The Knowledge Filter and Economic Growth:
The Role of Scientist Entrepreneurship

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Executive Summary

This study examines the prevalence and determinants of the commercialization of research by the top twenty percent of university scientists funded by grants from the National Cancer Institute (NCI). Because the two publicly available modes of scientist commercialization – patents and Small Business Innovation Research (SBIR) grants – do not cover the full spectrum of commercializing activities undertaken by university scientists, the study also includes two additional measures obtained from detailed scientist interviews: licensing of intellectual property and starting a new firm. These measures are used to assess both the prevalence and determinants of scientist commercialization of research. In particular, two distinct routes for commercializing scientist research are identified, the Technology Transfer Office (TTO) route and the entrepreneurial route, which does not involve assigning a patent to the university. This study in no way provides an assessment or judgment about the efficacy of the TTO. Rather, this study highlights the extent to which additional commercialization of research takes place, suggesting that the contribution of universities to U.S. innovation and ultimately economic growth may be greater than had previously been believed. Specific empirical findings suggest that:

- Scientists receiving funding from the National Cancer Institute exhibit a robust propensity to commercialize their research. However, the prevalence of commercialization depends highly upon the actual mode of commercialization. Some modes of commercialization, such as patents, are more prevalent, while other modes, such as funding by the SBIR program are rarely used.

- Scientist entrepreneurship is the sleeping giant of commercializing university research. More than one in four patenting NCI scientists have started a new firm.

- Two paths for commercialization of scientist research are identified - the *TTO route* and the *entrepreneurial route*. Scientists who select the TTO route by commercializing their research through assigning all patents to their university TTO account for 70 percent of NCI patenting scientists. Scientists who choose the *entrepreneurial route* to commercialize their research, in that they do not assign patents to their university TTO, comprise 30 percent of patenting NCI scientists.

- Social capital enhances the propensity for scientists to commercialize their research. The impact of social capital is particularly high for the commercialization mode of scientist entrepreneurship.

- For scientists who perceive that they are helped by their Technology Transfer Office, licensing is the most prevalent mode of commercialization. For scientists who perceive that they are not helped by their Technology Transfer Office, entrepreneurship emergences as a much more important mode of commercialization.

- Scientists choosing the *entrepreneurial route* to commercialize their research, by not assigning patents to their university to commercialize research, tend to rely on the commercialization mode of entrepreneurship. By contrast, scientists who select the TTO route by assigning their patents to the university tend to rely on the commercialization mode of licensing.

1. Introduction

The enormous investment in physical plant and equipment propelled the United States to unprecedented post World War II prosperity. In the new era of globalization, both scholars and policy makers have been looking towards the country's unrivaled investment in research and knowledge to generate economic growth, employment and competitiveness in internationally linked markets for continued prosperity. However, it has been long recognized that investment in scientific knowledge and research alone will not automatically generate growth and prosperity. Rather, these new knowledge investments must penetrate what Audretsch et al. (2006) Acs and Armington (2006) and Acs et al. (2004) term "*the knowledge filter*" in order to contribute to innovation, competitiveness and ultimately economic growth. In fact, the knowledge filter impeding the commercialization of investments in research and knowledge can be formidable. As Senator Birch Bayh warned, "A wealth of scientific talent at American colleges and universities — talent responsible for the development of numerous innovative scientific breakthroughs each year — is going to waste as a result of bureaucratic red tape and illogical government regulations…"[2] It is the knowledge filter that stands between

[2] Introductory statement of Birch Bayh, September 13, 1978, cited from the Association of University Technology Managers Report (AUTM) (2004, p. 5).

investment in research on the one hand, and its commercialization through innovation, leading ultimately to economic growth, on the other.

Seen through the eyes of Senator Bayh, the magnitude of the knowledge filter is daunting, "What sense does it make to spend billions of dollars each year on government-supported research and then prevent new developments from benefiting the American people because of dumb bureaucratic red tape?"[3]

In an effort to penetrate such a formidable knowledge filter, the Congress enacted the Bayh-Dole Act in 1980 to spur the transfer of technology from university research to commercialization.[4] The goal of the Bayh-Dole Act was to facilitate the commercialization of university science. Assessments about the impact of the Bayh-Dole Act on penetrating the knowledge filter and facilitating the commercialization of university research have bordered on the euphoric:[5]

> 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 through 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 nearly 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.[6]

An even more enthusiastic assessment suggested that:

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[3] Statement by Birch Bayh, April 13, 1980, on the approval of S. 414 (Bayh-Dole) by the U.S. Senate on a 91-4 vote, cited from (AUTM) (2004, p. 16).

[4] Public Law 98-620

[5] Mowery (2005, p. 40-41) argues that such a positive assessment of the impact on Bayh-Dole is exaggerated, "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."

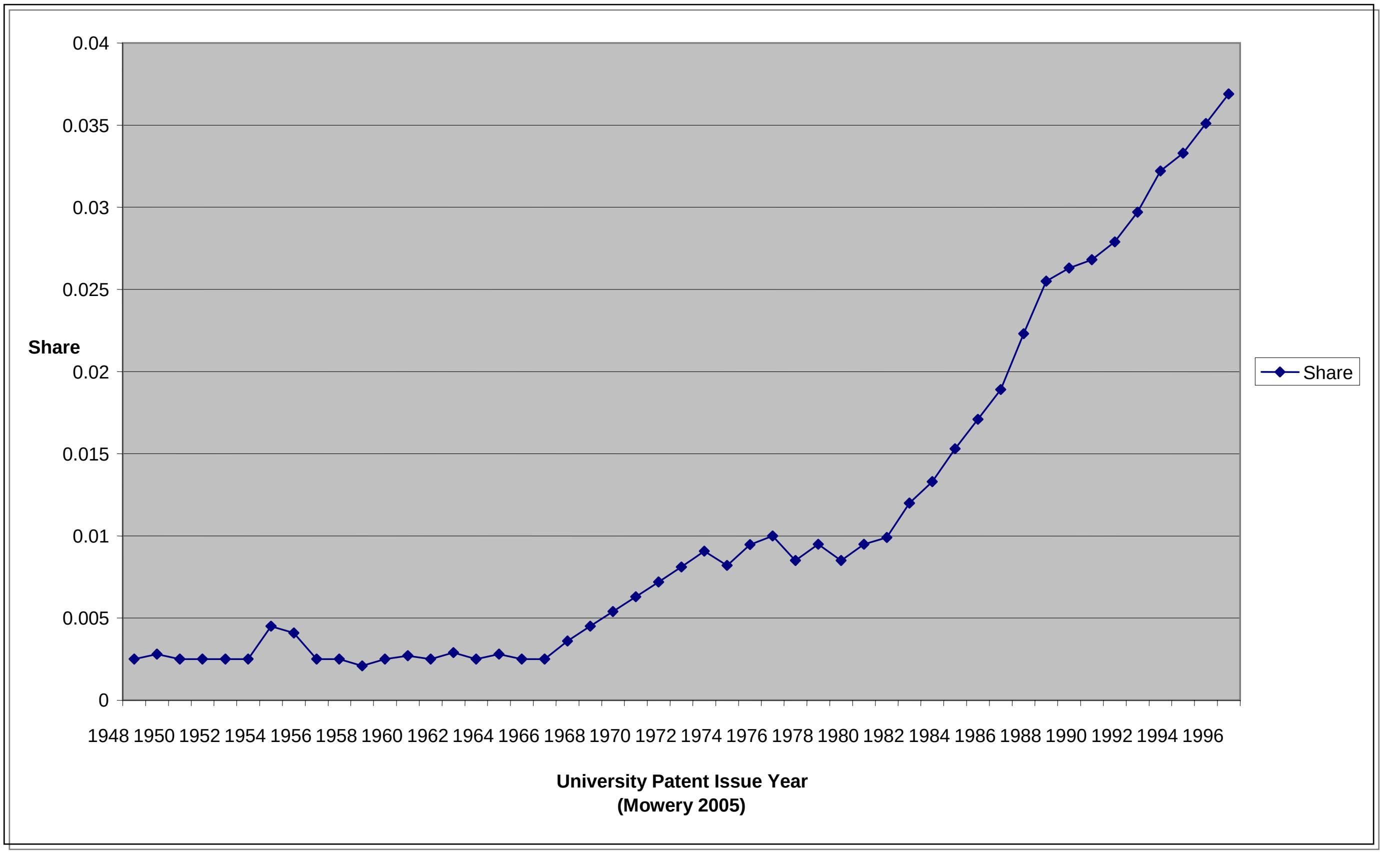
[6] "Innovation's Golden Goose," *The Economist*, 12 December, 2002.

> 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]

The mechanism or instrument attributed to facilitating the commercialization of university scientist research has been the university Technology Transfer Office (TTO). While the TTO was not an invention of the Bayh-Dole Act, its prevalence exploded following passage of the Act in 1980. Not only does the TTO typically engage in painstaking collection of the intellectual property disclosed by scientists to the university but also the extent of commercialization emanating from the TTO. The Association of University Technology Managers (AUTM) collects and reports a number of measures reflecting the intellectual property and commercialization of its member universities. A voluminous and growing body of research has emerged documenting the impact of TTOs on the commercialization of university research. Most of these studies focus on various measures of output associated with university TTOs (Shane, 2004, Siegel and Phan, 2005; Mowery, 2005.) By most accounts, the impact on facilitating the commercialization of university science research has been impressive. For example, as Figure 1 shows, the number of patents registered by universities exploded subsequent to passage of Bayh-Dole.

[7] Cited in Mowery (2005, p. 64)

Figure 1: University Patents as a Share of All Patents with Domestic Assignees



However, there are compelling reasons to suspect that measuring and analyzing the commercialization of university research by relying solely upon the intellectual property disclosed to and registered by the TTOs *may lead to a systematic underestimation of commercialization and innovation emanating from university research*. The mandate of the TTO is not to measure and document all of the intellectual property created by university research along with the subsequent commercialization. Rather, what is measured and documented is the intellectual property and commercialization activities with which the TTO is involved. This involvement is typically a subset of the broader and more pervasive intellectual property being generated by university research and its commercialization which may or may not involve the TTO office (Thursby and Thursby, 2005). For example, in his exhaustive study on academic spinoffs, Scott Shane (2004, p. 4) warns:

> Sometimes patents, copyrights and other legal mechanisms are used to protect the intellectual property that leads to spinoffs, while at other times the intellectual property that leads to a spinoff company formation takes the form of know how or trade secrets. Moreover, sometimes entrepreneurs create university spinoffs by licensing university inventions, while at other times the spinoffs are created without the intellectual property being formally licensed from the institution in which it was created. These distinctions are important for two reasons. First it is harder for researchers to measure the formation of spinoff companies created to exploit intellectual property that is not protected by legal mechanisms or that has not been disclosed by inventors to university administrators. As a result, this book likely underestimates the spin-off activity that occurs to exploit inventions that are neither patented nor protected by copyrights. This book also underestimates the spin-off activity that occurs "through the back door", that is companies founded to exploit technologies that investors fail to disclose to university administrators.

There is little empirical evidence supporting Shane's admonition that relying solely upon the data registered with and collected by the TTO will result in a systematic underestimation of commercialization of university research. Such an underestimation of commercialization of university research may lead to an underestimation of the impact that spillovers of investment in university research have on innovation and ultimately economic growth.

If the spillover of knowledge generated by university research is viewed as essential for economic growth, employment creation, and international competitiveness in global markets, the systematic underreporting of university spillovers resulting from the commercialization of scientist research concomitantly may lead to severe policy distortions. Thus, rather than relying on commercialization reported by the TTO to measure and analyze the commercialization of university research, this study instead develops alternative measures based on the commercialization activities reported by scientists. In particular, the purpose of this study is to provide a measure of scientist commercialization of university research and identify which factors are conducive to scientist commercialization and which factors inhibit scientist commercialization. We do this by developing a new database measuring the propensity of scientists funded by grants from the National Cancer Institute (NCI) to commercialize their research as well as the mode of commercialization. We then subject this new university scientist-based data set to empirical scrutiny to ascertain which factors influence both the propensity and mode of scientist commercialization of university research.

As the second section of this paper makes clear, there is no singular mode for scientist commercialization of research. Thus, in the third section, four distinct measures of scientist commercialization of research are introduced and explained: patents, SBIR awards, new firm startups and licenses. The main factors influencing the decision scientists make in choosing to commercialize their research are introduced in the fourth section. The four modes of commercialization are used to empirically identify the main determinants of scientist commercialization of research in the fifth section. Finally, in the last section, a summary and conclusion are provided. In particular, the results of this study suggest that exclusive reliance upon measures of commercialization of university research published by the TTOs may systematically underestimate the contribution university research makes to commercialization, innovation and ultimately economic growth. University scientists appear to be more vigorously involved in entrepreneurial activity, in the form of starting new science-based firms, than had been perceived by relying solely upon the more easily accessible databases offered by the TTOs. In particular, over one-quarter of the scientists who were awarded a patent report that they have also started their own business, which is an astonishingly high rate of entrepreneurship based on comparable measures for other sub-groups of the population. Scientist entrepreneurship appears to be the sleeping giant of the commercialization of university research.

The modes of research commercialization used by NCI funded scientists are quite heterogeneous with respect to both prevalence and determinants. Reliance on publicly accessible databases, such as patents and SBIR, represent, at best, the tip of the iceberg of commercialization activities by NCI scientists. Other important commercialization modes, such as new-firm startups, can only be measured and analyzed by creating new systematic and comprehensive sources of data. In addition, both the prevalence and mode of commercialization vary considerably across scientists. Not all scientists are equally helped by the TTOs. Those that do report being helped by the TTO have a higher propensity to license their intellectual property to an existing firm but a lower propensity to start a new firm. By contrast, scientists reporting not being helped by the TTO have a lower propensity to license their intellectual property to existing firms but a higher propensity to start their own firm.

Scientists assigning their patents to the TTO, or those commercializing through the *TTO route*, exhibit a higher propensity to commercialize their research by licensing but not by starting a new firm. By contrast, those scientists choosing what we term as the *entrepreneurial route* to commercialize their research, in that they do not assign all of their patents to the TTO, exhibit a higher propensity to start a new firm but a lower likelihood of licensing their intellectual property.

Social capital and networks, as measured by the extent to which a scientist engages in industry co-publication, co-patenting with other NCI scientists, and serving on a company board of directors or scientific advisory board (SAB) clearly promote the likelihood of commercialization, particularly for the mode of entrepreneurship. The impact of social capital on entrepreneurial activity is more pronounced for scientists not helped by the TTO, suggesting that social networks may be an additional mechanism to the TTO in facilitating the commercialization of university research.

2. Scientist Commercialization of University Research

Why and how will scientists decide to commercialize their scientific research? One answer to the question of why was provided by Stephan and Levin (1992), who suggest that a scientist will choose to commercialize research if this furthers her life goals. But how should a scientist best appropriate the value of her human capital? That is, what mode of commercialization is most appropriate for a given scientist with a stock of knowledge and scientific human capital? Alternatives abound, such as working full time or part time with an incumbent firm, licensing the knowledge to an incumbent firm, starting a new firm, or joining an existing firm.

Previous studies have identified several major modes of scientist commercialization. Ownership of intellectual property, in the form of patented inventions, is an important step in the commercialization process. Jaffe and Lerner (2001), Henderson, Jaffe and Trajtenberg (1998) and Jaffe, Trajtenberg and Henderson (1993) all identify patents as an important mode by which scientists commercialize their research.

Thursby and Jensen (2005), Thursby, Jensen and Thursby (2001) and Jensen and Thursby (2001) identify both patents and the licensing of patents as important modes of scientist commercialization. In particular, Thursby and Jensen (2004, p. 4) employ a principal-agent framework in which the university administration is the principal and the faculty scientist is the agent, and identify that the "whether or not the researcher remains in the university, and if so her choice of the amount of time to spend on basic and applied research, is complicated by the fact that she earns license income and prestige both inside and outside the university."

Several studies have identified the important role that the Small Business Innovation Research (SBIR) program can play as a mode of scientist commercialization (Lerner, 1999; Audretsch, Link and Scott, 2002). Toole and Czarnitzki (2005) find that only eight percent of the unique Principle Investigators (PIs) were awarded an SBIR grant from the U.S. Department of Health and Human Services between 1983 and 1996, which suggests that the SBIR may perhaps be an important instrument of public policy, but not a prevalent mechanism for commercializing university scientist research.

A different mode of commercialization involves academic entrepreneurship, where the scientist starts a new firm to bring her research to the market. Louis, Blumenthal, Gluck and Sioto (1989) identify the role of individual characteristics and attitudes, along with the norms of scientific peer groups as important factors in influencing the scientists' decision to commercialize their research in the form of a new-firm startup. Similarly, Shane (2004), Lockett, Siegel, Wright and Ensley (2005), Zucker, Darby and Brewer (1997), O'Shea, Allen, Chevalier and Roche (2005) and Audretsch and Stephan (1996 and 1999) focus on the role that new-firm startups play as a conduit for commercializing scientific research. Thus, research has pointed to four principle modes of scientist commercialization: patents, SBIR, licenses, and new-firm startups.

3. Measurement Issues

The commercialization activity of university scientists was measured by starting with those scientists awarded a research grant by the National Cancer Institute between 1998 and 2002. Of those research grant awards, the largest twenty percent, which corresponded to 1,693 scientist awardees, were taken to form the database used in this study. The National Cancer Institute (NCI) awarded a total of $5,350,977,742 to the 1,693 highest funded quintile of United States-based scientists from 1998 to 2002.

Since the focus of this paper is on the propensity for scientists to commercialize their research, commercialization must be operationalized and measured. Based on the literature identified in the previous section, five main measures of scientist commercialization are used, which reflect five different modes by which scientists can and do commercialize their research. These are (1) patenting inventions, (2) issuing licenses, (3) receiving an SBIR grant to obtain funding for an innovative small business, (4) starting a new firm, and (5) selling a patent. It should be emphasinzed that while there are interdependencies and linkages among the different modes of commercialiyation, there does not exist any one-to-one correspondence. There is no exact linear relationship among the various modes in that, say, licensing is a pre-requisite for starting a new firm.

There certainly are additional modes of commercialization remaining unexplored by this study. Examples include non-patenting scientists who start a new firm, the mobility of students or faculty from the university to the private sector, consulting contracts, and informal interactions. The absence of these types of modes of commercialization of university research by scientists from this study does not suggest that they are unimportant, but rather that they are difficult to measure.

Based on these five different measures reflecting distinct modes of scientist commercialization of research, an NCI awardee database was created to answer the question, "Why do some scientists commercialize while others do not?"

3.1 Patents

The first measure of commercialization of research by an NCI award scientist is inventions which are patented. The propensity for NCI award scientists to patent was analyzed by obtaining patent data from the United States Patent and Trademark Office (USPTO).[8] The patent database spans 1975 to 2004 and contains over three million patents.

To match the patent records with the 1,692 NCI recipient scientists, Structured Query Language (SQL) and Python programming languages were written to extract and manipulate data. A match between the patentee and NCI awardee databases was considered to be positive if all four of the following necessary conditions were met:

(1) A positive match was made with the first, middle, and last name. If, for example, the scientist did not have a middle name listed on either the NCI award database or the patent database, but did have a positive first and last name, this first condition was considered to be fulfilled.

[8] On July 25th, 2005, Jim Hirabashi of the Office of Electronic Information Products at the patent Technology Monitoring Division was sent a request order for the "U.S. Patent CDs" from 1975 to 2004.

(2) The second criterion involved matching the relevant time periods between the two databases. Observations from both databases were matched over the time period 1998-2004, which corresponds to the initial year in which observations were available from the NCI database (1998-2002) and the final year in which patents were recorded in the patent database (1975-2004). Because applications of patents may take anywhere from three months to two years to be issued, the 2003 and 2004 USPTO patent records were included in our query. Issued patents from 1998 to 2004 by NCI scientists fulfilled the second criterion.

(3) The third criterion was based on location. If the patentee resided within an approximate radius of 60 miles from the geographic location of the university, the third condition was fulfilled.

(4) The fourth criterion was based on USPTO patent classification. Using the USPTO patent classification code, all patents were separated into respective coding groups. Patents which did not fall under the traditional categories of biotechnology were identified. All non biotech patents were evaluated and patents such as "Bread Alfalfa Enhancer" were rejected as an NCI scientist patent (see Appendix A for a distribution of patent categories).

Based on these four match criteria, a subset of 398 distinctly issued patentees were identified between 1998 and 2004 with a total of 1,204 patents.

Survey Implementation

After identifying the full set of NCI patentees, a survey instrument was designed with two main criteria:

(1) To maximize information without overly burdening the nation's top medical scientists. Reducing the time and input burden imposed on the scientist was considered to have a favorable impact on the response rate; and

(2) To maximize information revealing the creation of intellectual property and its subsequent commercialization through licensing and entrepreneurial activity, while at the same time respecting the need for scientist confidentiality and not confronting the scientist with information requests that might compromise such confidentiality.

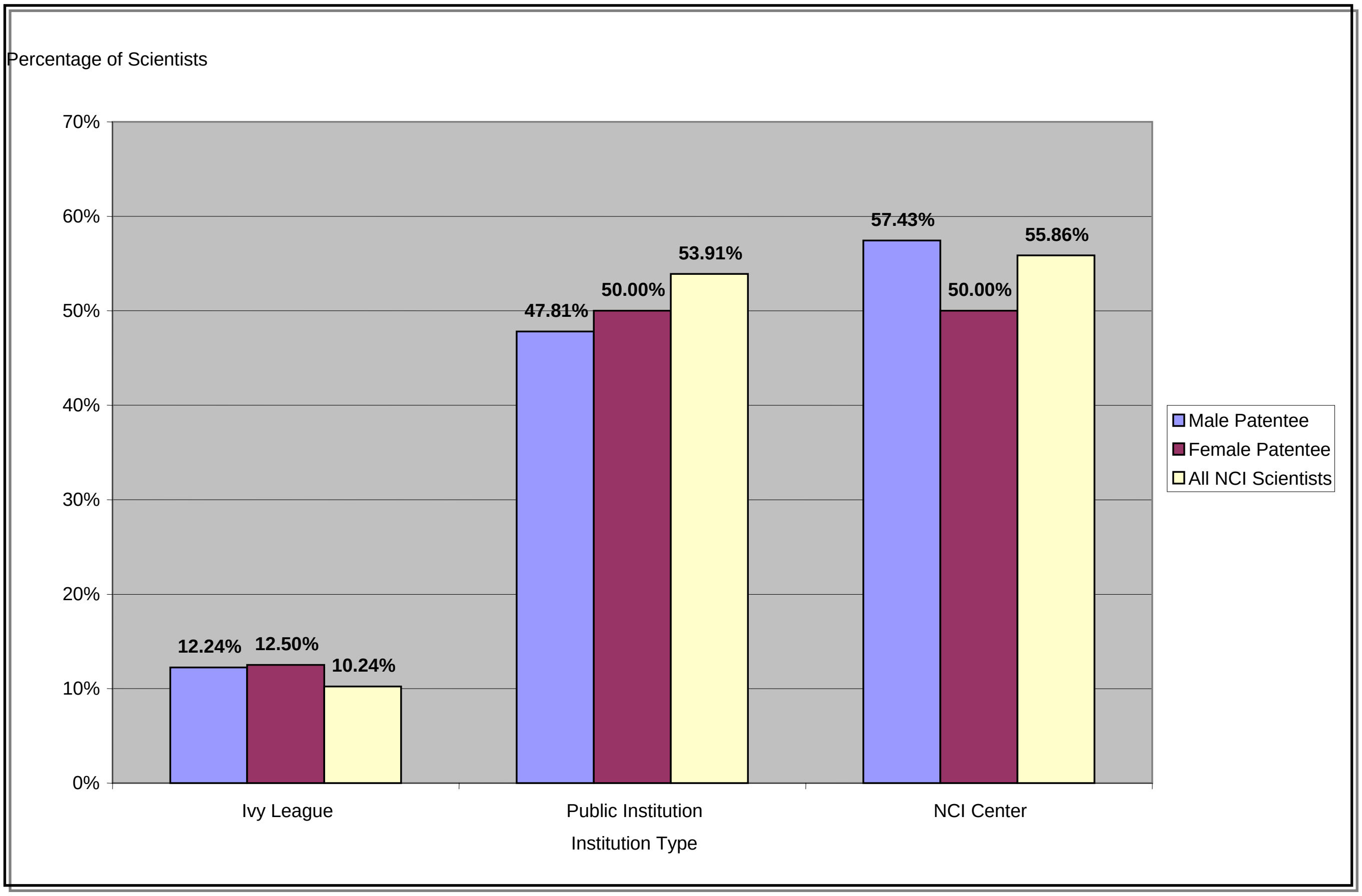
Based on these two criteria, an interview instrument was designed probing four subgroups of issues: licensing, entrepreneurship, social capital and the role of the TTO.

The question in the licensing section asked if the scientist has licensed. The question contained in the entrepreneurship section identified whether the scientist started a new firm. The questions concerning social capital asked the scientist if she sat on any industry science advisory boards (SAB) or board of directors, the extent to which the NCI grant award facilitated commercialization, along with other sources of major funding received from a governmental agency. The questions concerning the influence of the TTO asked whether the university's TTO "directly helped you to commercialize your research between 1998 to 2004".

The 398 patenting scientists were “Googled” to obtain their e-mail and telephone information. The records could, generally, be found by typing their full name, university and the word “oncology”. The ensuing patentee e-mail accounts and telephone numbers were then collected and registered in the scientist database. Of those 398 scientists identified in the database, 146 responded. Six respondents indicated that they had not patented the ascribed patents, therefore reducing the number of patentees to 392. The number of respondent, therefore, reflects a response rate of 36 percent. NCI awarded scientists commercializing through patents varied from those not commercializing in several important ways.

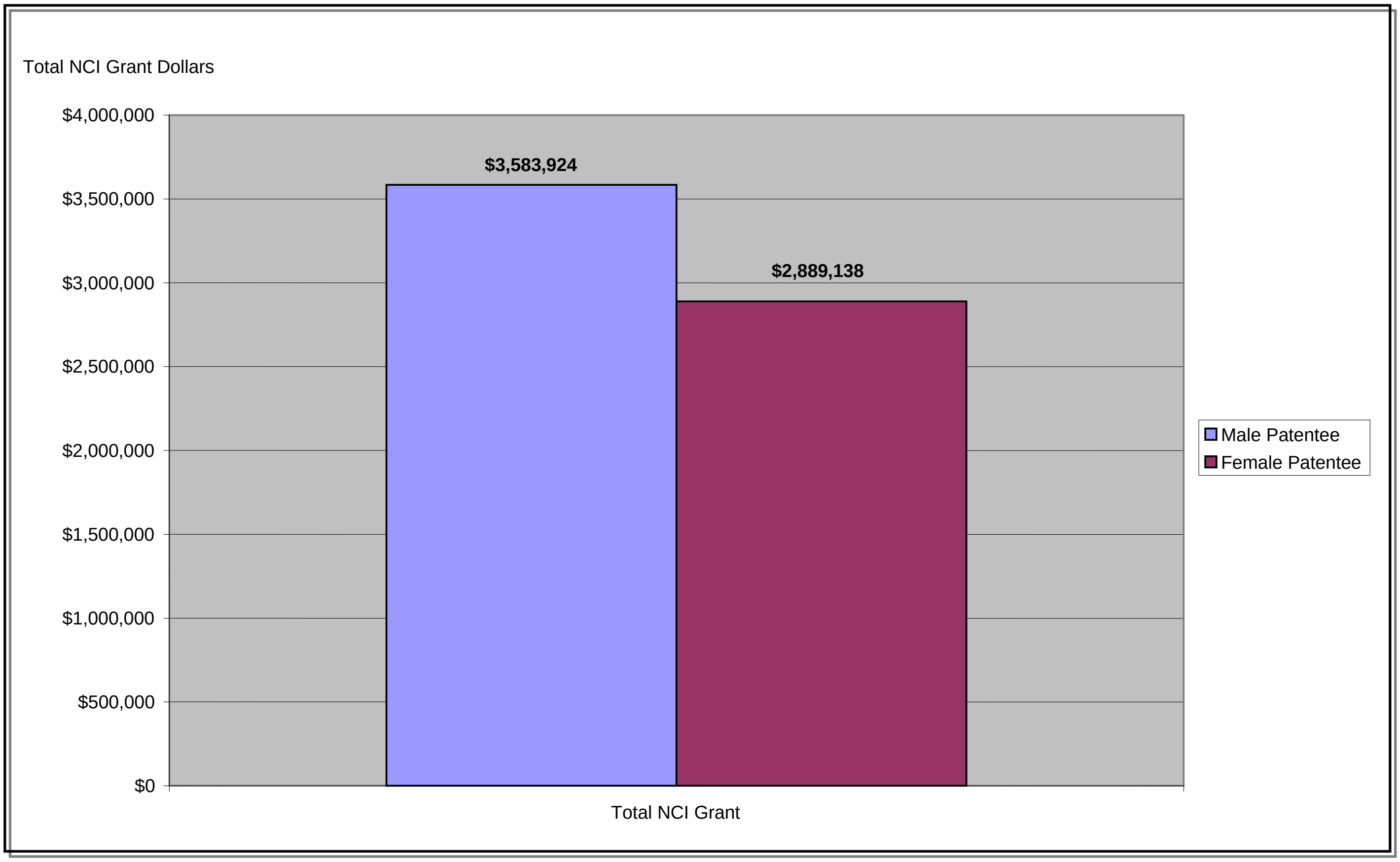
Figure 2 shows that the distribution of patentees varied both across institutions as well as by gender. In Ivy League and public institutions, the propensity for females to patent exceeded that of their male colleagues. Male scientists at universities with an NCI Center, however, had a greater propensity to patent.

Figure 2: Patents by Institution and Gender



Gender also clearly played a role in a number of other dimensions. For example, Figure 3 shows that the mean amount of the NCI grant was considerably greater for male scientists who patented than for their female counterparts.

Figure 3: NCI Grant Award by Gender for Patenting Scientists



3.2 Small Business Innovation Research (SBIR)

The second measure of scientist commercialization involves scientists awarded SBIR grants to finance innovative small businesses. Enactment of the SBIR program in the early 1980s was a response to the loss of American competitiveness in global markets. Congress mandated each federal agency with allocating around four percent of its annual budget to funding innovative small firms as a mechanism for restoring American international competitiveness (Wessner, 2000). SBIR provides a mandate to the major R&D agencies in the United States to allocate a share of the research budget to innovative small firms. In 2001 the SBIR program amounted to around $1.4 billion. The SBIR consists of three phases. Phase I is oriented towards determining the scientific and technical merit along with the feasibility of a proposed research idea. A Phase I Award provides an opportunity for a small business to establish the feasibility and technical merit of a proposed innovation. The duration of the award is six months and cannot exceed $70,000. Phase II extends the technological idea and emphasizes commercialization. A Phase II Award is granted to only the most promising of the Phase I projects based on scientific/technical merit, the expected value to the funding agency, company capability and commercial potential. The duration of the award is a maximum of 24 months and generally does not exceed $600,000. Approximately 40 percent of the Phase I Awards continue on to Phase II. Phase III involves additional private funding for the commercial application of a technology. A Phase III Award is for the infusion of a product into the commercial market. Private sector investment, in various forms, is typically present in Phase III. Under the Small Business Research and Development Enhancement Act of 1992, funding in Phase I was increased to $100,000 and in Phase II to $750,000.

The SBIR represents about 60 percent of all public entrepreneurial finance programs (Lerner, 1999). Taken together, the public small-business finance is about two-thirds as large as private venture capital. In 1995, the sum of equity financing provided through and guaranteed by public programs financing Small and Medium Enterprises was $2.4 billion, which amounted to more than 60 percent of the total funding disbursed by traditional venture funds in that year (Lerner, 1999). Equally as important, the emphasis on SBIR and most public funds is on early stage finance, which is generally ignored by private venture capital. Some of the most innovative American companies received early stage finance from SBIR, including Apple Computer, Chiron, Compaq and Intel.

There is compelling evidence that the SBIR program has had a positive impact on economic performance in the U.S. (Wessner, 2000; Audretsch, 2003; Audretsch, Weigand and Weigand, 2002; and Lerner, 1999). The relevant agency awarding SBIR grants to scientists for commercialization of science involving cancer research is the National Institutes of Health. This does not preclude the possibility that SBIR awards could be made to scientists engaged in cancer research from other agencies. The SBIR award data from the NIH between 1998 and 2002 is listed on the NIH home webpage at http://grants.nih.gov/grants/funding/award_data.htm.[9] The information provided in each SBIR record in the NIH database includes the phase type of the award, fiscal year, state, formal organizational name, award, application type, grant number, principle investigator (PI), project title, contact name, contact e-mail, organization line, address, research partner, and whether the SBIR award was a new grant.

Between 1998 and 2002, 6,461 SBIR awards were granted to 3,230 distinct scientists from the NIH. The Principle Investigator (PI) of each SBIR award was then matched to the 1,693 NCI scientists using an SQL program. Those scientists included in both the SBIR database as a PI and an NCI award recipient, and that were matched by last and first names, were considered for this study. The resulting 34 matches were then subjected to a location criterion: the address of the PI listed in the SBIR grant was matched to the NCI scientists using a 75 mile radius to the respective university. If the location was outside of a 75 mile radius, the match was not considered to be valid. For example, there are four PI scientists with the name David Johnson listed in the NIH SBIR database. Their

[9] The acting director of the Office of Extramural Research at NIH, Joanne Goodnight, and the "general help e-mail address" were twice e-mailed and called to confirm the veracity of the website's content. Neither the director nor any staff responded to confirmation requests.

addresses are given as Hamilton, Montana; Lawrence, Kansas; San Diego, California and Seattle, Washington. None of these addresses matched the two NCI recipients named David Johnson from Houston, Texas and Nashville, Tennessee. The geography criterion reduced the number of confirmed SBIR-NCI recipients to eight. Thus, one of the most striking insights to emerge in this study is that use of the SBIR is not a prevalent or even common mode of commercialization by scientists receiving NCI awards.

The most striking feature of the (small) group of SBIR scientists is that they tend to be highly accomplished in terms of research output and reputation. As Table 3 shows, their citations were about three times as great as the overall group of NCI scientists. Most of the SBIR scientists are employed at NCI Centers.

Interestingly, the mean value of their NCI award was relatively low. Thus, there are considerable reasons to view those scientists funded by the NCI who also obtain an SBIR grant as being outliers.

4. Determinants of Scientist Commercialization

4.1 Main Factors

A number of theories and hypotheses have posited why some scientists choose to commercialize research while others do not, and some compelling insights have been garnered through previous empirical studies. These include the gender, age, experience and also reputation of the scientist, as well the role of scientific human capital and resources, and the regional and university contexts, which highlight the role of geographically bounded spillovers and institutional incentives.

In addition to these control variables, which have already been probed in a number of studies examining factors that influence the propensity for a scientist to engage in commercialization activities, we also include a number of factors that can only be measured with the type of scientist-based data set constructed and described in the previous section. These additional factors include not just scientific human capital, but social capital as well, along with the role of the TTO, and the commercialization route selected by the scientist.

Social Capital

Social capital refers to meaningful interactions and linkages the scientist has with others. While *physical capital* refers to the importance of machines and tools as a factor of production (Solow, 1956), the endogenous growth theory (Romer 1986, 1990; Lucas 1988) puts the emphasis on the process of knowledge accumulation, and hence the creation of *knowledge capital*. The concept of *social capital* (Putnam, 1993 and Coleman, 1988) can be considered a further extension because it adds 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. 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 that facilitate coordination and cooperation for mutual benefits.

A large and robust literature has emerged attempting to link social capital to entrepreneurship (Aldrich and Martinez, 2003; Aldrich, 2005; and Thorton and Flynn, 2003). According to this literature, entrepreneurial activity should be enhanced where investments in social capital are greater. Interactions and linkages, such as working together with industry, are posited as conduits not just of knowledge spillovers but also for the demonstration effect providing a flow of information across scientists about how scientific research can be commercialized (Thursby and Thursby, 2004). Thus, the social capital of a scientist is posited to be conducive to the commercialization of research.

Scientist Commercialization Route

Scientists choose to commercialize their research through two different routes. They can assign their patents to the university's TTO, which we refer to as the *TTO route*. Alternatively, they can choose what we term the *entrepreneurial route* of commercialization. The *entrepreneurial route* to scientist commercialization refers to those scientists who do not assign all of their patents to the university's TTO. Of the NCI patenting scientists, 70 percent assigned all of their patents to their university TTO and 30 percent chose the *entrepreneurial route* to commercialize their research.

Whether or not the particular commercialization route influences the commercialization mode is an empirical question best left for the data analysis to answer.

Technology Transfer Office

The TTO has a mandate to facilitate and promote the commercialization of university science. As the President of the Association of American Universities observed:

> 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[10]

The Commission of the U.S. Patent and Trademark Office claimed:

> In the 1970s, the government discovered that inventions that resulted from public funding were not reaching the marketplace because no one could 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.[11]

This, presumably, would suggest that the TTO is expected to have a positive impact on scientist commercialization of university research.

On the other hand, there are reasons to suspect that *involvement of the TTO might not have the same impact across all modes of commercialization*. For example, one response from the in-depth scientist interviews conducted in this study revealed:

> I refuse to work with the TTO. They have destroyed any of my commercial work. I have given up on any sort of commercial enterprises with my TTO. I don't think any of my colleagues have attempted to commercialize anything here for the past six years.[12]

Similarly, a different scientist shared that "My commercial spirit stops at the TTO door."[13]

However, it is important to emphasize that such views are not reflective of all scientists. For example, a different scientist responded that "Our university technology

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[10] Cited in Mowery (2005, p. 65)
[11] Cited in Mowery (2005, p. 65)
[12] NCI scientist quote taken on January 25th, 2005
[13] NCI scientist quote taken January 15th, 2005

transfer office does ok. They occasionally have some problems with some technical issues, but over all, they have served me for the better."[14]

Thus, the actual impact of the TTO on scientist commercialization in general and on the specific commercialization modes of entrepreneurship and licensing is a question best left to empirical scrutiny.

Scientific Human Capital

An implication of the knowledge production function is that those scientists with greater research and scientific prowess have the capacity for generating greater scientific output. But how does scientific capability translate into observable characteristics that can promote or impede commercialization efforts? Because the commercialization of scientific research is particularly risky and uncertain (Audretsch and Stephan, 2000), a strong scientific reputation, as evidenced through citations, provides a greatly valued signal of scientific credibility and capability to any anticipated commercialized venture or project. This suggests a hypothesis linking measures of the quality of the scientist, or her scientific reputation as measured by citations, to commercialization.

Resources

The question of why some contexts generate more innovative activity than others has been the subject of considerable research in economics. While the conventional approach to analyzing innovative output at the microeconomic level has been at the level of the firm, it conceivably can apply to the unit of analysis of the individual knowledge

[14] NCI scientist quote taken on October 12th, 2005

worker, such as a scientist. The fundamental questions addressed in this literature are: *"What do firms do to generate innovative output?"* and "*Why are some firms more innovative than others?"* For the unit of observation of the individual scientist, this question translates into: "*What do scientists do to generate innovative output?*" and "*Why are some scientists more engaged in commercialization of scientific activity than others?*"

In what Zvi Griliches (1979) formalized as the *model of the knowledge production function*, knowledge generating inputs are linked to innovative outputs. Griliches, in fact, suggested that it was investments in knowledge inputs that would generate the greatest yield in terms of innovative output.

This might suggest a hypothesis that the propensity for a scientist to engage in commercialization activity is positively related to the amount of the award, on the grounds that a greater award amount, *ceteris paribus*, represents a greater investment in new knowledge.

Scientist Life-Cycle

A large literature has emerged focusing on what has become known as the appropriability problem. The underlying issue revolves around how firms which invest in the creation of new knowledge can best appropriate the economic returns from that knowledge (Arrow, 1962). Audretsch (1995) proposed shifting the unit of observation away from exogenously assumed firms to individuals — agents with endowments of new economic knowledge. When the lens is shifted away from the firm to the individual as the relevant unit of analysis, the appropriability issue remains, but the question becomes; *"How can scientists with a given endowment of new knowledge best appropriate the* *returns from that knowledge?"* Levin and Stephan (1991) suggest that the answer is, *It depends – it depends on both the career trajectory as well as the stage of the life-cycle of the scientist.*

The university or academic career trajectory encourages and rewards the production of new scientific knowledge. Thus, the goal of the scientist in the university context is to establish priority. This is done most efficiently through publication in scientific journals (Audretsch and Stephan, 2000). By contrast, with a career trajectory in the private sector, scientists are rewarded for the production of new economic knowledge, or knowledge which has been commercialized in the market, but not necessarily new scientific knowledge *per se*. In fact, scientists working in industry are often discouraged from sharing knowledge externally with the scientific community through publication. As a result of these differential incentive structures, industrial and academic scientists develop distinct career trajectories.

The appropriability question confronting academic scientists can be considered in the context of the model of scientist human capital over the life-cycle. Scientist life-cycle models suggest that early in their careers scientists invest heavily in human capital in order to build a scientific reputation (Levin and Stephan, 1991). In the later stages of their career, the scientist trades or *cashes in* this reputation for economic return. Thus, early in her career, the scientist invests in the creation of scientific knowledge in order to establish a reputation that signals the value of that knowledge to the scientific community.

With maturity, scientists seek ways to appropriate the economic value of the new knowledge. Thus, academic scientists may seek to commercialize their scientific research within a life-cycle context. The life-cycle model of the scientist implies that, *ceteris paribus*, scientist age should play a role in the decision to commercialize. In the early stages of her career, a scientist will tend to invest in her scientific reputation. As she evolves towards maturity and the marginal productivity of her scientific research starts to hit diminishing returns, the incentive for cashing in through commercialization becomes greater.

Scientists working in the private sector are arguably more fully compensated for the economic value of their knowledge. This will not be the case for academic scientists, unless they cash out, in terms of Dasgupta and David (1994), by commercializing their scientific knowledge. This suggests that academic scientists seek commercialization within a life-cycle context. This life-cycle context presents two distinct hypotheses: both age and scientific reputation should influence the decision of a university scientist to engage in commercialization activities.

Locational and Institutional Contexts

Scientist location can influence the decision to commercialize for two reasons. First, as Jaffe (1989), Audretsch and Feldman (1996), Jaffe, Trajtenberg and Henderson (1993), and Glaeser, Kallal, Sheinkman and Shleifer (2002) show, knowledge tends to spill over within geographically bounded regions. This implies that scientists working in regions with a high level of investments in new knowledge can more easily access and generate new scientific ideas. This suggests that scientists working in knowledge clusters should tend to be more productive than their counterparts who are geographically isolated.

As Glaeser, Kallal, Scheinkman and Shleifer (1992, p. 1,126) have observed, “Intellectual breakthroughs must cross hallways and streets more easily than oceans and continents.”

A second component of externalities involves not the technological knowledge, but rather behavioral knowledge. As Bercoviz and Feldman (2004) show for a study based on the commercialization activities of scientists at Johns Hopkins University and Duke University, the likelihood of a scientist engaging in commercialization activity, which is measured as disclosing an invention, is shaped by the commercialization behaviour of the doctoral supervisor in the institution where the scientist was trained, as well as the commercialization behaviour and attitudes exhibited by the chair and peers in the relevant department. Similarly, based on a study of 778 faculty members from 40 universities, Louis et al. (1998) find that it is the local norms of behaviour and attitudes towards commercialization that shape the likelihood of an individual university scientist to engage in commercialization activity, in their case by starting a new firm.

Thus, the location and institutional contexts can influence the propensity for scientists to engage in commercialization activities by providing access to spatially bounded knowledge spillovers and by shaping the institutional setting and behavioural norms and attitudes towards commercialization.

5. Estimation of a Probit Model

To shed light on the question; “*Why do some scientists commercialize their scientific research while others do not*?” a probit model was estimated for the unit of observation of the scientist identified in the NCI database where the dependent variable takes on the value of one if she has commercialized over the time period 1998-2004 and zero if she has not. As the previous section emphasized, there is no singular mode for scientist commercialization. Rather, scientists select across multiple modes of possible commercialization. Thus, the probit model was estimated for each of the main modes of commercialization – patents, licenses, new-firm startups, patent selling and SBIR discussed in the previous section. Each of these measures of commercialization is described and defined in Table 1. Because the sample size is large enough to warrant empirical estimation with a probit model, only four of the measures of commercialization- patents, licensing and startups, and commercializing -- could be used.

Table 1: The Modes of Commercialization

Dependent Variables	Description
Patenting Scientist	National Cancer Institute grant awarded scientist who patented from 1998 to 2004 (Sample 1693, *N*=392)
SBIR Grant Scientist	Scientist awarded an SBIR grant (Sample 1693, *N*=8)
Startup Scientist	Scientist who responded to survey question that she started new firm (Sample=140, *N*=36)
Licensing Scientist	Scientist who responded to survey question that she licensed (Sample=140, *N*=71)
Commercializing Scientist	Scientist who patented or licensed (Sample=140, N=83)
Patent Selling Scientist	Scientist who sold ownership of the patent (Sample=75, N=4)[15]

The previous section suggests five different types of factors shaping the decision by a scientist to commercialize her research: social capital, the TTO, resources, age, scientific

[15] Selling patents are dropped from the analysis due to the small number of patent sellers (N=4).

human capital (quality), nature of the university, and location. These factors are empirically operationalized through the following measures:

Social Capital

Co-patents – This variable reflects the extent of social capital and linkages between scientists by measuring the number of patents where two NCI scientists shared a patent. It is expected to have a positive coefficient, reflecting the propensity for social capital to be positively related to scientist commercialization of research.

Board – This is a binary variable taking on the value of one if the scientist has sat on a scientific advisory board or the board of directors of a firm. A positive coefficient would indicate that social capital, as reflected by board membership, is conducive to the commercialization of university research.

Industry Co-publications – This variable reflects social capital and linkages between university scientists and their counterparts in industry and is measured as co-authorship between a university scientist and an industry scientist in the Science Citation Index using the Institute for Scientist Information (ISI) Web of Science citation database. The total count of papers coauthored with an industry scientist between the years of 1998 and 2004 was estimated using several search queries on the ISI database. Using the address fields within each publication value in the ISI database, Co-publications were identified as a private sector address if the terms *Co, Co Ltd, Inc,* or *LLC,* were found. Also, in order to not misidentify the University of **Co**lorado as a company, for example, the query forced the previously mentioned search terms to be standalone words, and not part of larger words. The coefficient is expected to be positive, which would reflect that university-industry scientist interactions are conducive to commercialization.

Industry Co-publication Asia -- This variable reflects social capital and linkages between university scientists and their counterparts located in Asia. Scientist linkages are measured as co-authorship between a university and an Asian scientist in the Science Citation Index using the ISI Web of Science citation database. Using the address fields within each publication value of the ISI Web of Science citation index *Industry Co-publication Asia* was identified if any of the terms of *China*, *Japan*, *South Korea* and *Taiwan* were found in the ISI Web of Science address field. A binary variable was then created, taking on the value of one for all scientists with linkages in Asia and zero otherwise. The coefficient is expected to be positive which would reflect that interactions involving scientists located in Asia are conducive to commercialization.

Scientist Commercialization Route

Non TTO Assignee – This is a binary variable taking on the value of one for scientists who had at least one patent which was not assigned to their universities' TTO office, reflecting the TTO route to commercialization. According to the U.S. Patent Trademark Office a patent assignee may be defined as "The assignee, when the patent is assigned to him or her, becomes the owner of the patent and has the same rights that the original patentee had. The statute [of law] also provides for the assignment of a part interest, that is, a half interest, a fourth interest etc., in a patent."[16] Scientists not assigning a patent to their TTO are

[16] http://www.uspto.gov/web/offices/pac/doc/general

considered to choose the *entrepreneurial route* to commercialize their research. A positive coefficient would indicate that those scientists who have at least one non TTO assignee patent have a higher propensity to commercialize their research. A negative coefficient would suggest that those scientists choosing the *TTO route* are more likely to engage in commercializing their research.

Of the 392 patentees, 29.80 percent were determined to choose the entrepreneurial route to commercialization, in that they assigned at least one patent not to their university. For example, seven out of eight of Dr. Jon Doe's patent assignees belonged to the *Curators of the University of Missouri*. The eighth patent was assigned ownership to Pfizer, Inc. and not to the *Curators of the University of Missouri*. This example is typical of the *entrepreneurial route* to commercialization and was therefore categorized as a *Non TTO Patent Assignee*. In comparison, 70.20 percent of the 392 patenting scientist selected the TTO route to commercialization, in that they assigned all of their patents to the TTO.

Technology Transfer Office

TTO Helpful – This is a binary variable taking on the value of one for scientists who responded to the survey that their TTO directly helped them commercialize their research and zero otherwise. A positive coefficient would indicate that those scientists reporting that their TTO was helpful in commercializing their research have a higher propensity to commercialize their research.

TTO Age – This variable reflects the TTO age and is measured as the year in which the TTO was founded at the particular university. The measure is taken from the AUTM database. Because more recent years indicate a younger TTO, a positive coefficient would reflect a negative relationship between TTO age and the propensity for scientists to commercialize.

TTO Employees – This variable measures the mean number of employees per year responsible for license and patent acquisitions. The measure is taken from the AUTM database. A positive relationship would suggest that a greater commitment of TTO employee resources yields a higher propensity for scientists to commercialize their research.

TTO Licensing Commitment – Dividing the number of employees dedicated to licensing technology by the number of administrative employees reflects the commitment of the TTO to licensing relative to other TTO functions. This measure is derived from the AUTM database. A positive relationship would suggest that allocating a greater share of TTO employees to licensing would increase scientist commercialization.

TTO Efficiency – The mean number of patents applied for is divided by the number of issued patents, which reflects the efficiency of the TTO. This measure is derived from the AUTM database. A positive coefficient would reflect that a higher yield of patent applications resulting in patents granted lead to greater scientist commercialization.

Scientific Human Capital

Scientist Citations – A specific computer program was designed to measure the citations of NCI scientists between 1998 and 2004 through the "Expanded Science Citation Index." A higher number of citations reflects a higher level of human capital and scientific reputation

(Audretsch and Stephan, 2000). A positive coefficient would reflect that the likelihood of commercialization is greater for more productive scientists.

Prior Patents – This variable is measured as the number of patents issued to a scientist prior to 1998. The variable is included to control for previous experience with commercialization activities. A positive coefficient would suggest that, even after controlling for the influences of social capital, the TTO, scientific human capital, resources, age, and locational and institutional contexts, previous commercialization experiences elevates the propensity of a scientist to engage in commercialization activity.

Resources

NCI Grant – This variable is the mean total NCI grant awarded to a scientist between 1998 and 2002. If external funding of scientific research is conducive to commercialization, a positive coefficient of the *NCI Grant* would be expected.[17]

Government Funding – This binary variable takes on the value of one for scientists responding to the scientist survey that they received additional funding in excess of $750,000 from government sources and zero otherwise. A positive coefficient would indicate that an increase in funding from the government facilitates scientist commercialization.

[17] The NCI grant coefficient was multiplied by 1,000 for presentation purposes

Scientist Life-Cycle

Scientist Age **--** The age of the scientist, measured in terms of years, was obtained from the scientist survey. The Life-Cycle hypothesis of Stephan and Levin (1990) suggests a positive coefficient, which would reflect a higher propensity for more mature scientists to engage in commercialization activities.

Gender – This is a dummy variable assigned the value of one for males (1,310) of the overall 1,693 included in the NCI database. The gender of each scientist was obtained by "Googling" their names and finding their picture profile online. The estimated coefficient will reflect whether the gender of the scientist influences the propensity to commercialize research.

Locational and Institutional Contexts

Three different locational binary variables taking on the value of one for the *North East*, which includes all states on the Eastern Seaboard between Washington, D.C. and Maine (Washington, D.C., Connecticut, Rhode Island, New Hampshire, New Jersey, New York, Pennsylvania, Massachusetts, Maryland and Vermont), *California* and the *Great Lakes* (Ohio, Indiana, Illinois, Michigan and Wisconsin). Those regions which tend to have greater investments in research and science, and also have developed a culture more encouraging of university and scientist commercialization, such as California and the North East, might be expected to have a positive coefficient.

NCI Center – This is a binary variable taking on the value of one if the scientist is employed at one of the 39 nationally-recognized cancer centers, and zero otherwise. A comprehensive cancer center integrates research activities across the three major areas of laboratory, clinical and population-based research. The comprehensive cancer centers generally have the mission to support research infrastructure, but some centers also provide clinical care and service, reflecting the priority that community outreach and information dissemination play at the centers.[18] A positive coefficient would reflect that being located at a comprehensive center facilitates commercialization.

Ivy League – A binary variable taking on the value of one for all scientists employed at Brown University, Cornell University, Columbia University, Dartmouth College, Harvard University, Princeton University, the University of Pennsylvania and Yale University, and zero otherwise.

Public Institution – A binary variable taking on the value of one for scientists employed at public universities and zero otherwise. Because they are at least partially financed by the public, state universities tend to have a stronger mandate for outreach and commercialization of research. This may suggest a positive coefficient.

The definitions of the independent variables are summarized in Table 2. The means and standard deviations of all variables are provided in Table 3. Table 4 provides a correlation matrix between all variables.

[18] http://www3.cancer.gov/cancercenters/description.html

Table 2: Description of Independent Variables

Independent Variables	**Description**
Co-patents	The number of times a patenting scientist shared a patent with another NCI scientist
Industry Co-publications	The number of publications an NCI scientist shared with a private industry scientist
Board	Binary variable, for scientists indicating that they sat on either a board of directors or science advisory board, Board=1
TTO Helpful	Binary variable, for scientists indicating that the "TTO directly helped you commercialize your research", TTO Helpful=1
Government Funding	Binary variable, for scientists indicating that they received at least $750,000 of funding from a governmental source, Government Funding=1
Non TTO Assignee	Binary variable, for scientists who had at least one patent where the assignee was not the scientist's university, Non TTO Assignee=1
Industry Co-publications Asia	Binary variable, for scientists who shared a co-publication with a scientist located in Asia, Industry Co-publications Asia=1
NCI Helpful	Binary variable, for scientists indicating that the NCI grant was helpful for patenting, NCI Helpful=1
TTO Age	Year when TTO was founded
TTO Employees	The mean annual number of TTO employees dedicated to licensing and patenting
TTO Licensing Commitment	The number of TTO employees dedicated to licensing and patenting divided by administrative employees
TTO Efficiency	The ratio of patent applications to patents issued by the TTO at the scientist's university
NCI Grant	Total amount of funding received by a scientist
Scientist Age	The age of the scientist
Gender	Binary variable, where a male=1
Scientist Citations	The number of citations a scientist had, 1998 - 2004
Prior Patents	The number of issued patents a scientist had, 1975 - 1998
NCI Center	Binary variable, for a scientist whose institution is recognized by NCI as a comprehensive center for cancer research, NCI Center=1
Ivy League	Binary variable, for a scientist whose institution is an Ivy League university, Ivy League=1
North East	Binary Variable, for a scientist's institution that is in CT, DC, MA, MD, NJ, NH, PA, RI or VT. North East=1
California	Binary variable, for a scientist's institution located in California, California=1
Great Lakes	Binary variable, for a scientist's institution that is located in IL, IN, MI, OH, or WI

Table 3: Means and Standard Deviations of All Variables

	NCI Scientist	SBIR Scientist	Patent Scientist	Interviewed Scientist
Variable	N=1693	N=8	N=392	N=140
Patent (%)	23.35 (0.42)	25.00 (0.46)	100.00	100.00
License (%)	-	-	-	50.71 (0.50)
Startup (%)	-	100	-	25.71 (0.44)
Commercialize (%)	-	100	-	59.29 (0.49)
Industry Co-publications	1.83 (3.57)	3.75	3.01 (4.89)	2.56 (3.73)
Asia Industry Co-publications (%)	37.00 (0.48)	50.00 (0.53)	48.00 (0.50)	8.50 (0.28)
Board (%)	-	-	-	58.00 (0.50)
Co-patents	-	-	3.13 (4.26)	1.18 (3.97)
Government Funding (%)	-	-	-	38.04 (0.49)
TTO Helpful (%)	-	-	-	53.13 (0.50)
Non TTO Assignee (%)	-	50.00 (0.70)	29.98 (0.45)	20.14 (0.40)
TTO Employees	8.66 (11.44)	9.45 (14.52)	9.14 (11.6)	8.95 (11.65)
TTO Age	1981.70 (11.35)	1986 (5.11)	1980.77 (11.29)	1980.74 (11.25)
TTO Licensing Commitment	1.68 (2.29)	1.76 (2.08)	1.31 (1.45)	1.22 (1.24)
TTO Efficiency (%)	0.32 (0.12)	0.306 (0.13)	0.343 (0.12)	0.372 (0.17)
NCI Grant (Dollars)	3,161,943 (3,196,918)	2,744,319 (1,533,956)	3,484,128 (3,795,993)	3,053,465 (2,674,288)
Gender (%)	77.87 (0.42)	87.50 (0.35)	87.85 (0.33)	88.57 (0.32)
NCI Helpful (%)	-	-	-	45.04 (0.50)
Scientist Age	-	-	-	56.76 (8.40)
Scientist Citations	1316.44 (2472.29)	3770.00 (9133.90)	1741.19 (2441.07)	1500.34 (1603.49)
Prior Patents	1.35 (4.92)	1.63 (1.18)	4.40 (9.28)	3.88 (6.47)
NCI Center (%)	55.86 (0.50)	75.00 (0.46)	56.50 (0.50)	50.70 (0.50)
Public Institution (%)	53.91 (0.50)	50.00 (0.53)	48.10 (0.50)	49.29 (0.50)
Ivy League (%)	10.24 (0.30)	0.00 -	12.15 (0.33)	15.00 (0.36)
North East (%)	34.84 (0.48)	37.50 (0.51)	37.22 (0.48)	41.43 (0.51)
California (%)	13.66 (0.34)	12.50 (0.35)	16.71 (0.37)	15.71 (0.37)
Great Lakes (%)	12.95 (0.34)	25.00 (0.46)	10.89 (0.31)	08.57 (0.28)

Table 4: Simple Correlation Matrix

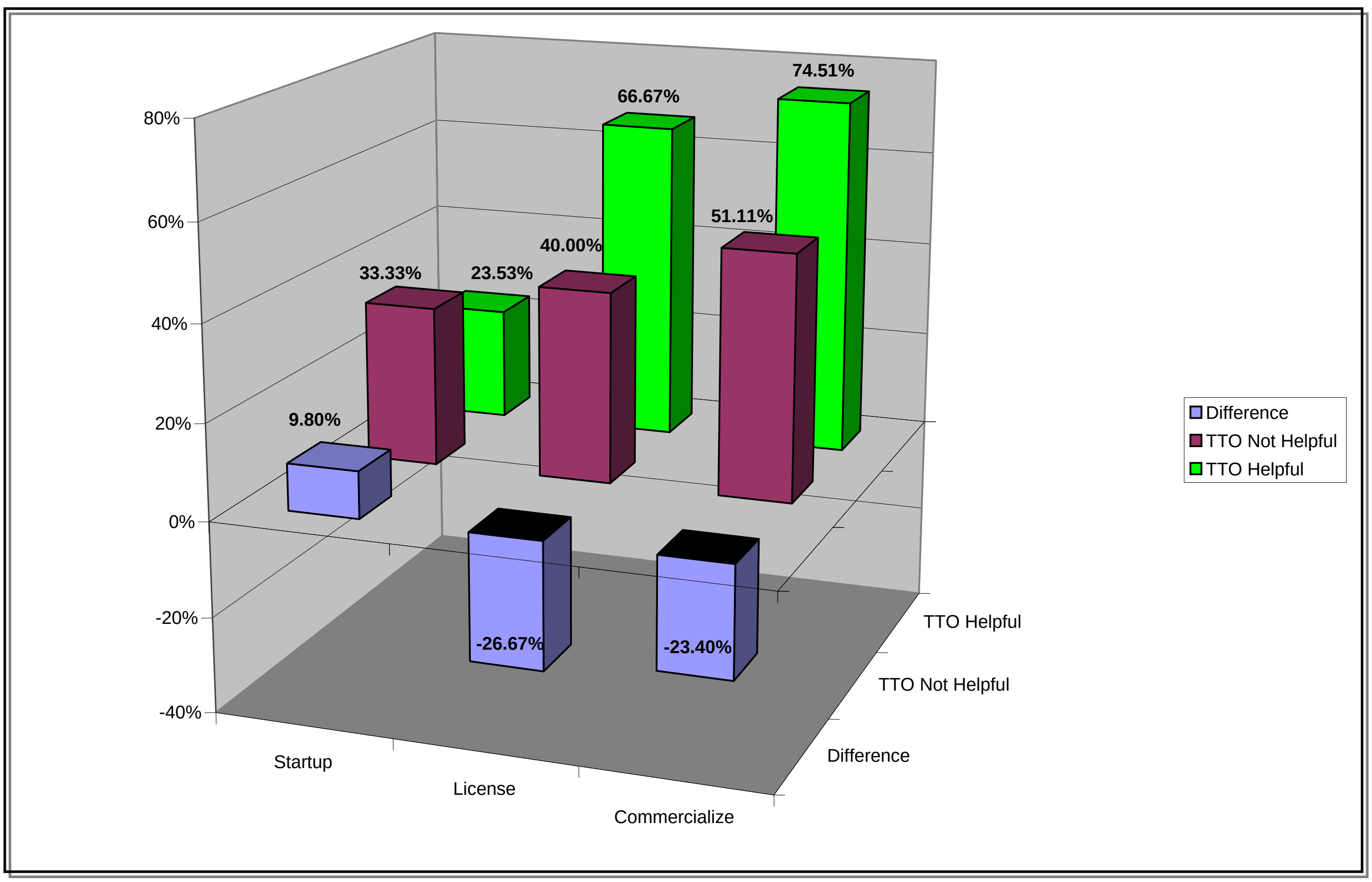
	Startup	License	Commercial	Co-patent	Industry Co-pubs	Board	TTO Helpful	Gov't Funding	Non TTO Assignee	Asia Co-pub
Startup	1.000									
License	0.203	1.000								
Commercial	0.520	0.802	1.000							
Co-patent	-0.077	0.148	0.092	1.000						
Industry Co-pubs	0.166	0.127	0.220	0.049	1.000					
Board	0.446	0.305	0.340	-0.080	0.031	1.000				
TTO Helpful	-0.113	0.284	0.280	0.149	0.007	0.014	1.000			
Gov't Funding	0.135	0.101	0.147	-0.014	0.021	0.057	0.015	1.000		
Non TTO Assign	0.130	-0.276	-0.048	-0.071	-0.078	-0.141	-0.109	0.152	1.000	
Asia Co-pubs	-0.080	0.132	0.191	-0.070	0.000	0.011	-0.074	-0.112	-0.103	1.000
TTO Age	-0.182	-0.083	-0.044	-0.108	-0.047	-0.206	-0.134	-0.024	0.046	0.106
TTO Employees	-0.015	0.051	-0.018	0.359	0.143	0.091	0.147	0.075	-0.144	-0.100
TTO Commit	0.006	0.059	0.004	0.368	0.126	0.089	0.139	0.094	-0.113	-0.095
TTO Efficiency	0.054	0.161	0.085	-0.127	0.133	-0.054	-0.033	-0.229	0.077	-0.112
NCI Grant	-0.053	-0.066	-0.031	0.165	0.073	0.120	0.250	0.031	-0.043	-0.027
NCI Helpful	0.277	0.265	0.333	0.051	-0.010	0.213	0.343	0.027	-0.156	0.053
Scientist Age	-0.137	-0.100	-0.167	0.125	-0.166	-0.066	0.051	0.049	-0.127	-0.044
Gender	0.157	-0.050	0.024	0.039	-0.017	0.315	0.027	0.023	0.007	0.091
Scientist Citations	-0.066	0.083	0.041	0.191	0.066	0.104	-0.052	0.085	-0.188	-0.073
Prior Patents	-0.051	0.156	0.156	0.583	-0.042	0.035	0.194	0.085	-0.028	-0.074
NCI Center	-0.057	0.124	0.113	0.091	0.237	-0.093	0.153	-0.254	-0.265	0.032
Public Institution	-0.075	-0.135	-0.203	0.100	-0.067	-0.031	-0.213	0.219	0.068	0.046
Ivy League	-0.007	0.248	0.264	-0.061	0.048	-0.100	0.175	-0.056	0.098	0.067
North East	0.082	0.194	0.263	-0.108	-0.003	-0.012	0.104	-0.190	-0.055	0.127
California	0.015	0.018	-0.015	0.250	0.217	0.130	0.099	0.020	-0.185	-0.126
Great Lakes	-0.108	0.067	0.005	0.028	0.087	0.052	0.075	0.055	0.030	0.119

	TTO Age	TTO Emply	TTO Commitment	TTO Efficiency	NCI Grant	NCI Helpful	Scientist Age	Gender	Scientist Citations	Prior Patents
TTO Age	1.000									
TTO Employees	-0.189	1.000								
TTO Commit	-0.166	0.983	1.000							
TTO Efficiency	-0.154	-0.194	-0.193	1.000						
NCI Grant	-0.315	0.150	0.134	-0.072	1.000					
NCI Helpful	-0.090	0.205	0.200	-0.007	0.106	1.000				
Scientist Age	-0.008	-0.038	-0.041	-0.169	0.041	0.004	1.000			
Gender	-0.043	-0.015	-0.007	0.081	-0.058	0.086	0.056	1.000		
Scientist Citation	-0.318	0.070	0.078	0.116	0.193	0.090	-0.103	0.053	1.000	
Prior Patent	-0.017	0.133	0.142	-0.121	0.090	0.159	0.289	0.028	0.228	1.000
NCI Center	0.143	0.232	0.268	0.150	-0.089	0.079	-0.099	-0.145	0.022	-0.040
Public Institution	0.266	0.278	0.292	-0.196	0.073	0.132	0.259	0.181	-0.193	-0.023
Ivy League	0.004	-0.152	-0.138	0.521	0.015	0.122	-0.214	-0.007	0.127	0.030
North East	-0.164	-0.213	-0.206	0.298	0.026	0.000	-0.221	-0.182	0.250	0.179
California	-0.179	0.791	0.746	-0.101	0.038	0.136	-0.027	0.052	0.026	-0.004
Great Lakes	0.209	-0.137	-0.123	-0.242	-0.091	-0.195	0.091	-0.059	-0.082	-0.010

	NCI Center	Public Institution	Ivy League	North East	California	Great Lakes
NCI Center	1.000					
Public Institution	-0.108	1.000				
Ivy League	0.175	-0.376	1.000			
North East	0.213	-0.511	0.480	1.000		
California	0.167	0.123	-0.174	-0.363	1.000	
Great Lakes	-0.121	-0.105	-0.107	-0.224	-0.139	1.000

Figure 4 compares the likelihood of scientist commercialization between the two modes of commercialization — startup and licensing — for those 54 scientists perceiving they were helped by their TTO offices and the 47 scientist perceiving they were not helped. The likelihood of licensing intellectual property is greater for scientists helped by the TTO than for those not helped. By contrast, the likelihood of starting a new firm is less for those scientists helped by the TTO than for those scientists not helped. This results in a difference for not being helped by the TTO that is positive for startups but negative for licensing.

Figure 4: TTO Helpfulness to Scientist by Commercialization Mode



Similarly, Figure 5 compares the likelihood of scientist commercialization between startups and licensing for the 111 scientists choosing the TTO route to commercialize their research, and the 29 scientists selecting the entrepreneurial route to commercialization. The likelihood of licensing intellectual property is greater for the scientists assigning all of their patents to their TTO. By contrast, the likelihood of starting a new firm is greater for those scientists not assigning all of their patents to their TTO. Thus, those scientists selecting the TTO commercialization route have a higher propensity to license, while those scientists choosing the entrepreneurial route to commercialziation have a higher propensity to start a new firm.

Figure 5: Scientist Commercialization Route by Commercialization Mode

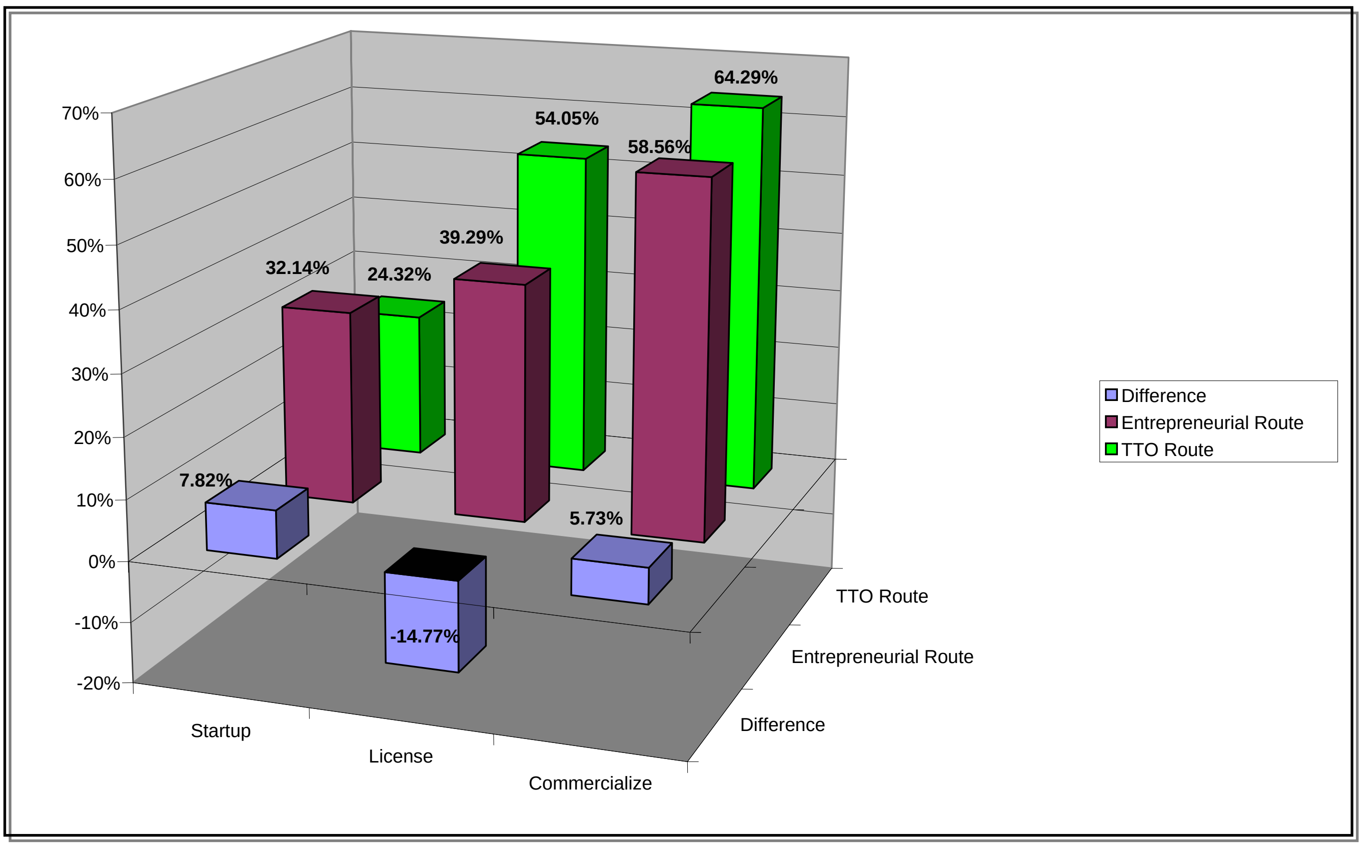
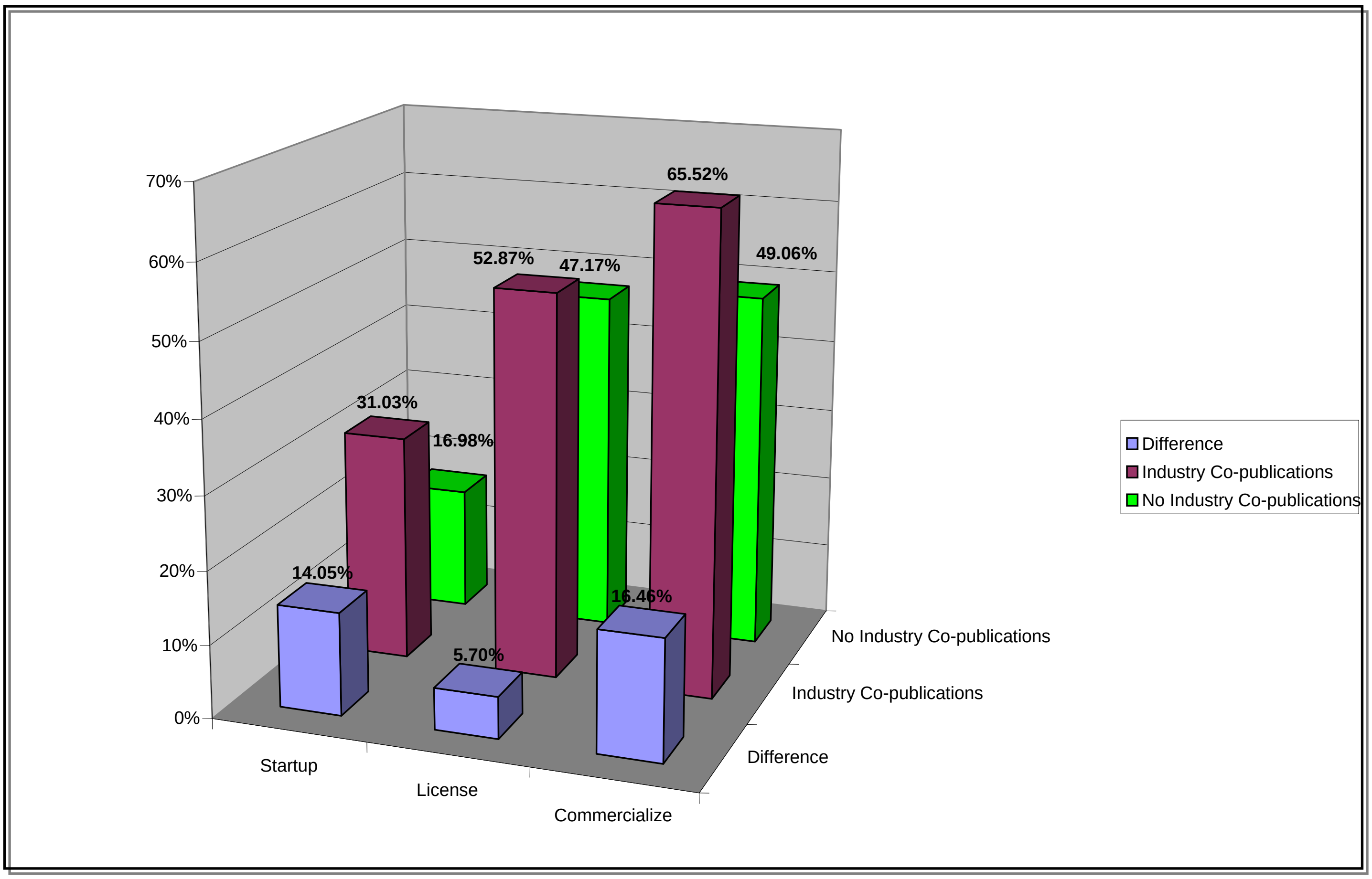


Figure 6 shows how one of the measures of social capital, co-publication with a scientist in industry, impacts the commercialization mode. Scientists with social capital, measured as having at least one co-publication with industry (N=88), exhibit a higher propensity to start a new firm, license their intellectual property, and commercialize their research, than do their colleagues with low social capital (N=54). Thus, there is at least some evidence suggesting that the impact of social capital on entrepreneurship is greater than on licensing.

Figure 6: Social Capital by Commercialization Mode



The results from estimating the probit model using the mode of scientist commercialization as starting a new firm are provided in Table 5. Because of multicollinearity, not all of the control variables could be included in the same estimation model.

Table 5: Probit Regression Results Estimating Scientist Commercialization - **Startups**

	1	*2*	*3*	*4*
Co-patents	0.141 **(1.76)***	0.155 **(1.65)***	0.155 **(1.67)***	0.191 **(1.77)***
Industry Co-publications	0.102 **(1.72)***	0.17 **(1.77)***	0.158 **(1.72)***	0.191 **(1.84)***
Board	1.696 **(3.40)*****	1.663 **(2.44)****	1.721 **(2.55)****	2.204 **(2.43)****
TTO Helpful	-1.319 **(2.65)*****	-1.665 **(2.50)****	-1.646 **(2.53)****	-1.602 **(2.23)****
Government Funding	0.892 **(1.91)***	1.328 **(2.13)****	1.298 **(2.13)****	1.602 **(2.14)****
Non TTO Patent Assignee	-	-	-	1.598 **(1.80)***
Asia Co-publications	-1.304 **(1.77)***	-0.899 (1.01)	-0.733 (0.88)	-0.684 (0.75)
TTO Age	-0.022 (1.09)	-0.042 (1.23)	-0.028 (0.85)	-0.042 (1.25)
TTO Employees	-0.025 (1.52)	-0.022 (0.58)	-	-0.032 (0.78)
TTO Licensing Commitment	-	-	-0.208 (0.83)	-
TTO Efficiency	-0.017 (0.01)	0.069 (0.04)	0.853 (0.51)	-0.742 (0.50)
NCI Grant	-0.001 (0.93)	-0.028 (1.07)	-0.022 (1.03)	0.001 (1.14)
NCI Helpful	1.67 **(3.39)*****	1.913 **(2.99)*****	1.932 **(3.06)*****	2.122 **(3.04)*****
Age	-	-0.009 (0.25)	0 (-0.01)	0.025 (0.60)
Gender	-	1.616 (1.24)	1.354 (1.09)	1.409 (1.03)
Scientist Citations	-0.37 **(2.16)****	-0.025 **(2.30)****	-0.032 **(2.38)****	-0.029 **(1.73)***
Prior Patents	-0.072 (1.41)	-0.078 (1.29)	-0.08 (1.33)	-0.101 (1.46)
NCI Center	-	0.091 (0.16)	-0.106 (0.19)	0.419 (0.64)
Public Institution	-	-0.742 (0.91)	-1.137 (1.48)	-0.552 (0.65)
Ivy League	-	-0.934 (0.84)	-1.255 (1.08)	-2.211 (1.38)
North East	0.918 **(1.99)****	1.234 (1.57)	1.156 (1.52)	1.677 **(1.76)***
California	-	-0.053 (0.05)	-0.591 (0.75)	0.113 (0.09)
Great Lakes	-	-0.095 (0.07)	-0.468 (0.36)	0.210 (0.17)
Constant	42.081 (1.04)	79.973 (1.19)	53.664 (0.81)	78.756 (1.17)
LR chi2	**44.26*****	**46.9*****	**47.26*****	**51*****
R-squared adjusted	0.42	0.48	0.48	0.52
Observations	83	76	76	76

Absolute value of z statistics in brackets
* significant at 10%; ** significant at 5%; *** significant at 1%

The first column provides results where the scientist-specific characteristics of age and gender, and the binary variables reflecting institution type and location are not included in the estimation. The estimated coefficient of all three measures of social capital, co-patents, co-publications and serving as a member of an industry board are positive and statistically significant. This suggests that for these three measures reflecting different dimensions of social capital, a greater degree of linkages and interactions, both with other academic scientists, with scientists in industry, and with industrial firms, tends to be conducive to scientist entrepreneurship.

While engaging in co-publications increases the likelihood of a scientist becoming an entrepreneur, there is at least some evidence suggesting that this measure of social capital may not be homogenous but rather sensitive to the location of the co-author. As the negative and statistically significant coefficient suggests, if the co-author is located in Asia, the propensity of a scientist to become an entrepreneur becomes lower. Thus, there is at least some evidence suggesting that measures of social capital may be highly nuanced and heterogeneous.

The negative and statistically significant coefficient of *TTO Helpful* suggests that the likelihood of starting a business is lower for those scientists indicating that the TTO at their university was helpful in commercializing their research, but higher for their counterparts indicating that their TTO was not helpful in commercializing research. Thus, if the scientist perceives the TTO as not being helpful with commercialization activities, the likelihood of starting a firm is greater.

Additional funding from (non-NCI) government agencies is conducive to scientist entrepreneurship, as reflected by the positive and statistically significant coefficient of *Government Funding*. None of the measures reflecting either TTO-specific characteristics or the amount of the NCI grant can be considered to be statistically significant. However, as the positive and statistically significant coefficient suggests, those scientists indicating that the NCI grant was helpful have a greater propensity to become an entrepreneur.

The negative and statistically significant coefficient of scientist citations suggests that more highly cited scientists have a systematically lower propensity to become entrepreneurs. Similarly, while prior patenting has no significant influence on scientist entrepreneurial behaviour, the positive and statistically significant coefficient of the binary variable for scientists at universities located in the North East suggests that those scientists located between Washington, D.C. and Maine tend to be more entrepreneurial.

In the second column, probit regression results estimating the likelihood of scientist startups are presented, where the scientist-specific characteristics of age and gender are included along with the measures of university type. Inclusion of these additional control variables leaves the main results reflecting the positive impact of the three measures reflecting social capital and the negative impact of a helpful TTO on the likelihood of scientist entrepreneurship virtually unchanged. The main difference in the results is that the location of a co-author in Asia and the Northeast dummy variable are no longer statistically significant. In the third column the measure reflecting the TTO commitment to licensing is substituted for the number of TTO licensing employees. Again, the main results remain the same.

The binary measure reflecting the route to commercialization, measured as patents not assigned to the TTO, is included in the probit model presented in the fourth column. The positive and statistically significant coefficient of *Non TTO Patent Assignee* suggests that those scientists choosing the entrepreneurial commercialization route, that is not through the TTO, have a higher likelihood of starting a new firm. Those scientists selecting the TTO commercialization route have a lower propensity to start a new firm. All of the other coefficients remain virtually unchanged.

Thus, the results estimating the likelihood of an NCI scientist starting a firm provide consistent and compelling evidence that social capital promotes scientist entrepreneurship, while having a helpful TTO and assigning the patent to the TTO are associated with a lower propensity for scientists to become entrepreneurs. These results might suggest that starting a new firm is a prevalent mechanism for scientists resorting to commercializing their research through the entrepreneurial commercialization route and the TTO route to commercialization.

A different mode of commercializing is licensing, and is examined in Table 6, which reports probit results from estimating the likelihood of scientists licensing their intellectual property. The coefficient of the social capital measuring co-publications cannot be considered to be statistically different from zero. However, the positive and statistically significant coefficient of the binary variable for scientists belonging to either a Scientific Board of Advisors (SAB), or Board of Directors of a private firm and co-patenting does provide at least some evidence suggesting that social capital promotes the likelihood of a scientist licensing her intellectual property.

Table 6: Probit Regression Results Estimating Scientist Commercialization - **License**

	1	*2*	*3*	*4*
Co-patents	0.154 (1.25)	0.400 **(2.25)****	0.388 **(2.20)****	0.470 **(2.51)****
Industry Co-publications	0.025 (0.64)	0.068 (1.02)	0.072 (1.12)	0.092 (1.19)
Board	1.123 **(2.99)*****	1.965 **(3.16)*****	1.946 **(3.19)*****	2.279 **(3.17)*****
TTO Helpful	0.769 **(2.16)****	1.261 **(2.45)****	1.264 **(2.45)****	1.413 **(2.45)****
Government Funding	0.681 **(1.90)***	0.883 **(1.78)***	0.873 **(1.76)***	1.346 **(2.21)****
Non TTO Patent Assignee	-	-	-	-2.978 **(2.54)****
Asia Industry Co-publications	1.343 **(1.72)***	2.165 (1.62)	2.223 **(1.67)***	2.497 (1.42)
NCI Helpful	0.277 (0.78)	0.565 (1.15)	0.554 (1.14)	0.478 (0.91)
TTO Age	0.025 (1.58)	-0.004 (0.15)	0.001 (0.01)	0.001 (0.02)
TTO Employees	0.004 (0.22)	-0.015 (0.43)	-	0.006 (0.16)
TTO Licensing Commitment	-	-	0.019 (0.12)	-
TTO Efficiency	2.281 **(2.25)****	2.744 **(1.95)***	2.932 **(1.90)***	4.300 **(2.42)****
NCI Grant	0.007 (0.14)	-0.004 **(2.50)****	-0.004 **(2.51)****	-0.005 **(2.58)*****
Scientist Age	-	-0.014 (0.40)	-0.01 (0.30)	-0.045 (1.13)
Gender	-	-2.173 **(2.42)****	-2.134 **(2.40)****	-2.505 **(2.48)****
Scientist Citations	-0.002 (0.24)	-0.002 (0.30)	-0.001 (0.320)	-0.010 (0.66)
Prior Patents	-0.02 (0.47)	-0.01 (0.18)	-0.013 (0.23)	-0.006 (0.11)
NCI Center	-	0.033 (0.06)	-0.047 (0.09)	-0.691 (1.04)
Public Institution	-	0.685 (0.87)	0.476 (0.74)	0.111 (0.12)
Ivy League	-	0.329 (0.38)	0.243 (0.26)	1.175 (0.97)
North East	0.416 (1.08)	0.448 (0.60)	0.325 (0.48)	-0.076 (0.08)
California	-	-0.26 (0.24)	-0.636) (0.92)	-1.301 (0.97)
Great Lakes	-	1.002 (0.93)	0.885 (0.83)	0.072 (0.06)
Constant	51.347 **(1.65)***	7.189 (0.14)	-0.201 (0.00)	0.584 (0.01)
LR chi2	**31.76*****	**44.02*****	**43.84*****	**54*****
R-squared adjusted	0.28	0.42	0.42	0.52
Observations	83	76	76	76

Absolute value of z statistics in brackets
* significant at 10%; ** significant at 5%; *** significant at 1%

As for the commercialization mode of startups, the coefficient of the TTO being helpful with scientist commercialization is statistically significant. However, the sign of the coefficient is actually the opposite, i.e. positive, suggesting that those scientists who indicate that they are helped by the TTO have a higher propensity to license their intellectual property, which is in stark contrast to the findings in Table 6 indicating a lower propensity to become an entrepreneur. This might suggest an asymmetric effect of TTOs on scientist entrepreneurship versus scientist licensing. The TTOs appear to be more helpful to a scientist in licensing their intellectual property than for starting a new firm.

While the positive and statistically significant coefficient of *Government Funding* is similar to that found for the mode of startups, the positive and statistically significant coefficient of the variable measuring co-publications with an industry co-author located in Asia is the opposite. This might indicate that while having a co-author located in Asia reduces the likelihood of starting a firm it actually increases the propensity for U.S. based scientists to license their intellectual property.

The coefficients of the variables measuring the helpfulness of the *NCI Grant* towards commercialization, *TTO Age*, and number of TTO employees are not statistically significant. However, the positive and statistically significant coefficient of *TTO Efficiency* indicates that those scientists located at a university where the TTO is more efficient exhibit a higher likelihood of licensing their intellectual property. None of the remaining variables, *Scientist Citations*, *Prior Patents*, or *Northeast*, are found to have statistically significant impact on the likelihood of scientist licensing.

The second column reports regression results where measures reflecting scientist age, gender, and university type and location are included in the estimation model. There are three main differences. First, the coefficient of *Co-patents* becomes statistically significant and positive, indicating that, for the entrepreneurship mode of commercialization, this dimension of social capital is positively related to the likelihood of licensing intellectual property.

Second, the coefficient of *NCI Grant* becomes negative and statistically significant, suggesting that the higher the NCI grant award, the lower is the likelihood of a scientist licensing their intellectual property. Finally, the coefficient of *Gender* is negative and statistically significant. The negative coefficient of this binary variable may seem surprising, given that a slightly higher share of male scientists license their intellectual property than do their female colleagues.[19] However, one interpretation of the negative coefficient is that if female scientists had the same degree of co-patenting with other scientists, participation on boards, help from the TTO, additional funding from non-NCI government agencies, and level of efficiency at their universities' TTO, they would actually exhibit a higher propensity to license than do their male colleagues. According to this interpretation, what explains the gender gap, in terms of licensing behaviour, is not gender *per se*, but rather access to and participation in social capital, such as sitting on scientific advisory boards and boards of directors, as well as co-patenting with other academic scientists. The measure of *TTO Licensing Commitment* is substituted for *TTO Employees* in the regression results presented in the third column. The results remain virtually identical to those reported in column two.

[19] 51 percent of the patenting male scientists licensed their intellectual property and 49 percent of the patenting female scientists licensed their intellectual property.

The measure reflecting the scientist commercialization route is included in the fourth column. As the negative and statistically significant coefficient of *Non TTO Patent Assignee* suggests, those scientists choosing the entrepreneurial route to commercialize their research exhibit a lower likelihood of licensing their intellectual property. In comparison, those scientists selecting the TTO commercialization route have a higher propensity to license.

Overall, the results reported from estimating scientist licensing reveal several striking similarities but also differences from those estimating scientist entrepreneurship. First, the impact of social capital is positive for both entrepreneurship and licensing. Co-patenting with other academic scientists as well as sitting on a scientific advisory board or board of directors of a private company increases the likelihood of a scientist both starting a business and licensing her intellectual property. However, co-publishing with scientists in industry spurs scientist entrepreneurship, while it has no impact on licensing behaviour.

Second, scientist perception that the TTO is helpful in commercializing research leads to disparate results between the two modes of commercialization. While those scientists indicating that the TTO was helpful exhibited a higher propensity to license their intellectual property, they also were less entrepreneurial in that they have a lower likelihood to start a new firm. However, those scientists indicating that the TTO was not helpful were less likely to license their intellectual property, but had a higher propensity to start a new business. This is also consistent with the finding that TTO efficiency promotes scientist licensing but not entrepreneurship. These disparate findings may suggest that the impact of the TTOs is not symmetric across difference modes of commercialization.

Third, the particular commercialization route chosen by the scientist influences the mode of commercialization. Those scientists choosing the TTO commercialization route exhibit a higher likelihood of licensing but a lower propensity to start a new firm. By contrast, scientists choosing the entrepreneurship route to commercialize their research have a greater propensity to start new firms rather than license their intellectual property.

In Table 7 the two modes of commercialization, entrepreneurship and licensing, are combined to identify the likelihood of a scientist commercializing her research. There is at least some evidence suggesting that social capital promotes scientist commercialization. While co-patenting with other academic scientists seems to have no significant impact on commercialization behaviour, both co-publishing with an industry scientist and sitting on a board of a firm are found to increase the likelihood that a scientist commercializes her research.

Table 7: Probit Regression Results Estimating Scientist Commercialization - **Commercialize**

	1	*2*	*3*	*4*
Co-patents	0.097 (1.17)	0.272 (1.46)	0.152 (0.96)	0.306 (1.59)
Industry Co-publications	0.140 **(2.11)****	0.206 **(2.00)****	0.191 **(2.13)****	0.215 **(2.00)****
Board	1.335 **(3.25)*****	1.532 **(2.76)*****	1.586 **(2.93)*****	1.496 **(2.62)*****
TTO Helpful	0.571 (1.43)	0.552 (1.00)	0.706 (1.34)	0.503 (0.90)
Government Funding	0.910 **(2.14)****	0.936 **(1.87)***	0.904 **(1.85)***	0.768 (1.46)
Non TTO Patent Assignee	-	-	-	0.922 (1.03)
NCI Helpful	0.907 **(2.26)****	1.433 **(2.44)****	1.140 **(2.26)****	1.393 **(2.30)****
TTO Age	0.021 (1.26)	-0.016 (0.50)	0.009 (0.30)	-0.018 (0.57)
TTO Employees	-0.017 (0.92)	-0.066 (1.45)	-	-0.073 (1.53)
TTO Licensing Commitment	-	-	-0.298 **(1.67)***	-
TTO Efficiency	0.970 (0.90)	0.712 (0.54)	1.827 (1.15)	0.916 (0.66)
NCI Grant	0.004 (0.64)	-0.003 (1.46)	-0.003 (1.32)	-0.003 (1.47)
Scientist Age	0.002 (0.65)	-0.043 (1.22)	-0.031 (0.94)	-0.049 (1.33)
Previous Patents	-0.018 (0.41)	-0.913 (1.05)	-0.552 (0.70)	-0.943 (1.06)
Citations	-	0.010 (1.38)	0.020 (1.06)	0.012 (1.47)
Previous Patents	-	0.001 (0.02)	-0.011 (0.21)	0.015 (0.25)
NCI Center	-	-0.005 (0.01)	-0.167 (0.32)	0.070 (0.12)
Public Institution	-	0.053 (0.07)	-0.717 (1.11)	0.125 (0.17)
North East	0.881 **(2.20)****	1.234 **(1.71)***	0.821 (1.34)	1.303 **(1.77)***
California	-	1.095 (0.82)	-0.714 (1.01)	1.352 (0.97)
Great Lakes	-	0.705 (0.54)	-0.165 (0.13)	0.536 (0.37)
Constant	-44.366 (1.31)	32.443 (0.52)	-16.937 (0.28)	37.238 (0.59)
LR chi2	**39.22*****	**44.87*****	**45.30*****	**46.06*****
R-squared adjusted	0.37	0.46	0.46	0.47
Observations	83	76	76	76

Absolute value of z statistics in brackets
* significant at 10%;** significant at 5%; *** significant at 1%

There is no statistically significant evidence that being at a university where the scientist indicates that the TTO is helpful with commercialization efforts actually impacts the likelihood of that scientist commercializing. However, the results do suggest that additional funding from non-NCI government agencies, as well as the NCI grant itself increases the propensity of scientists to commercialize their research.

Since the measure of scientist commercialization combines two modes of commercialization, entrepreneurship and licensing, it may not be surprising that the results generally reflect a combination of the individual findings for startups and licensing.

It is also possible to provide a comparison between the two modes of commercialization and patenting behaviour. However, since the survey was administered to the 140 respondents from the 392 NCI scientists who had patented, it is not possible to apply the variables formed from the survey instrument to the larger sample of 1,431 NCI scientists. The results from estimating the likelihood of a scientist patenting are reported in Table 8. As the positive and statistically significant coefficients of *Co-publications* indicate, there is evidence suggesting that measures of social capital increase the scientist propensity to patent as well as license and become an entrepreneur. Furthermore, the location of the co-author apparently influences the propensity to patent. If the co-author is located in Asia, the likelihood of a U.S. based scientist patenting in the U.S. is greater.

Table 8: Probit Regression Results Estimating Scientist Commercialization - **Patents**

	1	*2*	*3*
Co-publications	0.061 **(5.82)*** **	0.043 **(3.45)*** **	0.055 **(5.06)*** **
Asia Co-publications	0.269 **(3.47)*** **	0.228 **(2.64)*** **	0.222 **(2.78)*** **
TTO Employees	0.042 **(1.75)* **	-0.006 (-1.00)	0.039 (-1.51)
TTO Efficiency	1.006 **(3.23)*** **	0.894 **(2.41)** **	**0.867** **(2.60)*** **
TTO Age	-0.015 **(3.40)*** **	-0.004 (0.76)	-0.010 **(2.14)** **
Scientist Citations	-	0.045 (0.33)	0.022 (1.45)
NCI Grant	-	0.007 (0.55)	0.004 (0.36)
Gender	-	0.245 **(2.30)** **	0.397 **(3.95)*** **
Public Institution	-	-0.129 (1.24)	-0.175 **(1.94)* **
NCI Center	-	0.021 (0.24)	0.018 (0.22)
Ivy League	-	-0.082 (0.53)	0.042 (0.30)
North East	-	0.013 (0.11)	0.087 (0.79)
California	-	0.262 (1.25)	0.154 (1.31)
Great Lakes	-	0.048 (0.35)	0.064 (0.50)
Previous Patents	-	0.230 **(12.14)*** **	-
Constant	27.50 **(3.25)*** **	6.343 (0.60)	19.142 **(1.98)** **
Observations	1431	1431	1431
LR chi2	**83.75*** **	**341.44*** **	**112.65*** **
R-squared adjusted	0.05	0.22	0.07
Absolute value of z statistics in brackets * significant at 10%; ** significant at 5%; *** significant at 1%			

The other consistent result involves *TTO Efficiency*. Those scientists working at universities with a more efficient TTO exhibit a higher propensity to patent. There is also at least some evidence suggesting that older and more established TTOs and larger TTOs, as measured by employment, tend to be associated with a higher scientist propensity to patent.

Because the samples of scientists are not the same, comparisons across these different commercialization modes must be qualified and considered to be provisional at best. Still, there are at least some indications suggesting that social capital promotes all modes of commercialization, but perhaps entrepreneurship the strongest. By contrast, the TTO seems to be most effective in promoting first and foremost patents and then licensing, but much less startups.

To further probe the impact that the TTO plays in facilitating different commercialization modes, the sample of survey respondents is decomposed into those scientists indicating that they were helped with their commercialization efforts by the TTO and those that were not. Based on these two sub-samples, regression results estimating the likelihood of a scientist licensing are reported in Table 9. Results for the sub-sample of scientists indicating that they were helped by the TTO are reported in the first two columns, while those not helped are reported in the last two columns.

Table 9: Probit Regression Results Estimating Scientist Licensing by Helpfulness of TTO

	TTO Helped Scientist		TTO Did Not Help Scientist	
	1	2	3	4
Startup	-2.957 **(1.90)***	-	2.507 **(2.13)****	-
Co-patents	1.384 **(2.22)****	1.065 **(2.25)****	0.353 (0.62)	0.181 (0.66)
Industry Co-pubs	0.192 (1.31)	0.125 (0.98)	-0.296 **(1.65)***	-0.081 (0.84)
Government Funding	4.795 **(2.22)****	1.897 **(2.19)****	-0.495 (0.50)	0.011 (0.02)
NCI Helpful	-0.053 (0.07)	-0.200 (0.28)	2.931 **(1.72)***	2.526 **(2.79)*****
TTO Efficiency	4.797 **(1.73)***	3.366 (1.59)	4.938 (1.41)	2.807 (1.58)
TTO Employees	0.005 (0.15)	0.011 (0.33)	-0.114 (1.41)	-0.068 (1.58)
TTO Age	-0.234 **(2.34)****	-0.104 **(1.77)***	-0.046 (0.67)	-0.012 (0.28)
Scientist Age	0.093 (1.43)	0.039 (0.86)	-0.168 **(1.97)****	-0.093 (1.61)
North East	0.682 (0.84)	0.000 **(2.32)****	0.000 (0.99)	0.000 (0.62)
Great Lakes	3.362 **(1.92)***	0.680 (0.95)	0.263 (0.19)	0.287 (0.31)
NCI Grant	-0.007 **(2.35)****	2.258 (1.59)	3.122 **(1.66)***	1.703 (1.36)
Constant	457.962 **(2.33)****	203.606 **(1.75)***	99.986 (0.71)	29.158 (0.31)
LR chi2	**28.15****	**23.27****	**28.54*****	**21.45****
R-squared adjusted	0.55	0.45	0.61	0.46
Observations	41	41	35	35

Absolute value of z statistics in brackets
* significant at 10%; ** significant at 5%; *** significant at 1%

The first column also includes a binary variable taking on the value of one if the scientist started a new firm. As the negative and statistically significant coefficient of this variable suggests, those scientists indicating they were helped by TTO and started a new firm exhibited a lower likelihood of licensing their intellectual property. The positive and statistically significant coefficient of this binary variable in the third column suggests that of those scientists not helped by the TTO, starting a firm increases the likelihood of licensing.

6. Conclusions

A consequence of globalization in the most developed countries, such as the United States, has been to shift the comparative advantage away from traditional manufacturing industries and towards new knowledge-based economic activity. But where is this knowledge to come from? At this point, the answer is uncertain, but along with education and human capital, as well as critical research and development (R&D) by private industry and government agencies, research undertaken by universities is sure to play a prominent role. As research and knowledge become perhaps the most crucial component to generating economic growth and competitive jobs in globally-linked markets, universities emerge as a key factor in determining the future well-being of the country. After all, it ranks among the most important tasks of universities to create new scientific knowledge. In addition, the magnitude of resources being invested in university research, including some of the most capable and creative scientists in the country, is the envy of the world.

The massive investment in university research can impact economic growth only if knowledge can be transformed into actual innovations and new and better products through the commercialization process. That is, the extent to which university research becomes commercialized. It matters for economic growth, for jobs and for global competitiveness.

Thus, a large literature has emerged trying to gauge and analyze the extent to which university research spills over into commercial activity. Much, if not most, of this previous research has been restricted to focusing on the activities emanating from Technology Transfer Offices, which have provided systematic and consistent documentation of their efforts over a fairly long period of time. Analyses of these data have typically led to conclusions suggesting that while patents and licenses from university research have increased over time, the typical TTO does not generate significant commercialization of university research. However, an important qualification is that, by restricting themselves to TTO generated data, such studies are not able to consider any commercialization activities not emanating from the TTOs.

This study has taken a different approach. Rather than focus on what the TTOs do, it instead focuses on what university scientists do. Thus, the findings about the commercialization of university research are based on actual university scientists and not the TTOs. The results are revealing. In particular, while all modes of commercialization are important, scientist entrepreneurship emerges as an important and prevalent mode of commercialization of university research. More than one in four patenting NCI scientists has started a new firm. This is a remarkably high rate of entrepreneurship for any group of people, let alone university scientists. Thus, the extent to which university research is being commercialized and entering the market may be significantly greater than might have been inferred from studies restricted only to the commercialization activities of the

TTO. Scientist entrepreneurship may prove to be the sleeping giant of university commercialization.

Second, the mode of commercialization is apparently not independent of the commercialization route. Nearly one-third of patenting NCI scientists rely on the entrepreneurial commercialization route, in that they do not assign all of their patents to the university. These scientists exhibit a higher likelihood of starting a new firm but a lower propensity to license. By contrast, scientists choosing the TTO commercialization route exhibit a higher propensity to license but a lower likelihood to start a new firm. These findings in no way provide any evaluation or judgment about the efficacy of the TTO office. Rather, they do suggest that the extent of commercialization of scientist research has been greater and more vigorous than previously had been measured.

Third, we find that the determinants of scientist commercialization vary considerably according to the specific mode of commercialization. Social capital, measured in terms of co-patenting with other NCI scientists, co-publishing with industry scientists, and sitting on a scientific advisory board (SAB) or board of directors, generally promotes all modes of commercialization, although the impact seems to be the strongest for scientist entrepreneurship. However, the role of the TTO is sharply divided depending upon the commercialization mode. Having a TTO that is perceived to be helpful for commercialization seems to increase the likelihood of a scientist licensing but decrease the propensity of the scientist to start a new firm. By contrast, having a TTO that is perceived not to be helpful reduces the licensing activity of scientists but increases their likelihood of becoming entrepreneurs.

How are scientists able to start a business without TTO support? There is at least some evidence indicating that social capital can serve as a mechanism to compensate for lack of TTO help when starting a new firm. This would suggest that university governance and public policy facilitating participation in scientific networks may be a valuable investment accruing positive returns in terms of knowledge spillovers and technology transfer, ultimately leading to commercialization, innovation and economic growth.

Future research needs to further probe why and how scientists choose to commercialize their research, what commercialization route they select, what mode of commercialization is most effective, and how university governance and public policy can best promote such commercialization efforts. A host of pressing questions remain. For example, are all social networks equivalent, that is are they homogeneous, or do some facilitate scientist commercialization more than others? Similarly, do non-patenting scientists engage in commercialization activities, particularly entrepreneurship, or does their lack of patented intellectual propensity preclude commercialization of their research? Whatever answers to these and other crucial questions future research can uncover, the sleeping giant of scientist entrepreneurship may prove to be one giant that is worth waking up.

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Appendix A: Breakdown of Patents by U. S. Patent and Trademark Office Classification

Classification of Patents by USPTO Category	Percentage of total NCI patents	Title
435	0.352%	Chemistry: molecular biology and microbiology
514	0.184%	Drug, bio-affecting and body treating compositions
424	0.152%	Drug, bio-affecting and body treating compositions
530	0.060%	Chemistry: natural resins or derivatives; peptides or proteins; lignins or reaction products
536	0.038%	Organic compounds -- part of the class 532-570 series
128	0.017%	Surgery
436	0.014%	Chemistry: analytical and immunological testing
250	0.013%	Radiant energy
382	0.012%	Image analysis
600	0.011%	Surgery
800	0.010%	Multicellular living organisms and unmodified parts thereof and related
324	0.008%	Electricity: measuring and testing
549	0.008%	Organic compounds -- part of the class 532-570 series
604	0.006%	Surgery
548	0.006%	Organic compounds -- part of the class 532-570 series
364	0.005%	Electric power conversion systems
606	0.004%	Surgery
528	0.004%	Synthetic resins or natural rubbers -- part of the class 520 series
422	0.004%	Chemical apparatus and process disinfecting, deodorizing, preserving, or sterilizing
560	0.004%	Organic compounds -- part of the class 532-570 series
546	0.003%	Organic compounds -- part of the class 532-570 series
564	0.003%	Organic compounds -- part of the class 532-570 series
356	0.002%	Optics: measuring and testing
378	0.002%	X-ray or gamma ray systems or devices
210	0.002%	Liquid purification or separation
385	0.002%	Optical waveguides
568	0.002%	Organic compounds -- part of the class 532-570 series
623	0.002%	Prosthesis (i.e., artificial body members), parts thereof, or aids and accessories therefor
556	0.002%	Organic compounds -- part of the class 532-570 series
359	0.002%	Optical: systems and elements
426	0.002%	Food or edible material: processes, compositions, and products
73	0.001%	Measuring and testing
260	0.001%	Chemistry of carbon compounds
362	0.001%	Illumination
544	0.001%	Organic compounds -- part of the class 532-570 series

*Note, the top 95% of the patent breakdown is shown