administration. The current model returns half the proceeds realized from a given docket, after covering that docket's expenses, to the innovators; one-fourth to their departments; and one-fourth to the administration. This remaining fourth has amounted to roughly half the TTO's operating costs in recent years. As a result, general university funds have been required as a subsidy for the remainder. In addition, a substantial debt has accumulated to date, representing the aggregate of docket expenses for unsuccessful commercialization attempts and those cases that have not yet begun to generate revenue. Note that Carnegie Mellon chose to invest the capital gains from the Lycos transaction toward construction of Newell-Simon Hall; had these funds been reinvested in the TTO, the office could have operated for several years without a subsidy. The URC believes that the appearance of a need for subsidy currently creates pressure for short-term revenue generation, whether or not intended, that is destructive to the university's service mission for this function.

The URC believes that the university should not need to subsidize innovation transfer on an annual basis. The Innovation Network must be judged on its ability to cover its costs as well as bring additional benefits to the university, and must be held accountable for its ability to meet this objective. Revenue beyond self-sufficiency will enable the university to support new initiatives.

The URC notes that other major universities deduct 15% from their commercialization proceeds to cover the expenses of their licensing offices, prior to distributing these revenues among the innovators and university units. The URC proposes likewise that Carnegie Mellon should set aside a fraction of the university's proceeds from commercialization (after covering legal expenses) to offset the Innovation Network's operating expenses.

ORGANIZATIONAL MODULARITY AND INTRA-UNIVERSITY RELATIONSHIPS BETWEEN ENTREPRENEURSHIP EDUCATION AND TECHNOLOGY TRANSFER

Andrew Nelson and Thomas Byers

ABSTRACT

Both entrepreneurship education and commercialization of university research have witnessed remarkable growth in the past two decades. These activities may be complementary in many respects, as when participation in an entrepreneurship program prepares a student to start a company based on university technology, or when technology transfer personnel provide resources and expertise for an entrepreneurship course. At the same time, however, the activities are distinct along a number of dimensions, including goals and mission, influence of market conditions, time horizon, assessment, and providers and constituency. We argue that this situation presents an organizational dilemma: How should entrepreneurship and technology transfer groups within a university maintain independence in recognition of their differences while still facilitating synergies resulting from overlapping areas of concern? In response to

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this dilemma, we draw on the organizational modularity perspective, which offers the normative prescription that such situations warrant autonomy for individual units, but also require a high degree of cross-unit awareness in order to capture synergies. To illustrate this perspective in an intra-university population of entrepreneurship and technology transfer groups, we present network images and statistics of inter-group relationships at Stanford University, which is widely recognized for its success in both activities. The results highlight that dependence between groups is minimal, such that groups retain autonomy in decision-making and are not dependent on others to complete their goals. Simultaneously, cross-unit awareness is high, such that groups have frequent formal and informal interactions and communication. This awareness facilitates mutually beneficial interactions between groups. As a demonstration of the actual functioning of this system, we present three thumbnail case studies that highlight positive relationships between entrepreneurship education and technology transfer. Ultimately, we argue that to fully realize the synergies between entrepreneurship education and technology transfer, we must also recognize differences between them and ensure the autonomy that such differences warrant.

1. INTRODUCTION

Recognizing the important role that universities play in innovation and in economic growth as a whole, innovation and management scholars have increasingly turned an analytical lens on universities themselves. On one hand, university engagement with external economic interests is nothing new. In *Universities in the Marketplace*, Bok (2003) reminds us that as early as 1915, the Yale University football team earned more than $1 million (in current dollars) for the university. Rosenberg (2002) offers several early examples of state universities' interaction with local industry. Similarly, Lenoir et al. (2004) describe the co-evolution of Stanford University and Silicon Valley over several decades. But, on the other hand, recent decades have witnessed deepening ties between U.S. universities and the marketplace. Indeed, university–firm boundaries in the United States have become a model as other regions and governments attempt to emulate their apparent success (Mowery & Sampat, 2004).

This chapter focuses on two particular changes that concern universities' engagement with external economic interests. First, the past two decades have witnessed a remarkable growth in technology licensing from universities (Association of University Technology Managers (AUTM), 2004; Mowery, Nelson, Sampat, & Ziedonis, 2001). Such activity is indicative of the university's role in technology transfer activities and of changes in this role. Second, recent years have witnessed an explosion of entrepreneurship education programs, not only within MBA courses, but also serving undergraduates and graduates in a variety of other disciplines (Charney & Libecap, 2000; Vesper & Gartner, 1997). These programs have expanded beyond formal courses to include seminars, business plan competitions, university-facilitated internships, and student organizations.

Our purpose in this chapter is to consider the relationship between these two activities – technology transfer and entrepreneurship education – and to offer normative observations regarding the appropriate organization of these activities within the university. We take as our starting point a survey of programs at Stanford University, which has been identified as particularly successful in both technology transfer and entrepreneurship education. This success lies in Stanford's ability to capture synergies between these activities, while simultaneously recognizing that they are fundamentally different along some dimensions. For example, students' experiences in entrepreneurship education activities may lead them to later transfer technologies from the university. But, technology transfer and entrepreneurship education groups are assessed according to their own criteria and maintain autonomy in their activities and strategies. The Stanford arrangement therefore reflects a "modular" (Brown & Eisenhardt, 1997; Martin & Eisenhardt, 2003) organization in which administrative interdependence and hierarchical structures are minimized, while cross-unit awareness and bottom-up processes are maximized.

We begin by describing trends in both university technology transfer and entrepreneurship education in Section 2. In Section 3, we describe both potential synergies and distinctions between the two activities. In Section 4, we present a network analysis of relations between Stanford groups along a number of dimensions to illustrate the organizational modularity perspective. Section 5 supplements this overall picture with three thumbnail case studies that provide a rich understanding of how relations may play out. Finally, in Section 6 we offer conclusions and discuss limitations and extensions of our study.

2. TRENDS IN UNIVERSITY TECHNOLOGY LICENSING AND ENTREPRENEURSHIP EDUCATION

Over the past two decades, both university technology licensing and entrepreneurship education have experienced remarkable growth. As we will illustrate, these trends are important not only individually, but also for the potential relations between the two activities. For example, increases in technology licensing may provide motivation for growing entrepreneurship programs, the success of which may in turn lead to further increases in licensing. Proper management of this relationship is essential, however, to the health of both activities.

University technology transfer can be defined very broadly to describe "the movement of ideas, tools, and people among institutions of higher learning, the commercial sector and the public" (AUTM, 2004). This movement may take place through a variety of mechanisms, including formal education, such as training provided to students and to current employees via continuing education programs; knowledge sharing, including personnel exchanges and faculty consulting to industry; public dissemination, such as journal articles, books and conferences; research relationships, including sponsored research; and technology licenses. In a similar vein, Cohen, Nelson, and Walsh (2002) list several sources for industry information about university technologies: patents, informal information exchange, publications and reports, public meetings and conferences, recently hired graduates, licenses, joint or cooperative ventures, contract research, consulting, and temporary personnel exchanges.

Certainly, some mechanisms are more important than others. In a survey of 600 U.S. R&D managers, Nelson and Levin (1986) found that three quarters of the most important contributions of academic research to technological development were in the form of uncodified knowledge and skill transfers. Only one quarter were in the form of codified knowledge such as patents and licenses. Thursby and Thursby (2000) found that licensing executives pointed to personal contacts and, less so, publications and presentations as their most important sources for university technologies. Cohen et al. (2002) relay the importance of various mechanisms for each of several industries. Across all industries, publications, public meetings, and conferences were the most important, followed by informal information exchange and consulting.

Nevertheless, one of the most salient measures of university technology transfer may be found in licensing and patenting data. In the past 2 decades, licensing and patenting of university technologies has increased significantly. Mowery et al. (2001) relay data from the United States Patent and Trademark Office (USPTO) that utility patents issued to all U.S. universities and colleges rose from 188 in 1969 to 264 in 1979, and 2,436 in 1997. In fact, according to AUTM, the vast majority of university technology transfer offices were started in the past two decades. AUTM's membership itself swelled from 1,015 in 1993 to 3,155 in 2004.

Since 1993, AUTM has administered an annual survey to track changes in university patenting and licensing. While year-to-year statistics are not strictly comparable due to changing respondent groups, the survey indicates that licenses and options yielding income rose from 2,711 in FY1991 to 10,682 in FY2003 (AUTM, 2004). Even considering only those universities that were consistent respondents from 1994 to 1998, yearly invention disclosures increased by 7.1% per year (Thursby & Thursby, 2002). Moreover, increases are apparent not only in the number of invention disclosures, but also in the percentage of those on which patent applications are filed, rising from 26% in 1991 to 51% in 2003. Much of this licensing (12.9% in FY2003) is to start-ups, meaning companies that were established specifically to develop the licensed technology. A further 52.5% of FY2003 licenses were to existing small companies with less than 500 employees (AUTM, 2004).

Stanford's invention and license data is representative of these national trends. At Stanford, invention disclosures grew from 28 in 1969 to 362 in 2003, while licenses grew from 3 to 127 for those same years. Similarly, annual royalty income grew nearly 1000-fold from 1969 to 2003, rising from $50,000 to $45.4 million. Thus, Stanford's Office of Technology Licensing (OTL) has grown into a relatively large office with seven licensing professionals and 25 total staff members, which consistently ranks among the top 10 offices in annual royalty income.

Many scholars have noted that the rise in university licensing coincided with the passage of the Bayh-Dole Act of 1980 (Henderson, Jaffe, & Trajtenberg, 1998; Mowery et al., 2001; Mowery & Ziedonis, 2002). While some findings indicate that this has coincided with a decline in the "importance" and "generality" of university patents (Henderson et al., 1998), other studies (Mowery et al., 2001; Mowery, Sampat, & Ziedonis, 2002) indicate that such a decline is due to new, less-skilled entrants into academic patenting, rather than declines among existing players. Owen-Smith and Powell (2003) find further evidence for this latter perspective, noting the importance of network ties to industry in enabling institutions to develop higher impact patent portfolios. Thus, in short, there appears to be an important "learning" process among university technology licensing offices.

Learning processes of a different sort characterize a second major trend on university campuses. In recent years, entrepreneurship courses and programs have experienced remarkable growth. Charney and Libecap (2000) note that within a 50-year period, entrepreneurship education has grown from a single course to a wide range of opportunities at more than 1,500 colleges and universities around the world. Vesper and Gartner (1997) estimate that 400 colleges and universities offered entrepreneurship courses in 1995, up from approximately 16 in 1970. Solomon et al. (2002) estimates that this 1995 number tripled to as many as 1,200 in a scant 5-year period. Katz (2003) provides a detailed chronology of entrepreneurship education from 1876. He concludes that since the first university class in 1947, "an American infrastructure has emerged consisting of more than 2,200 courses at over 1,600 schools, 277 endowed positions, 44 English-language refereed academic journals and over 100 centers" (Katz, 2003, p. 284).

As the number of programs has grown, so has the range of offerings. Indeed, our review of various offerings at Stanford indicates that entrepreneurship education may take a variety of formats, including:

- Courses – both full-credit and seminars – on a wide range of subjects, including venture capital, technology/innovation management, new venture creation, and entrepreneurial marketing
- Internships, including both stand-alone internships and work/study internships that are integrated with a course
- Competitions (with accompanying workshops) for new for-profit businesses, new non-profit businesses, and pure technological innovation
- Research by faculty and Ph.D.s
- Student clubs and organizations
- Conferences and outreach to both educators and industry.

Moreover, these activities are organized across a variety of schools, including business, engineering, and medicine (Vesper, 1986; Kauffman, 2001). The prevalence of programs in both engineering and medicine is particularly notable since those same individuals who may create scientific and technological breakthroughs are also being trained to develop these breakthroughs commercially. Stanford's School of Engineering provides an illustrative example of these trends. As late as 1995, the School of Engineering offered a single entrepreneurship course with a maximum enrollment of 65 students. It now offers 13 courses with 1,500 seats available across a variety of entrepreneurship subjects. These, of course, complement offerings in the medical and business schools, the latter offering 20 courses with 1,850 seats.

Given the increases in both university licensing and entrepreneurship education, a natural question concerns the relationship between the two. The entrepreneurship literature offers limited discussion on the role of education. Studies have found that entrepreneurs with a good education tend to be more successful than those without (Vesper, 1990; Robinson & Sexton, 1994). Education also positively influences entrepreneurial intentions

(Autio, Keelyey, Klofsten, & Ulfstedt, 1997; Krueger, 1993; Peterman & Kennedy, 2003). But, little research examines the impact of entrepreneurship courses on entrepreneurial activity itself, particularly as that activity intersects with technology transfer (Honig, 2004; Gorman, Hanlon, & King, 1997; Autio et al., 1997). In an important contribution toward this research gap, Charney and Libecap (2000) find that entrepreneurship education contributes to the formation of new ventures, increases the propensity of graduates to be self-employed, contributes to the growth of small firms, and promotes technology transfer from the university to the private sector.

Our own intention in this chapter is not to provide a quantitative assessment of the impact of entrepreneurship education on technology transfer. Rather, we start with a simple pair of observations: (1) entrepreneurship education and technology transfer share obvious synergies and (2) entrepreneurship education and technology transfer have (somewhat less) obvious differences. To illustrate the first observation, we offer initial results from a survey of groups at Stanford. To expound the second observation, we distinguish between entrepreneurship education and technology transfer along a number of dimensions. The coexistence of both synergies and differences sets the stage for our primary question: How should a university structure relations between entrepreneurship education and technology transfer activities?

3. TECHNOLOGY TRANSFER AND ENTREPRENEURSHIP EDUCATION: SYNERGIES AND DISTINCTIONS

There are two aspects to synergies between technology transfer and entrepreneurship education. First, entrepreneurship education may enhance technology transfer efforts. Second, technology transfer may, in fact, enhance entrepreneurship education. Fig. 1, a network illustration of collaboration in teaching, offers an example of this latter perspective.[1] (The appendix describes the various groups.)

As the figure indicates, Stanford's OTL is not at all disconnected from this activity. In fact, the OTL's eigenvector centrality score places it eighth out of 13 among the groups.[2]

Ties between entrepreneurship and technology transfer groups are multifaceted and may carry a number of benefits. We surveyed each of the Stanford groups involved in these activities about the benefits they have

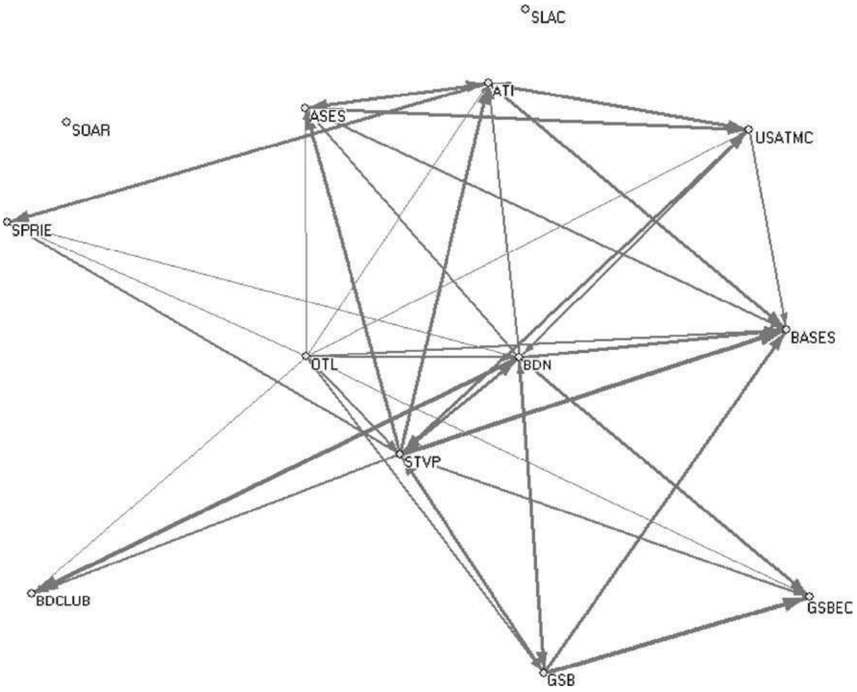

Fig. 1. Responses to the Question "Faculty or Staff from your Group are Involved in Teaching students from:" Thickness of Line Indicates Frequency on a Five-point Scale from "Never" To "Nearly Always."

realized from interacting with other groups in the survey set. The results are relayed in Table 1.

Every group with a technology transfer component responded that interaction with entrepreneurship education groups led to more effective technology transfer. Moreover, entrepreneurship groups pointed to the importance of various types of information and access due to interaction with technology transfer groups. For example, courses have benefited from using Stanford inventions for their class projects and from OTL participation in these courses. Thus, in sum, not only does entrepreneurship education enhance technology transfer, but technology transfer can be an integral part of entrepreneurship education, providing resources and first-hand experience to aid in classroom objectives.

Table 1. Benefits from Interaction with Other Groups.

Information about activities	12
Collaboration on activities	11
Access to other people within the university	9
Access to resources	8
Access to students	8
Access to people outside the university	7
Information about best practices	6
Other information	6
Access to faculty	6
Information about technologies	4
Improved educational opportunities	4
More effective technology transfer	4
Increased stature/prestige	1

The existence of synergies should not, however, obscure differences between technology transfer and entrepreneurship education. Indeed, the activities are distinct along a number of dimensions, including goals and mission, market influence, time horizon, assessment, and providers and constituency. These distinctions are summarized in Table 2.

3.1. Goals and Mission

The mission of the Stanford OTL is to "transfer Stanford technology for society's benefit and to generate royalty income to support research and education" (Stanford OTL, 2005, p. 1). Thus, there is both an economic aspect to the activity along with a desire for social good. Technology transfer is central to both goals. Jensen and Thursby's (2001) survey of technology transfer offices at 62 U.S. research universities reveals that these offices share similar goals. At least 50% of respondents indicated that revenue, inventions commercialized, and licenses executed were "extremely important" outcomes.

By contrast, entrepreneurship education is centered on learning rather than technologies. Solomon, Duffy, and Tarabishy (2002, pp. 1–2) argue that the purpose of entrepreneurship education is to "produce entrepreneurial founders capable of generating real growth and wealth." Charney and Libecap (2000) note that entrepreneurship education may accomplish a variety of goals: integrate various courses and disciplines; provide the foundation for new businesses (economic growth); improve graduates' employment prospects; promote the transfer of university-based technology; forge

Table 2. Distinctions between University Technology Transfer and Entrepreneurship Education.

	Technology Transfer	**Entrepreneurship Education**
Goals and mission	Commercialize inventions; generate income	Develop leadership skills; integrate courses and disciplines; provide the foundation for new businesses; forge links between academic and business communities; promote university technology transfer
Influence of market conditions	Significant	Less
Time horizon	0–10 years	0–40 years
Assessment	Straightforward: Inventions commercialized; licenses executed; revenue	Difficult: student enrollment and evaluations; correlations with later behavior
Providers and constituency	Administrators and firms (that may involve faculty and/or students)	Faculty and students

links between the business and academic communities; and provide an opportunity to experiment with curriculums. To this exhaustive list, we might add the development of leadership skills.

3.2. Influence of Market Conditions

These differing goals are reflected in the extent to which the market and commercial concerns influence technology transfer and entrepreneurship education, respectively. Since technology transfer typically involves transactions in the marketplace (in the form of technology licenses), market logics influence it extensively. Participants in the process must not only embrace the language and norms of the commercial sector, but also interact with it extensively if their programs are to be successful. A downturn in the economic climate for a particular industry will typically have a direct effect upon licensing efforts in that industry. Conversely, entrepreneurship education is first and foremost a scholarly pursuit. Therefore, it is relatively isolated from market pressures. While entrepreneurship education, too, often embraces the language of the commercial sector, interactions are often based upon theory or historical case studies, which are not directly tied to current market conditions and which therefore permit some degree of separation from this influence.

3.3. Time Horizon

The market orientation of technology transfer offices is reflected in their relatively short time horizon. In a study of Harvard University technology licenses, Elfenbein (2004) found that a new invention's hazard rate of first sale reached a peak approximately 12 months after disclosure and declined steadily from that point. Conversely, entrepreneurship education often has a "career" focus, with payoffs realized over the course of several decades. In fact, there may be significant time lags between participation in an entrepreneurship program and later related behaviors, such as starting a new venture. These lags also make assessment of entrepreneurship programs challenging.

3.4. Assessment

Assessment of technology transfer efforts is straightforward. Indeed, the outputs that Jensen and Thursby (2001) identify – revenue, inventions commercialized, and licenses executed – are easily measured. The AUTM (2004) licensing survey includes a number of additional measures as well, such as patents and start-up activity, which are also amenable to simple tallies.

By contrast, it is difficult to measure the performance of entrepreneurship education activities (Block & Stumpf, 1992; McMullan & Long, 1987). Certain quantitative measures of program elements themselves are available, including enrollment and student evaluations. But, to assess the subsequent impact of these programs is more challenging and studies are therefore limited (Wang & Kleppe, 2000). The issues are twofold. First, the number of observations is relatively small. Since entrepreneurship programs are relatively new, extensive longitudinal data are absent. To the extent that variables of interest – such as technology transfer – exhibit time lags between education and impact, this problem is exacerbated. Similarly, numbers surrounding outcome variables of interest are also small. For example, the most recent AUTM licensing survey (AUTM, 2004) reports that 374 new companies based on an academic discovery were started in FY2003, reported by 190 institutions. Even the most successful institutions such as Stanford average less than a dozen new start-ups per year, including those founded by professors (not only students). Thus, correlations between entrepreneurship education and later behaviors may suffer from small samples.

A second challenge lies in the fact that numbers may be misleading. For example, quantitative analysis of the relationship between entrepreneurship education and technology transfer may fail to capture those cases in which participation in a course, club, or activity led a student *not* to pursue a business idea. While such decisions may be counted as a success from an educational and business perspective, they complicate attempts to compute a simple positive correlation between education and technology transfer or new venture creation. As a result, most assessments of entrepreneurship education rely on qualitative accounts (Wang & Kleppe, 2000).

3.5. Providers and Constituency

University technology transfer offices are typically staffed by professionals with backgrounds in business, law, and/or specific realms of science and technology. These employees are part of the university's administration, not its faculty. They serve a bridging role in the network between faculty and students, who provide the invention disclosures, and industry representatives (including entrepreneurs), who consume them. By contrast, the providers of entrepreneurship education are faculty. These instructors may include both regular tenure-line professors and adjunct faculty in business, engineering, medicine, and law, often with extensive entrepreneurial experience. The consumers of this output are students.

3.6. Discussion

Certainly, the above delineation between technology transfer and entrepreneurship education is not exhaustive and finds its foundation in our observations at Stanford. But regardless of its precise reflection of the specific situation at other universities, the fact remains that technology transfer and entrepreneurship education are different along many dimensions. Moreover, entrepreneurship education programs themselves may vary in specific goals, students, regional emphases and, of course, format. Indeed, the variety in entrepreneurship programs even within a single university is one indication that entrepreneurship education is multifaceted.

It is from the variance across these dimensions that a management dilemma arises: on one hand, there are clear synergies between entrepreneurship education and technology transfer programs; on the other hand, if programs are too tightly coupled, it is impossible to successfully pursue multiple goals and outputs by diverse providers serving varied constituencies and assessed according to different criteria under separate timetables. In other words, units cannot be completely disconnected, such that they miss opportunities for fruitful collaboration. But, they need to interact in a way that is sensitive to their differences.

4. ORGANIZATIONAL STRUCTURE AND PROGRAM NETWORKS

Friedland and Alford (1991) developed the concept of an institutional logic to capture the material practices and symbolic constructions that constitute an institution's organizing principles (see also Scott, Ruef, Mendel, & Carconna, 2000; Thornton, 2004). Thus, differences in goals – and the diverse influence of market conditions, time horizons, assessment standards and participants that these differences entail – may be taken as indicative of different logics associated with technology transfer and entrepreneurship education. These logics may both reinforce and conflict with each other. Where logics are mutually reinforcing, such multiplicity may actually be beneficial to the organization as a whole, as individual participants learn to be "multivocal" in drawing from both (Nelson, 2005). But, when logics conflict and participants vary within a closely linked organization, the outcome is dependent upon individual proponents of each logic and is influenced by the extent to which institutionally specific roles affect the resources available to these proponents (Friedland & Alford, 1991). In such a "battle of logics," the material resources from licensing income and the facile demonstration of relatively immediate and measurable effectiveness would lead technology transfer concerns to dominate educational ones. Thus, a challenge in organizational structure arises in attempting to nurture multiple logics without allowing one to co-opt the other.

In a seminal article, Weick (1976) argues that when an organization is pursuing multiple goals that may conflict, its formal structure may be only "loosely" integrated. As Weick (1976, p. 14) writes, "The imagery is that of numerous clusters of events that are tightly coupled within and loosely coupled between. Those larger loosely coupled units would be what researchers usually call organizations.'' For our purposes, the larger unit is the university while the smaller subassemblies with their unique goals are individual entrepreneurship education and technology transfer programs. Thus, in this perspective, these programs are only loosely linked. Adkison's (1979) study of a project within the Kansas Public School System found early support for the effectiveness of such an environment. In her study, loose coupling between participants allowed them to define unique roles and responsibilities while avoiding conflict.

The concept of loose coupling has been usefully extended in the literature on organizational modularity, which focuses exclusively on the structures of organizations, rather than on individuals or inter-organizational relationships (Brown & Eisenhardt, 1997; Martin & Eisenhardt, 2003; Hallen & Eisenhardt, 2005). In this view, the autonomy afforded to individual units within a system depends upon both the work undertaken within each unit (Thompson, 1967; Galbraith, 1973) and the potential synergies arising from the leveraging of multiple units (Gupta & Govindarajan, 1986; Larsson & Finkelstein, 1999; Martin & Eisenhardt, 2003). Higher levels of organizational modularity allow individual units to maintain autonomy surrounding goals, actors, measurement, and responsiveness to external pressures. This autonomy facilitates success in multiple activities at the same time. For example, Tushman and O'Reilly (2004) found that companies with high levels of modularity – those that were ''ambidextrous'' in their view – were able to flourish in very different kinds of businesses simultaneously. A primary function of unit autonomy through modularity is to reduce potentially harmful tendencies to apply a single model or perspective to all subunits of a business. Thus, Gilbert's (2003) study of the newspaper industry highlighted the tendency of less modular newspaper organizations to apply models from print editions to the online world, with unfortunate consequences given these unique environments.

While higher levels of modularity facilitate the simultaneous pursuit of independent goals by individual units, it is still desirable to facilitate synergies between units. For example, Tushman and O'Reilly (2004) point to the benefits from integrated top management teams when units are independent. One of the most important roles that such integration serves is to facilitate and encourage cross-unit awareness. This awareness may take place via direct connections between units, without the necessity of hierarchical oversight. For example, in a study of 12 cross-business synergy initiatives, Martin and Eisenhardt (2003) found that high-performing initiatives originated in the business units, not at the corporate level, and that high-performing initiatives had an "engaged multi-business team decision process," rather than a top-down corporate decision process. Similarly, Tsai's (2002) investigation of a large diversified organization revealed that formal hierarchical structure had a negative effect on knowledge-sharing between units, while informal lateral relations had a positive effect. Hansen (1999) points to the role of "weak ties" in knowledge sharing across organizational subunits. Thus, the organizational prescription is twofold. To the extent that technology transfer and entrepreneurship organizations differ in goals, they should remain autonomous. But, to facilitate synergies, they should have high cross-unit awareness.

4.1. Survey Description and Methodology

To explore this conclusion, we assessed relations between all of Stanford's entrepreneurship education and technology transfer groups along two dimensions: cross-unit dependence and awareness. In sum, we surveyed 13 groups, which are described in the appendix. We pre-tested the survey with four of the groups. Though we had only one respondent for each group, we believe that this still provides an accurate picture of relations between groups since each group is relatively small and members are aware of the type, quality, and extent of relations that their colleagues maintain between groups. We confirmed this perception by presenting survey responses to non-respondents within three groups, who verified the validity of the responses for their groups.

To gauge dependence and awareness, we asked a total of nine questions, measured on a five-point Likert scale. (The survey included additional questions on overlapping activities, experiences with cross-unit collaboration, administrative structure and budgets, as reported in Fig. 1, Table 1, and below.) We performed a factor analysis on the nine questions and found that the dependence and awareness measures loaded on two separate factors, as predicted. One measure, communication between units, was loaded on both factors, though its association with awareness was higher. Given its importance toward capturing non-meeting-based awareness, we retained it as an awareness measure despite this dual loading. The Cronbach alpha for the five dependence measures was 0.88, indicating that the set of questions is a good measure of a single unidimensional latent construct. The Cronbach alpha for the four awareness measures was lower at 0.71, but still above a cutoff value of 0.7 (Nunnally, 1978).

For our network images, we employed the Kamadi–Kawai algorithm for network layout, which is based on the idea of a balanced spring system and energy minimization. The most central actors typically appear in the middle of the image and thickness of lines is indicative of the strength of the tie. For ease of display, we removed the weakest ties, though they were retained for all calculations.

4.2. Dependence

As a first cut at cross-unit dependence, we surveyed whether groups shared a common administrative structure or budget. Predictably, these measures clumped those groups that were in the same department. There were only two instances of shared budgets, both involving student groups connected to larger departmental initiatives. Thus, most positive responses did not represent resource dependence. Moreover, ties did not necessarily indicate administrative dependence. In the organizational modularity literature, modularity is measured by the extent to which individual units within an organization have independence and autonomy. Thus, a simple delineation by department is inadequate since it fails to capture the extent to which units within a department may or may not have autonomy, and the extent to which departments themselves may or may not be dependent upon one another. To develop a more sophisticated measure of cross-unit dependence, we therefore crafted five additional questions based upon the organizational modularity literature: "If you changed *your* core activities, it would impact the following groups:", "If the following groups changed *their* core activities, it would impact you:", "You depend on the following groups to fulfill your mission:", "The output of the following groups serves as a critical input for your group:", and "For your core activity, you need approval from the following groups:".

Owing to space constraints, we present only one example network image of responses to an individual dependence question. Fig. 2 illustrates responses to the question, "The output of the following groups serves as a critical input for your group."

The resulting density of the network is 0.131, indicating that roughly 13% of all potential ties at the strongest level are actually present. (In this diagram, the thickest lines reflect the response "sometimes.") This particular measure had the highest density of all dependence measures, indicating more and/or stronger ties than in other dependence networks. Density measures for all dependence questions are displayed in Table 3.

The extremely low density of the "Need approval" measure indicates that decision-making resides largely at the level of the individual units and that few units are subservient by any degree to other units. In fact, only three groups provided any sort of positive response to the question and each represents, effectively, a subset of another group: the business school's entrepreneurship club (The Entrepreneur Club at the Graduate School of Business (GSBEC)) is the student group portion of The Center for Entrepreneurial Studies at the Graduate School of Business (GSB); Stanford Student Biodesign (BDCLUB) is a group of students who participate in the Stanford Biodesign Network (BDN); and the Stanford Linear Accelerator Center Office of Technology Transfer (SLAC) manages the OTL's efforts surrounding inventions from an electron accelerator research lab. (These disclosures account for a very small percentage of Stanford's total.)

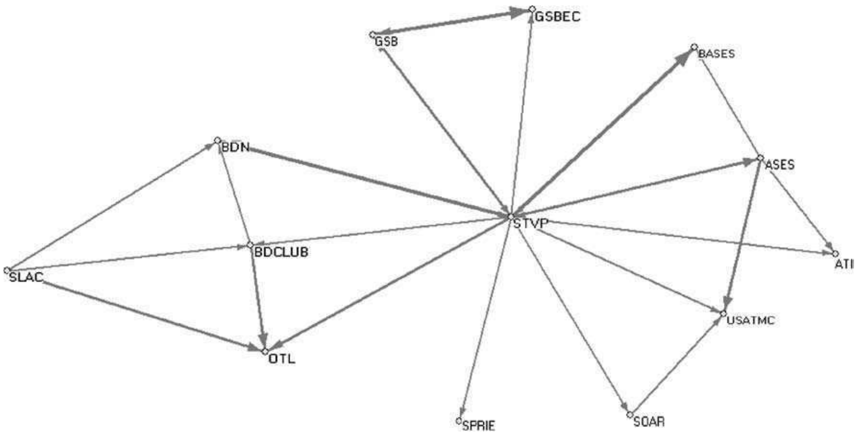

Fig. 2. Responses to "The Output of the Following Groups Serves as a Critical Input for your Group." Arrows Point from the Group that Provides Output to the Group that Relies on this Output.

Table 3. Density Measures for Dependence Network.

If you changed *your* core activities, it would impact the following groups	0.106
If the following groups changed *their* core activities, it would impact you	0.117
You depend on the following groups to fulfill your mission	0.103
The output of the following groups serves as a critical input for your group	0.131
For your core activity, you need approval from	0.013

In sum, the dependence measures indicate that individual entrepreneurship education and technology transfer units have a high degree of autonomy and independence. Fig. 3 collapses the five measures to provide an overall assessment of dependence between units.

This sparse network of dependence (density = 0.0939) indicates that Stanford's entrepreneurship and technology transfer efforts are highly modular. As argued, however, successful modular organizations should employ mechanisms to ensure cross-unit awareness that facilitates potential synergies. In the section that follows, we analyze awareness measures for the Stanford network.

4.3. Awareness

We used four measures to capture the opportunities that units have to exchange information and to become aware of the activities and interests of other units: formal meetings, informal meetings, attendance at Stanford Entrepreneurship Network meetings, and communications such as emails and newsletters. We used a five-point Likert scale to capture the information. For formal meetings, informal meetings and communications, the scale ranged from "Never" to "Once/Week or More." For attendance at SEN meetings, which are held monthly, the scale ranged from "Never" to "Always."

Formal meetings are diagrammed in Fig. 4.

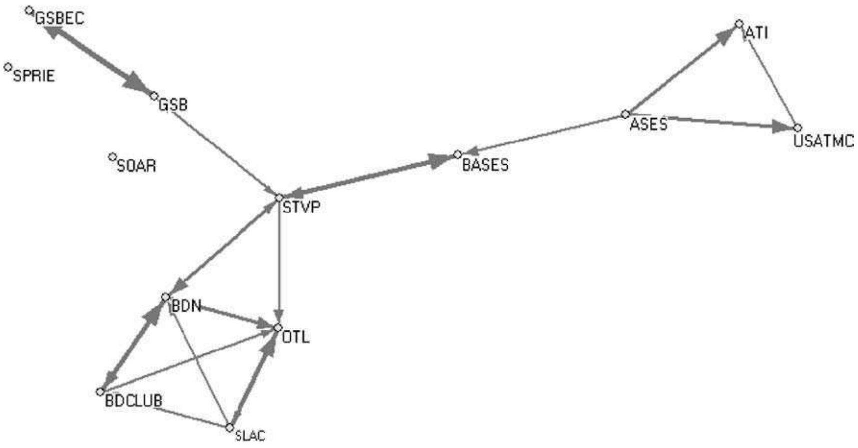

Fig. 3. Network of Dependence – Sum of All Questions.

As the figure indicates, formal meetings (outside of the SEN) are relatively uncommon and typically occur between groups in the same school. For example, the highest values are between the GSBEC and the GSB, and between the engineering school's entrepreneurship program (Stanford Technology Ventures Program (STVP)) and an engineering-based student entrepreneurship group (The Business Association of Stanford Engineering Students (BASES)). Formal meetings also appear common between those groups with overlapping areas of concern. For example, The Asia-Pacific Student Entrepreneurship Society (ASES) and U.S.–Asia Technology Management Center (USATMC) are a student group and an administrative program, respectively, both of which are focused on activities in Asia. Similarly, the OTL and SLAC are both directly engaged in technology transfer.

In contrast to formal meetings, informal interactions between programs are frequent, as indicated in Fig. 5.

In fact, informal interactions capture all network relations that also occur through formal meetings, with the exception of four formal meetings that occur "rarely." Moreover, informal interactions capture several cross-unit (non-shared department) relationships. For example, there are frequent informal interactions between STVP and OTL, between STVP and the medical school's entrepreneurship program (BDN), and between BDN and the GSB. The prevalence of informal interactions compared to formal meetings is reflected in their respective network densities: 0.293 versus 0.151.

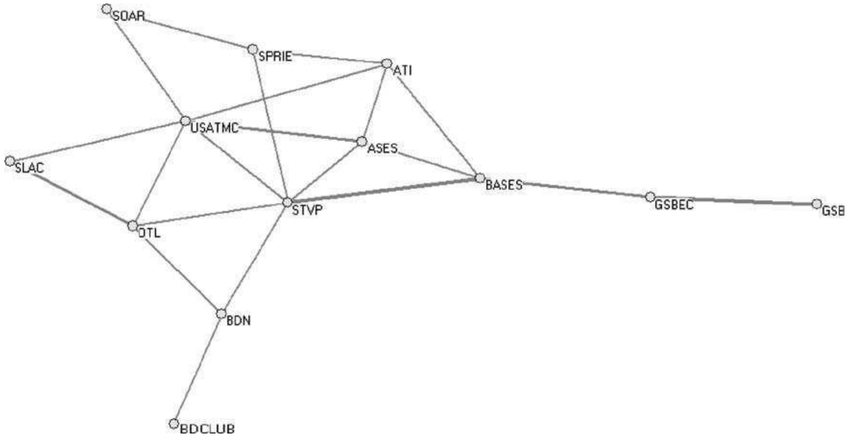

Fig. 4. Formal Meetings between Groups.

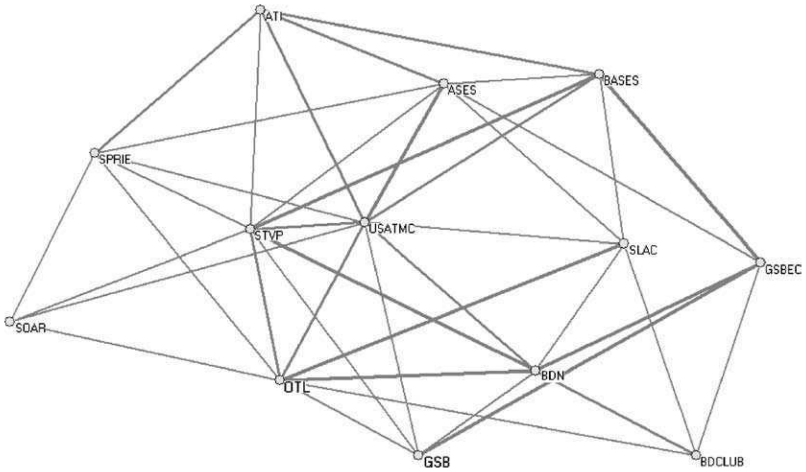

Fig. 5. Informal Interactions between Groups.

The Stanford Entrepreneurship Network (SEN) represents an institutionalized mechanism for encouraging cross-unit awareness. SEN started as a bottom-up effort, led by members of two entrepreneurship education groups and one OTL associate. Participation is optional and there is no formal structure to the group. But, attendance is quite strong, as indicated in Fig. 6.

In fact, the majority of respondents (8 of 13) always attend, and most others (3 of 13) often attend.

A final mechanism for facilitating cross-unit awareness consists of various communications, including emails and newsletters. Fig. 7 illustrates these results.

The most central units here are those that communicate often to other units. For this measure, BASES, a student group that has a weekly email/newsletter with broad circulation, scores highly. By contrast, SLAC, a unit that engages in relatively little communication, is more dependent on other mechanisms for sharing news of its activities and interests.

Fig. 8 illustrates the collapsed network of all four awareness measures.

As the figure indicates, the awareness network is densely interconnected. This result is to be contrasted with Fig. 3, the collapsed image of the dependence network. The comparative network densities are 0.0939 for dependence versus 0.357 for awareness, indicating that the latter is four times as dense as the former; it has more and/or stronger ties.

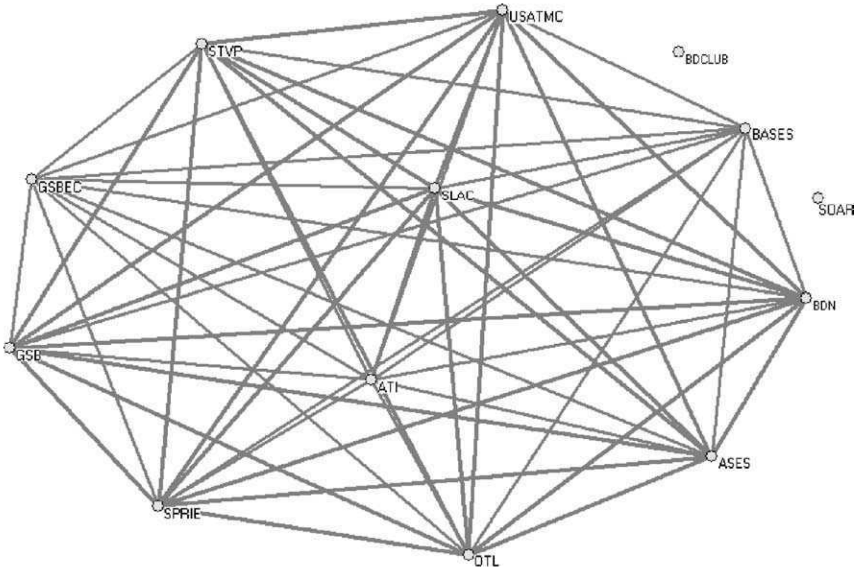

Fig. 6. Interactions via SEN Meetings.

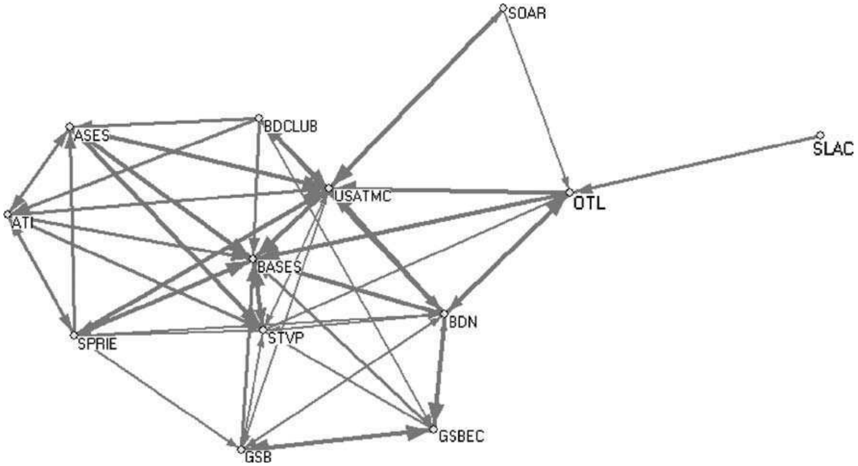

Fig. 7. Awareness Communications between Groups. (Arrows Point to Sender.)

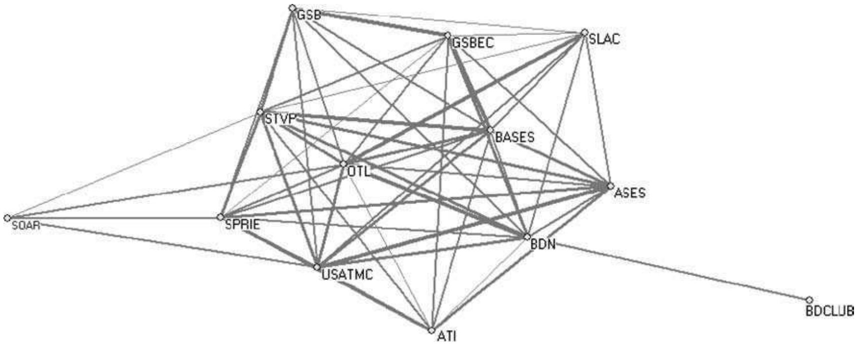

Fig. 8. Network of Awareness – Sum of All Questions.

4.4. Relations between Technology Transfer and Entrepreneurship Groups

These network measures of dependence and awareness can be isolated to consider only ties that cross the two categories: technology transfer and entrepreneurship education. Thus, all ties between the two technology transfer units are removed, as are those between any two entrepreneurship education units. Figs. 9 and 10 illustrate the results for dependence and awareness, respectively. These illustrations allow us to gauge the extent to which technology transfer and entrepreneurship education units interact and how dependence interactions compare to awareness interactions across the two unit types.

The respective density measures provide a further indication of these differences. The dependence density is 0.0189, while the awareness density is 0.0950.[3] These figures indicate that in considering only cross-type ties (only those between technology transfer and entrepreneurship groups), the awareness network is five times as dense as the dependence network, whereas in the network as a whole the awareness network is four times as dense. Thus, even more so than in the network as a whole, technology transfer at Stanford interacts with entrepreneurship education by emphasizing awareness but exhibiting little dependence. This result is consistent with expectations since the activities are in separate spheres.

That said, the OTL occupies a central role in both the awareness and dependence networks. This position indicates that it is taking advantage of synergies and, indeed, relies on these relationships to carry out its mission as effectively as it does. But, again, the large difference between the awareness and dependence density scores indicates that the OTL is primarily capturing

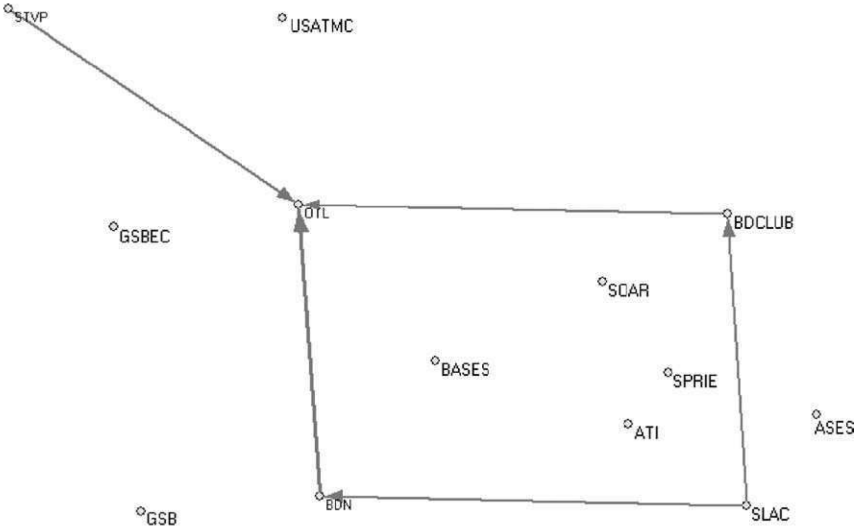

Fig. 9. Dependence Network – Only Cross-Type Ties Retained.

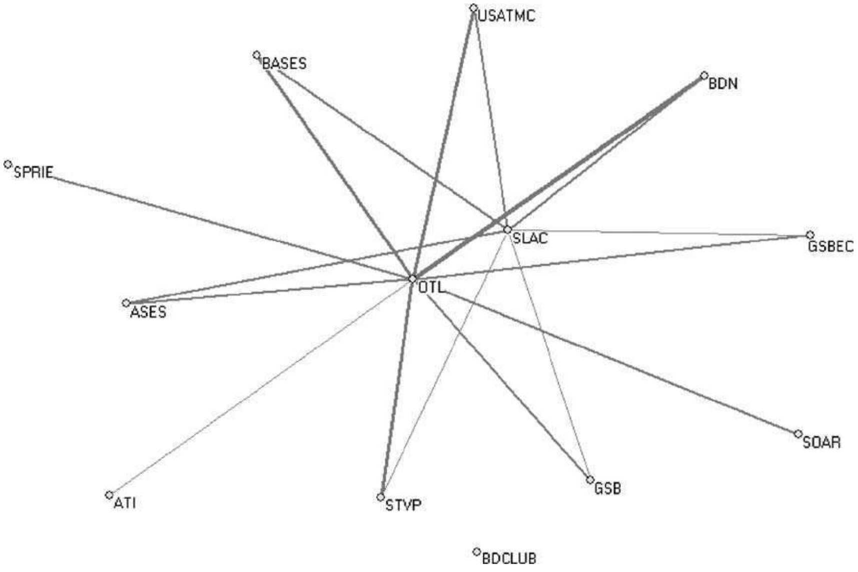

Fig. 10. Awareness Network – Only Cross-Type Ties Retained.

synergies via awareness relationships rather than formal dependence mechanisms.

5. CASE STUDIES

While network images and statistics provide an overall perspective on relations between groups at Stanford, case studies provide a rich understanding of how these relations have actually played out. The following three thumbnail cases differ across a number of dimensions, including entrepreneurship programs, student experience, technologies, departments, and outcomes. Moreover, the nature of the synergy realized varies. In the first case, participation in an entrepreneurship program facilitated the successful founding and growth of a company. In the second case, a company's engagement with technology transfer opened the door for its involvement with entrepreneurship education. In the third case, a feedback loop has emerged in which OTL associates assist in teaching an entrepreneurship course, which has facilitated technology licensing by firms resulting from this course, which in turn encourages further OTL involvement. But despite these different relationships, the three cases are united in illustrating both positive synergies between entrepreneurship education and technology transfer and the maintenance of autonomy for each.

5.1. Voltage Security and BASES

In November 2000, Professor Dan Boneh of Stanford's computer science (CS) department, in collaboration with Professor Matt Franklin at UC Davis, discovered a new way to solve the mathematics behind identity-based encryption (IBE). Months later, two undergraduate CS students, Matt Pauker and Rishi Kacker, met with Boneh to discuss research projects and they subsequently embarked on a study of the practical applications of IBE. In October 2001, Pauker and Kacker joined up with Guido Appenzeller, a Ph.D. candidate also doing research in IBE, to enter the Stanford BASES Entrepreneur's Challenge. BASES is a student group whose goal is to "build the next generation of entrepreneurs" by facilitating networking and discussion of entrepreneurship among undergraduate and graduate students from a variety of disciplines. The Entrepreneur's Challenge is an annual business plan competition run by BASES, which is accompanied by workshops, team building activities, and a mentorship program. Appenzeller had also taken a global entrepreneurial marketing class, MS&E 271, through the School of Engineering and STVP, which made him sensitive to marketing issues and provided basic tools for identifying target segments. As he later recalled, "271 was maybe the single most valuable class at Stanford. It's this all-inclusive introduction to marketing and business."

In May 2002, the entry by Pauker, Kacker, and Appenzeller won the BASES competition. The success provided visibility and important introductions to many in the venture capital community, which the founders later identified as essential. The next month, in June 2002, the team entered the global business plan competition in Singapore, which it won. That same month, Pauker and Kacker received their undergraduate CS degrees, while Tim Choi, the student president of BASES, completed his Masters in Management Science and Engineering. Choi had been contemplating marketing jobs at large firms, but as president of BASES he had followed the winning team closely. They offered him a position and the team incorporated under the name IdentiCrypt, which later became Voltage Security. The company has since raised two rounds of venture capital financing and has shipped products to customers in the financial services and healthcare sectors.

In reflecting on the role of BASES and entrepreneurship course experience, the founders pointed to both the contacts that it facilitated and the content that allowed them to effectively formulate a strategy for the company, even in the earliest stages. As Appenzeller commented on the role of entrepreneurship course experience in facilitating technology transfer, "It was essential."

5.2. Cooligy and the Mayfield Fellows Program

Brian Biggott was a member of the 2004 class of Mayfield Fellows. The Mayfield Fellows Program (MFP) was founded at Stanford University in 1996 as a 9-month work/study program to develop both a theoretical and a practical understanding of the techniques for growing emerging technology companies. The program combines an intense sequence of courses on the management of technology ventures, a paid summer internship at a start-up company, and ongoing mentoring and networking activities. Enrollment is limited to 12 outstanding Stanford undergraduate engineers and scientists.

The summer internship is an integral part of the program; it provides an opportunity to reflect on the course materials from the spring and it forms the basis of the fall quarter class, in which students develop and teach case studies based on a critical decision that their company faced during the summer. Biggott was a co-terminal student in mechanical engineering (ME). Like most Mayfield Fellows, he sought a summer internship that would bear some relation to his technical background, but would immerse him in the business, rather than purely technical, aspects of a start-up.

In several ME courses, Biggott had heard of Cooligy, a company founded on technology primarily developed by three Stanford ME professors: Tom Kenny, Ken Goodson, and Juan Santiago. The technology consists of a closed-loop active cooling system for computer chips that is small, light, and quiet, and provides excellent thermal performance compared to traditional fans. The company and the technology intrigued Biggott, and he sought to pursue a summer internship. Cooligy, however, had never considered hiring an intern, largely due to concerns with confidentiality. As Biggott recalled, "Bringing someone in and doing valuable work at this stage in the company entailed knowing too much."

That spring, the Mayfield Fund, the entrepreneurship program's namesake venture capital firm and also one of Cooligy's funders, hosted a reception for the Mayfield Fellows. At the reception, one of the partners, Kevin Fong, mentioned Cooligy as an interesting portfolio company; Fong is the Cooligy board member from Mayfield. Biggott subsequently sent an email to the associate at Mayfield who was in charge of liaison contacts, who in turn encouraged him to contact the operations officer that Mayfield had on loan to Cooligy. Subsequently, Fong also sent messages encouraging the company to consider Biggott. These were supplemented by emails from the Mayfield Fellows program director and from Tom Kenny, one of the professors who developed the technology. Biggott was interviewed for the position and was hired. As he later reflected, "There's not a chance I could have been hired coming from another school, and there's a minimal chance I could have been hired outside of this [the Mayfield Fellows] program."

The tight network between the Stanford entrepreneurship program, the venture capital firm and the start-up influenced not only Biggott's hiring, but also his subsequent internship experience. As Biggott recalled, "Even if I was able to get a position, I would have been doing engineering stuff and there's no chance I would have been doing marketing." Instead, he spent most of his summer investigating and picking new markets, and developing marketing pitches. In fact, one of the requirements that MFP places on summer employers is that they provide the Fellow with access to senior management, provide a mentor within the company, host a summer open house for other program participants to explain their business, and generally play an active role in the program; it is not a typical summer job.

In reflecting on the doors opened by the MFP, Biggott remarked, "My exposure and my understanding of what was going on in that company, and more importantly my *point of observation* about what was going on in that company, was made a thousand times more valuable by having that sort of access." Thus, Cooligy's Stanford roots and OTL relationship opened the door for them to become intricately involved in entrepreneurship education. Per data from the OTL, at least a half-dozen MFP internship companies held earlier technology licenses from Stanford.

5.3. Picarro and the Technology Venture Formation Class

As a Ph.D. student at Stanford, Barb Paldus did groundbreaking research on cavity ring-down spectroscopy (CRDS). Due to its insensitivity to fluctuations in laser output and its ability to achieve large pathlengths through the sample, CRDS is the preferred method for ultra-sensitive, quantitative absorption measurements. While there were clear commercial applications for the technology, neither Paldus nor the two professors with whom she worked had ever started a company. Paldus looked through the course catalog and spotted Management Science & Engineering 273, "Technology Venture Formation," which is taught by a team of experienced entrepreneurs and venture capitalists.

As Paldus recalled:

> The course was a major eye-opener. I knew absolutely nothing about business or starting businesses…It was not a career option that I considered at the time. Many of us from EE were thinking of academic careers in the university. And developing technology in a startup was, in a way, a concept that none of us had ever really thought about. Trying to figure out where the market was, and where the market would be. That was something we had never really done either. So they taught us the basics of doing that. It was really neat.

After taking part in the course, Paldus and her professors approached the OTL. As they explored the technology licensing possibility, the course instructors – experts in entrepreneurship – also contacted the OTL to reinforce the opinion that the concept could form the basis of a start-up. When Paldus graduated in 1998, she co-founded Inform Diagnostics, which later became Picarro. The company completed its Series C round in 2004. Significantly, the OTL regularly participates in the MS&E 273 course that opened Paldus' eyes to the world of entrepreneurship by having a licensing associate share information about technologies available for license and by providing an overview of the licensing process. Thus, a feedback loop has emerged in which the OTL assists in entrepreneurship classes, which may result in actual companies that license Stanford technologies, which further encourages OTL involvement.

5.4. Discussion

In each of these cases, entrepreneurship education and technology transfer were closely linked while also being independent. For the Voltage founders, coursework, workshops, and a business plan competition provided both background knowledge and connections that were vital to the company's success. For the MFP, a company's participation in university technology transfer paved the way for its integration into an entrepreneurship education program. For the Picarro co-founder, initial engagement with an entrepreneurship course facilitated the successful launch and growth of the company.

In each of these cases, the technologies were developed at Stanford and the companies have licenses from the OTL. But, the OTL's licensing decisions were very much independent of entrepreneurship education and the office did not give preferential treatment to potential licensees with Stanford connections, including those involved in entrepreneurship programs. Rather, the OTL "markets" all inventions, meaning that they are shown to others who may have an interest in commercializing them. From a technology transfer perspective, the firm with an entrepreneur committed to developing a particular technology may be the best licensee, but that firm must offer a viable plan to commercialize an invention in order to receive a license. Entrepreneurship education, such as that highlighted in the Voltage and Picarro cases, helped the inventors create the viable business plan that was presented to the OTL.

For other groups, too, the disconnect between technology transfer and entrepreneurship education is clear. BASES, for example, provides resources for potential companies. But, its success as an organization is not tied to the success (or lack thereof) of these companies. As Tim Choi, the former BASES president who joined Voltage, commented, "BASES, at the end of the day, is about education." Similarly, OTL portfolio companies are not required to take part in the MFP and, conversely, the program is not tied to the performance of these companies. In each case, awareness relations between technology transfer and entrepreneurship education groups led to synergies that were exploited, in these cases, to the benefit of technology transfer, entrepreneurship education, or both. Dependence ties were absent – and, indeed, unnecessary.

6. DISCUSSION AND CONCLUSION

Several observers have identified universities as an important source of commercial innovation (Jaffe, 2000; Nelson & Levin, 1986; Rosenberg, 2002). Similarly, support for entrepreneurship marks a vital element of both regional and national economies (Schramm, 2004; Byers, Keeley, Leone, Parker, & Autio, 2000). Our purpose in this chapter has been to describe the intra-organizational relationships between a university's technology transfer and entrepreneurship education units. Reporting survey data, we highlighted some synergies between entrepreneurship education and technology transfer activities. We then delineated several dimensions that distinguish these activities and therefore encourage independence of units. The co-existence of such synergies and differences led to a prescription for a modular organization design. In this arrangement, individual units retain independence and autonomy. But, the units themselves develop mechanisms to facilitate cross-unit awareness. Thus, units are able to learn about and act upon potentially fruitful opportunities for collaboration. The network analysis of the Stanford model along various dimensions of dependence and awareness provided an overall illustration of the modular arrangement, while three thumbnail case studies provided descriptions of actual synergies realized.

Network analyses also offer universities the opportunity to perform an internal assessment. For example, groups that appear on the periphery of the awareness network may wish to engage with others more. Groups that score high on dependence measures may wish to assess if this dependence is mutual and to consider its implications. Network data over time could provide compelling insights into the evolution of a university's efforts and could point to further areas for improvement.

There are, of course, limitations to our observations. First, we acknowledge that there is no "one size fits all" and that approaches to these relationships are context-dependent. Indeed, even within Stanford, entrepreneurship education programs differ along many dimensions that influence their interaction with both other entrepreneurship programs and technology transfer. We contend that the degree of modularity is proportional to the extent to which groups differ. That is, increased modularity is more appropriate as groups increasingly differ.

The organizational modularity literature also suggests that the dynamic nature of an environment influences the appropriate degree of loose coupling (Gupta & Govindarajan, 1986; Tushman & O'Reilly, 1996; Brown & Eisenhardt, 1997; Martin & Eisenhardt, 2004). Thus, a challenge moving forward is to consider the degree of modularity in relation to a (potentially) changing environment. It may be that universities are experiencing a particularly turbulent time and that as trends in both technology transfer and entrepreneurship education stabilize, tighter coupling will be more appropriate.

Second, the study raises the question of how we should measure the success of organizational practices. This determination is, of course, dependent upon the goals, which vary across programs. Even with a clear goal, such as determination of the socioeconomic impact of entrepreneurship programs, measurement is very difficult (Block & Stumpf, 1992; McMullan & Long, 1987). In their detailed longitudinal study of an entrepreneurship program at the University of Arizona, Charney and Libecap (2000) accomplish this to some extent. More studies along this line are certainly in order. A primary challenge to impact measurement of this sort stems from the fact that most entrepreneurship education programs may be too new to exhibit significant impact. But, while it may be difficult to measure outcomes, we can still ascertain the conditions for growth; while the garden may not yet yield produce, we can judge the quality of the soil, sun, and water.

Finally, an obvious extension would consider other universities' experiences. At Stanford, all entrepreneurship and technology transfer programs are in agreement that the modular organization works very well. But, the single case study has two limitations. First, samples from other universities, both where relations are perceived to work well and not, are essential to determine the generality of our findings. Second, it may be that regardless of organizational structure, awareness networks are always more dense than dependence networks. With data from multiple universities, we could test how different degrees of dependence are related to different degrees of awareness, and could regress this against measures of individual universities' strength at both technology transfer and entrepreneurship education. Such a diverse sample could also compare those universities, like Stanford, where entrepreneurship has close ties to the engineering school, to those that rely wholly or primarily upon initiatives in business schools.

Beyond the specifics of technology transfer and entrepreneurship education programs, it is also important to recognize the role of a university's overall culture. As Lenoir et al. (2004) point out with respect to Stanford, the university has long had an "entrepreneurial attitude." This facilitates experimentation with new curricula and the formation of novel ties between groups. Consistent with the literature on modular organizations, these ties are most effective when they emerge from lateral relations between groups acting in an entrepreneurial fashion, rather than from a "top-down" administrative directive. Indeed, ultimately we need to be entrepreneurial in our entrepreneurship education and technology transfer programs themselves. Those same tools developed to advise entrepreneurial businesses should be applied within the university to the novel relationships between entrepreneurship education and technology transfer programs at this early stage in their co-evolution.

NOTES

1. Section 4.1 describes our network analysis methodology.
2. We employ eigenvector centrality in our analyses. Unlike betweenness or *n*-degree centrality, eigenvector centrality weights scores according to the value of ties and the centrality of those to whom the focal actor is tied.
3. Technically, these are incomplete density measures since density is the ratio of ties that are actually present to those that could potentially be present. In these calculations, we have explicitly removed non-cross-type ties so the number of possible ties is overstated. But, the error in the denominator applies equally to both networks and therefore does not affect a comparison.

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APPENDIX. DESCRIPTION OF GROUPS IN THE STUDY

ASES – The Asia-Pacific Student Entrepreneurship Society. The Asia-Pacific Student Entrepreneurship Society at Stanford is affiliated with ASES International. The Stanford group hosts two major annual summits that explore transpacific business and leadership issues, and sponsors several small events throughout the year that are focused on entrepreneurship in Asia.

ATI – Asia Technology Initiative. The Stanford Asia Technology Initiative seeks to cultivate entrepreneurship through hands-on entrepreneurial experience and by promoting links between Stanford and technology clusters throughout Asia. Each summer, a number of Stanford students are selected to go to different hotspots within Asia for a 10-week internship and a capstone conference.

BASES – The Business Association of Stanford Engineering Students. BASES is a student group whose goal is to build the next generation of entrepreneurs by facilitating networking and discussion of entrepreneurship among undergraduate and graduate students from a variety of disciplines. The group organizes a weekly Entrepreneurial Thought Leaders seminar, hosts three annual business plan competitions and sponsors several workshops and lectures throughout the year.

BDCLUB – Stanford Student Biodesign. Stanford Student Biodesign is a student group that aims to prepare students for careers in biotechnology, biomedical technology, bioengineering, and other fields at the intersection of life sciences and engineering. The group offers career seminars, lectures, dinners with industry and faculty, community service opportunities, and hands-on innovation experience. It is affiliated with Stanford Biodesign.

BDN – Stanford Biodesign Network. The Biodesign Network focuses on technology transfer, providing education, advocacy and mentoring to students and faculty who wish to bring their innovations forward through the university to be developed into commercialized healthcare products. BDN also provides connections to the professional communities that specialize in biomedical technology, such as investors, medical technology equipment manufacturers, and attorneys.

GSB – The Center for Entrepreneurial Studies at the Graduate School of Business. The Center for Entrepreneurial Studies was founded to address the need for greater understanding of the issues faced by entrepreneurial individuals and companies. The Center focuses on case development, research, curriculum development and student programs in the areas of entrepreneurship and venture capital, and also supports alumni and students engaged in entrepreneurial pursuits.

GSBEC – The Entrepreneur Club at the Graduate School of Business. The Entrepreneur Club at the Graduate School of Business is a student group with the goal of stimulating interest in entrepreneurship among GSB students and other members of the Stanford community. The group hosts frequent events and workshops to raise awareness about both traditional start-up paths and entrepreneurial "start-up" opportunities within existing organizations.

OTL – Stanford Office of Technology Licensing. The Stanford Office of Technology Licensing is responsible for managing the intellectual property assets of Stanford University. OTL receives invention disclosures from Stanford faculty, staff and students, evaluates these disclosures for their commercial possibilities, and when possible licenses them to industry. OTL has the responsibility to identify the best source or sources for commercialization, including large corporations, medium-sized companies and start-ups. Royalties collected by OTL provide funding to the inventors' departments and schools, as well as personal shares for the inventors themselves.

SLAC – Office of Technology Transfer at the Stanford Linear Accelerator Center. The Stanford Linear Accelerator Center is one of the world's leading research laboratories. Their mission is to design, construct, and operate state-of-the-art electron accelerators and related experimental facilities for use in high-energy physics and synchrotron radiation research. The Office of Technology Transfer at SLAC is responsible for managing the intellectual property assets at SLAC and oversees technology licensing for the Center.

SOAR – Stanford Office of Asian Relations. The mission of the Stanford Office of Asian Relations is to: (1) raise funds from Asia to support the university; (2) strengthen Stanford's relationship with alumni, parents, friends, and organizations in Asia and assist them with their Stanford interests; (3) work with schools, departments, institutes and centers at Stanford to promote their interests in the region.

SPRIE – Stanford Project on Regions of Innovation and Entrepreneurship. The mission of the Stanford Project on Regions of Innovation and Entrepreneurship is to contribute to the understanding and practice of innovation and entrepreneurship. Located within Stanford University's Asia/Pacific Research Center in the Institute for International Studies, SPRIE investigates a number of questions surrounding models and networks of innovation and entrepreneurship.

STVP – Stanford Technology Ventures Program. Stanford Technology Ventures Program is the entrepreneurship education center located within Stanford University's School of Engineering. STVP supports academic research on high-technology entrepreneurship and teaches a wide range of courses to scientists and engineers on campus. STVP has a strong outreach effort that includes hosting four international conferences on teaching entrepreneurship and extensive online resources open to all educators.

USATMC – U.S.–Asia Technology Management Center. The U.S.–Asia Technology Management Center is an education and research center located within the Stanford University School of Engineering. U.S.–ATMC programs aim at integrating practical perspectives into international strategic technology management along with analysis of research trends in selected areas of leading-edge electronics and information technology. U.S.–ATMC activities include public lecture series and seminars, sponsorship of faculty research projects, development and delivery of new university courses, and major Internet web site projects.

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