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The Bayh-Dole Act and scientist entrepreneurship

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ABSTRACT

Much of the literature examining the impact of the Bayh-Dole Act has been based on the impact on patenting and licensing activities emanating from offices of technology transfer. Studies based on data generated by offices of technology transfer, suggest a paucity of entrepreneurial activity from university scientists in the form on new startups. There are, however, compelling reasons to suspect that the TTO generated data may not measure all, or even most of scientist entrepreneurship. Rather than relying on measures of scientist entrepreneurship reported by the TTO and compiled by AUTM, this study instead develops alternative measures based on the commercialization activities reported by scientists. In particular, the purpose of this paper is to provide a measure of scientist entrepreneurship and identify which factors are conducive to scientist entrepreneurship and which factors inhibit scientist entrepreneurship. This enables us to compare how scientist entrepreneurship differs from that which has been established in the literature for the more general population. 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 for scientists to become an entrepreneur. The results suggest that scientist entrepreneurship may be considerably more robust than has generally been indicated in studies based on TTO data.

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 has been termed "*the knowledge filter*" in order to contribute to innovation, competitiveness and ultimately economic growth (Acs et al., 2010). 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, ..."[1] It is the knowledge filter that stands between 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?"[2]

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.[3] The goal of the Bayh-Dole Act was to facilitate the commercialization of university science (Kenney and Patton, 2009; Link et al., 2005, 2007). Assessments about the impact of the Bayh-Dole Act on penetrating the knowledge filter and facilitating the commercialization

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[1] Introductory statement of Birch Bayh, September 13, 1978, cited from the Association of University Technology Managers Report (AUTM) (2004, p. 5).
[2] 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).
[3] Public Law 98–620

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of university research have bordered on the euphoric,[4] "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."[5]

An even more enthusiastic assessment suggested that, "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."[6]

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 (Lockett et al., 2003, 2005; O'Shea and Rory, 2008; Phan et al., 2005; Siegel et al., 2007). Most of these studies focus on various measures associated with university TTOs (Mustar et al., 2006; Mosey and Wright, 2007; Shane 2004; Powers and McDougall, 2005; Phan and Siegel, 2006; Di Gregorio and Shane, 2003; Mowery et al., 2004) By most accounts, the impact on facilitating the commercialization of university science research has been impressive.

However, in terms of scientist entrepreneurship, measured by new ventures started by university scientists, the data reported by university TTOs and collected by AUTM suggests a paucity of commercialization spilling over from universities. In the first years of this century, which also pre-dated the financial and economic crises, the number of startups emanating from U.S. universities reported by AUTM averaged 426 per year from 1998 to 2004. Given the magnitude of research budgets and investments in knowledge at American universities, an estimated total between 1998 and 2004 funded by the United States government granting agencies, this measure of university startups is both startling and disappointing.

Similarly, O'Shea et al. (2008) report that, for all its research prowess and headlines as an engine of the Route 128 high tech entrepreneurial cluster around Boston (Saxenien, 1994), the technology transfer office at MIT registered only 29 startups emanating from the university in 2001. Its counterpart, which is generally considered to have fuelled the Silicon Valley high-tech cluster (Saxenien, 1994), Stanford University, registered just six startups. Based on the TTO data measuring scientist entrepreneurship at universities compiled by AUTM, the Bayh-Dole does not seem to have had much of an impact on the economy.

However, there are compelling reasons to suspect that measuring and analyzing the commercialization of university research by relying solely upon data collected 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 are 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; Mosey and Wright, 2007). For example, in his exhaustive study on academic spinoffs, 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 (2004) admonition that relying solely upon the data registered with and collected by the TTO will result in a systematic underestimation of commercialization and ownership of university research (Thursby et al., 2009; Aldridge and Audretsch, 2010). Such an underestimation of commercialization of university research may lead to an underestimation of the impact that spillovers accruing from 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 measures of scientist entrepreneurship reported by the TTO and compiled by AUTM, this study instead develops alternative measures based on the commercialization activities reported by scientists. Some of this intellectual property is co-owned by the university; some is completely owned by the scientist In particular, the purpose of this paper is to provide a measure of scientist commercialization of university research and identify which factors are conducive to scientist entrepreneurship and which factors inhibit scientist entrepreneurship. We do this by developing a new database mea-

[4] 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."

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

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

suring 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 the propensity for scientists to become an entrepreneur. This enables a comparison of the factors conducive to scientist entrepreneurship to what has already been solidly established in the literature for the more general population. We should emphasize that in this paper we are considering a specific context for scientist entrepreneurship – the creation of a new firm. While this fits within the broader definition of scientist entrepreneurship stated in the introductory paper for this special issue, it should be recognized that we are only focusing on this sole aspect and measure of scientist entrepreneurship.

Section 2 of the paper develops the main hypotheses about why some university scientists engage in entrepreneurship while others abstain from entrepreneurial activities, and why the entrepreneurial behavior of scientists may either emulate or not emulate the entrepreneurial behavior that has been identified in the literature for the more general population, enabling us to posit seven main hypotheses about what influences scientist entrepreneurship. In Section 3 the data base for university scientists funded by the National Cancer Institute of the National Institutes of Health (NIH) is explained. The main hypotheses for scientist entrepreneurship are tested in Section 4 and the results are presented. The findings are discussed and highlighted in Section 5. Finally, a summary and conclusions are presented in Section 6. In particular, by asking scientists what they do rather than the university technology transfer offices, this paper finds that the Bayh-Dole Act has resulted in a strikingly robust and vigorous amount of scientific entrepreneurship. We find that one-quarter of patenting scientists have commercialized their research by starting a firm. In addition, the results suggest that in some aspects scientist entrepreneurship emulates what the literature has found to exist for the broader population. However, in other aspects, scientist entrepreneurship diverges from what the literature has established for the more general population.

2. The scientist entrepreneurial decision

A compelling literature has been developed, both theoretically, as well as being substantiated with robust empirical evidence, explaining why some people choose to become an entrepreneur, in the form of starting a new firm, while others do not (Parker, 2010). However, a review of Parker's comprehensive and exhaustive review of the literature reveals that virtually none of these studies have focused on the decision by university scientists to become an entrepreneur. What is known about entrepreneurial scientist startups originating from universities has normally been inferred from data where the unit of analysis was the university.

Thus, the starting point for analyzing the decision by a scientist to become an entrepreneur is the extensive literature on the entrepreneurial choice for the context of a broad population. To this we will add specific considerations for the scientist context. Five types of factors have been found to shape the individual decision to become an entrepreneur – characteristics specific to the individual, human capital, social capital, the institutional context, and access to financial capital.

2.1. Individual characteristics

A vast and extensive literature has accumulated linking the characteristics of individuals to the propensity to become an entrepreneur (McClelland, 1961; Roberts, 1991; Brandstetter, 1997; Gartner, 1990). While McClelland (1961) undertook pioneering work, Zhao and Seibert (2006) summarize a more focused series of studies on personality characteristics conducive to becoming an entrepreneur. For example, Reynolds et al. (2004) use the PSID to identify the key role that personality characteristics play in becoming an entrepreneur.

A particular focus for framing the decision to become an entrepreneur has been on entrepreneurial intentions (Wright et al., 2006; Ajzen, 1991; Gaglio and Katz, 2001) However, none of these studies is concerned with the particular type of individuals which are the focus in this present studies – university scientists. Thus, it is not clear whether the consistent findings concerning entrepreneurship and entrepreneurial intentions for the more general population also hold for scientists. In fact, there are reasons to suspect that the main influences underlying entrepreneurial intentions may differ for scientists when compared to the more general population. For example, studies by Levin and Stephan (1991) and Stephan and Levin (1992), posited and found empirical evidence supporting a life cycle model of scientist commercialization, which suggested that, in particular, that age may have a different impact on the propensity for a scientist to engage in entrepreneurial behavior than for the overall population. While the preponderance of studies based on the overall population tend to find that age is negatively related to the likelihood of an individual becoming an entrepreneur, Levin and Stephan (1991) and Stephan and Levin (1992) found that age is positively related to scientist entrepreneurship. Their empirical results were consistent with their life-cycle framework, which predicted that in the early stages of their career, scientists are the most productive and have the greatest incentives to invest in creating knowledge which is public in nature, in an effort to enhance their scientific reputation. As they mature and have achieved prominence, they then have an incentive to invest in knowledge which is private and can be commercialized, so that they are more likely to become entrepreneurs as they mature rather than when they are starting out in their careers.

The scientist life cycle prediction is consistent with the focus of Wright et al. (2006), Shapero and Sokol (1982) and Ajzen (1991) on entrepreneurial intentions. Such entrepreneurial intentions and the propensity to be sensitive to entrepreneurial opportunities may increase as a scientist evolves over her life cycle. Based on the life-cycle framework of Levin and Stephan (1991) and Stephan and Levin (1992) we postulate

Hypothesis 1. Age is positively related to the propensity for scientists to become an entrepreneur.

2.2. Gender

An important individual specific characteristic that has consistently been found to influence the decision to become an entrepreneur is gender (Minniti and Nardone, 2007). Studies have consistently found that females have a lower propensity to become entrepreneurs (Allen et al., 2007). For example, in 2003, the U.S. self employment rate of females was about 55% as high as the male self-employment rate; and 6.8% of women in the labor force were self-employed, compared with 12.4% of men. Similarly, according to Allen et al. (2007), the results from the Global Entrepreneurship Monitor (GEM) identify 10.73% prevalence rate of entrepreneurial activity by U.S. females, measured in terms of owning a business, as compared to 18.45% by U.S. males.

There is also at least some evidence that female scientists and engineers have a lower propensity to engage in commercialization activities, such as entrepreneurship. Elston and Audretsch (2010, 2011) find that gender is the most significant determinant of using an Small Business Innovation Research (SBIR) grant to start a firm, and that, female applicants were far less likely than males to report SBIR grants as their primary source of start-up capital. The negative effect of being female on probability of receiving SBIR funding was robust and persistent even after controlling for age, race, education, and wealth. Similarly, Link and Scott (2009) find that only 17.5% of the SBIR firms in their sample from the NIH SBIR program were owned by females, with the remaining 82.5% owned by males. Thus, the evidence suggests not only is there low participation of females in the SBIR program, but it is significantly lower than the prevalent rates for U.S. female entrepreneurs. This suggests

Hypothesis 2. Female scientists will have a lower likelihood of being entrepreneurs.

2.3. Human capital

A large literature has emerged examining the link between human capital and entrepreneurship (Bates, 1995; Evans and Leighton, 1989; Gimeno et al., 1997; Davidsson and Benson, 2003). Higher levels of human capital facilitate the ability of individuals to recognize entrepreneurial opportunities as well as to act on them through entrepreneurial action. Studies have typically found a positive relationship between human capital and entrepreneurship. The human capital of the individual, typically measured in terms of years of education, has been found to have a positive impact on the decision to become an entrepreneur.

There is no reason to suspect that the relationship between human capital and scientist entrepreneurial behavior differs from that of the more general population, which would suggest a positive relationship. However, an important caveat is that scientists represent a highly truncated part of the overall distribution of human capital. All scientists exhibit very high levels of human capital. Still, with this caveat in mind, we propose

Hypothesis 3. The propensity for a scientist to become an entrepreneur is positively related to human capital.

2.4. 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; 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."

Similarly, social capital is considered by Coleman (1988) to be "a variety of entities with two elements in common: they all consist of some aspect of social structure, and they facilitate certain actions of actors, . . ., within the structure." A large and robust literature has emerged attempting to link social capital to entrepreneurship (Mosey and Wright, 2007; Aldrich and Martinez, 2010; Shane and Stuart, 2002; Davidsson and Benson, 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, 2002). This leads us to

Table 1
Technology transfer office mission statements.

Primary objectives of the UTTO	Percentage of times appeared in mission statement (%)
Licensing for royalties	78.72
IP protection/management	75.18
Facilitate disclosure process	71.63
Sponsored research and assisting inventors	56.74
Public good (disseminate information/technology	54.61
Industry relationships	42.55
Economic development (region, state)	26.95
Entrepreneurship and new venture creation	20.57
N = 128 TTOs	

Source: Markman et al. (2005).

Hypothesis 4. Social capital is positively related to the propensity for a scientist to become an entrepreneur.

2.5. Institutional influences

In addition to individual specific characteristics, the entrepreneurship literature has identified the institutional context within which the decision to become an entrepreneur is made. Henrekson and Stenkula (2010) and Karlsson and Karlsson (2002) suggest that certain institutional features are more conducive to individuals recognizing and acting on entrepreneurial opportunities, while other institutions are actually impediments to entrepreneurship. There are additional considerations that are special or unique to the scientist context. One of these is the role played by the technology transfer office (Mustar et al., 2006; Chapple et al., 2005). Studies provide evidence that offices of technology transfer are not homogeneous across universities and are likely to impact scientific entrepreneurship in different ways. In particular, some offices of technology transfer simply are larger, and have great resources, both human and financial, at their disposal (Mowery, 2005). Presumably, better endowed offices of technology transfer can offer scientists greater assistance in commercialization activities.

A second dimension of the offices of technology transfer is that some may put a higher priority on licensing of intellectual property rather than on facilitating scientist startups. For example, as shown in Table 1, Markman et al. (2005) illustrate how the mission statements of 128 university TTOs prioritize licensing intellectual property over scientist startups. Similarly, O'Shea et al. (2005), and Lockett et al. (2005) show that characteristics of the TTO influence the propensity for scientists to become an entrepreneur.

This leads us to posit two hypotheses concerning the institutional context in which the scientist is working

Hypothesis 5. Scientist entrepreneurship is positively related to the resources available to the technology transfer office.

Hypothesis 6. Scientist entrepreneurship is negatively related to the extent to which the TTO devotes resources to licensing.

2.6. Financial resources

Having access to financial resources to facilitate starting a new firm is one of the biggest issues confronting nascent entrepreneurs. As Kerr and Nanda (2009, p. 1) point out, "Financing constraints are one of the biggest concerns impacting potential entrepreneurs around the world." Similarly, Gompers and Lerner (2010) emphasize that such financing constraints may be even more severe for scientists, where the ideas generating entrepreneurial ventures are highly uncertain, asymmetric and characterized by high costs of transaction. This suggests

Hypothesis 7. Access to additional financial resources is positively related to scientist entrepreneurship.

In addition, Roberts and Malone (1996) and Breznitz et al. (2008) emphasize that the external environment external may also influence the propensity for scientists to start a new firm. While this paper will not posit any explicit hypotheses linking the external environment to scientist entrepreneurship, we explain in Section 3 that several control variables are included to at least control for several external influences.

3. Measurement

While AUTM collects and makes available data identifying TTO sponsored and approved scientist startups, the data are aggregated at the level of the university TTO. In fact, no large-scale, systematic data base measuring scientist entrepreneurship for the disaggregated level of the individual scientist exists.

Thus, in order to analyze scientist entrepreneurship at the level of the individual scientist, rather than at the level of the aggregated university TTO, we had to create a unique and new data base. The starting point for creating a data base measuring the entrepreneurial activity, in terms of scientist startups, was to identify those scientists awarded a research grant by the National Cancer Institute between 1998 and 2002. Of those research grant awards, the largest 20%, which corresponded to 1693 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 1693 highest funded quintile of United States-based scientists from 1998 to 2002.

The second step in creating the scientist entrepreneurship data base was to identify which of the scientists receiving funding to support basic research from The National Cancer Institute subsequently received patent protection for an invention. This suggested a sub-set of scientists receiving support for basic research that had potential commercialization applications. NCI award scientists being granted a patent was identified by obtaining patent data from the United States Patent and Trademark Office (USPTO).

To match the patent records with the 1692 NCI recipient scientists, Structured Query Language (SQL) and Python programming languages were written to extract and manipulate data. A match between the patent and NCI databases was considered to be positive if all four of the following necessary conditions were met:

The first necessary condition was that 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.

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 3 months to 2 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.

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. 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. Based on these four match criteria, a subset of 398 distinctly issued patentees were identified between 1998 and 2004 with a total of 1204 patents.

While the patent records identify which of the NCI Award scientists have been awarded a patent to protect the intellectual property representing an invention, they provide no indication whether or not the scientist has started a business. To identify whether a scientist had started a firm, we implemented a survey of the NCI scientists with a patent. The survey instrument was designed with two main criteria. The first was 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. The second was 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 their intellectual property. 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 and 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%. Of these respondents, one in four reported that they had, in fact, started a firm. This is a strikingly high degree of entrepreneurial activity exhibited by these high profile scientists, and certainly reflects a much more robust and extensive degree of entrepreneurship than has been indicated by the TTO data collected by AUTM.

Section 2 identified from the literature five different types of factors shaping the decision by a scientist to become an entrepreneur – personal characteristics, human capital, social capital, financial resources, and TTO characteristics. These factors are empirically operationalized through the following measures:

3.1. Personal characteristics

Two measures reflecting the personal characteristics of scientists are included. The first is the age of the scientist, measured in terms of years, which was obtained from the scientist survey. Hypothesis 1, which is based on the life-cycle framework for scientists posited by Levin and Stephan (1991) and Stephan and Levin (1992), suggests that age will be positively related to scientist entrepreneurship.

The second measure is gender. This is a dummy variable assigned the value of one for males (1310) of the overall 1693 included in the NCI database. The gender of each scientist was obtained by "Googling" their names, i.e. pictures. The estimated coefficient will reflect whether the gender of the scientist influences the propensity to commercialize research. Hypothesis 2 suggests a positive relationship between gender and scientist entrepreneurship.

3.2. Scientist human capital

A unique computer program was used to measure scientist citations over the period 1998–2004, using the "Expanded Science Citation Index." Higher levels of human capital were inferred by a greater citation count divided by the number of publications. This measure has been used elsewhere to reflect the human capital of scientists. As Hypothesis 3 suggests, a positive relationship is expected to emerge between scientist human capital and the propensity of a scientist to start a new firm.

3.3. Social capital

Two different measures were used to reflect the extent of a scientist's social capital in the context of linkages with private industry. Such linkages are hypothesized to be conducive to generating both entrepreneurial opportunities and the access to expertise and experience in commercializing those opportunities through entrepreneurship. The first measure a binary variable taking on the value of one if the scientist has been a member of 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. The second measure is *industry co-publications*, which 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 co-authored 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 Colorado as a company, for example, the query forced the previously mentioned search terms to be standalone words, and not part of larger words. Hypothesis 4 suggests that the coefficient is expected to be positive, which would reflect that university–industry scientist interactions are conducive to scientist entrepreneurship.

3.4. Characteristics of the technology transfer office

Hypotheses 5 and 6 involve the relationship between the technology transfer office and scientist entrepreneurship. Two dimensions of the technology transfer office at the university are included. The first is *TTO employees*, which measures the mean number of employee. The measure is taken from the AUTM data base. A positive relationship would suggest that a greater commitment of TTO employee resources yields a higher propensity for scientists to become an entrepreneur. The second measure is *TTO licensing*, which is obtained by dividing the number of employees dedicated to licensing technology by the number of administrative employees. This variable reflects the commitment of the TTO to licensing relative to other TTO functions. This measure is derived from the AUTM data base. A positive relationship would suggest that allocating a greater share of TTO employees to licensing would increase scientist entrepreneurship.

3.5. Financial resources

There are two measures reflecting financial resources available to the scientist. The first is NCI grant, which is the mean total NCI awarded to the scientist between 1998 and 2002. The award amount was obtained from the original NCI award excel sheet. If external funding of scientific research is conducive to scientific entrepreneurship, a positive coefficient of the NCI grant would be expected. The second measure reflects the extent to which the NCI grant helped the scientist commercialize by obtaining patent protection of her invention. This measure was obtained from the survey of scientists. A positive coefficient would be consistent with Hypothesis 7, which suggests a positive relationship between additional financial resources and scientist entrepreneurship.

3.6. Control variables

Several other measures were included to control for the external context in which the scientist was working. The first is *NCI center*, which 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 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 dissemination play at the centers. A positive coefficient would reflect that being located at a comprehensive cancer center facilitates scientist entrepreneurship. The second measure is *Ivy league*, which is 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. The third variable is *public universities*, which is 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 final control variable includes a dummy variable taking on the value of one if the patent was licensed. This may preclude entrepreneurial activity by the scientist, at least in the form of a start up, so that a negative relationship would be expected.

The independent variables are summarized and described in Table 2. The mean and standard deviation of each variable is given in Table 3. The means and standard deviations are provided for three different samples – the top grant recipients from the National Cancer Institute, those top funded scientists with a patent, and those who were interviewed. There are some differences across these groups. For example, the number of citations per scientist is considerably greater for those scientists with a patent, than those who did not patent their intellectual property. The patenting scientists have a greater propensity of being male and of co-authoring an article with a scientist from industry.

The correlation coefficients for the variables are listed in Table 4. These variables do not exhibit high levels of correlation. The highest correlation coefficient is 0.292, between the scientist working at a public institution and the TTO commitment to licensing. Most of the correlation coefficients are below 0.20.

4. Model and results

The purpose of the analysis is to identify factors which are conducive to scientist entrepreneurship and those which impede it. The dependent variable, which was obtained from the interviews,

Table 2
Description of independent variables.

Independent variables	Description
Board	Binary variable, for scientists indicating that they sat on either a board of directors or science advisory board, board = 1
Industry co-publications	The number of publications an NCI scientist shared with a private industry scientist
NCI helpful	Binary variable, for scientists indicating that the NCI grant was helpful for patenting, NCI helpful = 1
Scientist age	The age of the scientist
Male	Binary variable, where a male = 1
NCI grant	Total amount of funding received by the scientist
NCI center	Binary variable, for a scientist whose institution is recognized by NCI as a comprehensive center for cancer research, NCI center = 1
Public institution	Binary variable, for a scientist whose institution is a public institution, public institution = 1
Ivy league	Binary variable, for a scientist whose institution is an Ivy league university, Ivy league = 1
Average citation per publication	Aggregate number of ISI citations divided by the number of ISI publication a scientist received from 1998 to 2004
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
Scientist patent licensed	Binary variable, for scientists indicating that the at least one of their patents were licensed, scientist patent licensed = 1

Table 3
Means and standard deviations.

Variable	NCI scientist $N = 1693$	Patent scientist $N = 392$	Interviewed scientist $N = 140$
Patent (%)	23.35 (0.42)	100.00	100.00
Startup (%)	–	–	25.71 (0.44)
Industry co-publications	1.83 (3.57)	3.01 (4.89)	2.56 (3.73)
Board (%)	–	–	58.00 (0.50)
TTO employees	8.66 (11.44)	9.14 (11.6)	8.95 (11.65)
TTO licensing commitment	1.68 (2.29)	1.31 (1.45)	1.22 (1.24)
NCI grant (Dollars)	3,161,943 (3,196,918)	3,484,128 (3,795,993)	3,053,465 (2,674,288)
Gender (%)	77.87 (0.42)	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)	1741.19 (2441.07)	1500.34 (1603.49)
NCI center (%)	55.86 (0.50)	56.50 (0.50)	50.70 (0.50)
Public institution (%)	53.91 (0.50)	48.10 (0.50)	49.29 (0.50)
Ivy league (%)	10.24 (0.30)	12.15 (0.33)	15.00 (0.36)

takes on a value of one if the scientist started a firm and zero if she did not. Because of the binary nature of the dependent variable, a probit regression model is appropriate.

The results from the probit estimation are provided in Table 5. The results suggest considerable support for Hypothesis 4. Both measures of social capital, the scientist serving on a scientific advisory board, and co-authoring a publication with a scientist employed in private industry are positively related to the likelihood of that scientist starting a new firm. These results for the entrepreneurial behavior of scientists are certainly consistent with those found for the more general population by Davidsson and Benson (2003), among others, and suggest that the entrepreneurial behavior of top university scientists emulates the entrepreneurial behavior of the general behavior, at least in terms of the important role played by social capital.

The positive and statistically significant coefficient of NCI helpful is consistent with Hypothesis 7. The financial resources provided

Table 4
Correlation coefficients of variables.

	Startup	Industry Co-pubs	Board	TTO employees	TTO Commit	NCI grant	NCI helpful
Startup	1						
Industry Co-pubs	0.166	1					
Board	0.346	0.031	1				
TTO employee	−0.015	0.143	0.091	1			
TTO commit	0.006	0.126	0.089	0.983	1		
NCI grant	−0.053	0.073	0.12	0.15	0.134	1	
NCI helpful	0.277	−0.01	0.213	0.205	0.2	0.106	1
Scientist age	−0.137	−0.166	−0.066	−0.038	−0.041	0.041	0.004
Gender	0.157	−0.017	0.315	−0.015	−0.007	−0.058	0.086
Avg citation per Pub	−0.066	0.066	0.104	0.07	0.078	0.193	0.09
NCI center	−0.057	0.237	−0.093	0.232	0.268	−0.089	0.079
Public institution	−0.075	−0.067	−0.031	0.278	0.292	0.073	0.132
Ivy league	−0.007	0.048	−0.1	−0.152	−0.138	0.015	0.122

	Scientist age	Gender	Average Citation per Pub	NCI center	Public institution	Ivy league
Scientist age	1					
Gender	0.056	1				
Average citation per pub	−0.103	0.053	1			
NCI center	−0.099	−0.145	0.022	1		
Public institution	0.259	0.181	−0.193	−0.108	1	
Ivy league	−0.214	−0.007	0.127	0.175	−0.376	1

Table 5
Probit regression results estimating scientist commercialization – startups.

Independent variables	1	2	3	4
Board	**1.277*****	**1.502*****	**1.525*****	**1.488*****
	[3.747]	[4.456]	[4.517]	[4.628]
Industry co-publications	6.425*	**8.687****	**9.083****	**9.404****
	[3.401]	[3.997]	[4.094]	[4.229]
NCI helpful	**8.284*****	**9.148****	**9.277****	**8.965****
	[3.212]	[3.682]	[3.704]	[3.787]
Scientist age		−2.102	−2.190	−2.123
		[2.487]	[2.496]	[2.499]
Male		5.649	5.718	5.997
		[1.006]	[1.008]	[1.018]
NCI grant		−8.558	−8.601	−8.289
		[9.982]	[1.004]	[9.929]
NCI center		−2.277	−2.013	−1.875
		[3.966]	[3.886]	[3.909]
Public institution		−2.652	−2.675	−2.963
		[3.995]	[3.998]	[4.008]
Ivy league		−6.405	−6.739	−7.586
		[8.085]	[8.131]	[8.396]
Average citation per publication		−1.197	−1.168	−1.160
		[1.011]	[1.012]	[1.013]
TTO employees		−4.721		
		[9.528]		
TTO licensing employees			−1.286	−1.389
			[1.705]	[1.748]
Scientist patent licensed			1.580	−1.076
				[4.046]
Constant	**−2.247*****	−9.534	−9.366	−1.076
	[4.519]	[1.715]	[1.720]	[1.768]
Observations	91	82	82	82
chi^2	27.66	33.43	33.77	33.93

Standard errors in brackets. *Note*: all units have been multiplied by 10,000. The bold values mean that the coefficient is statistically significant for a two-tailed test at the 95 percent level of confidence.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

by the NCI grant are conducive to scientist entrepreneurship. Those scientists who suggested that the grant from the National Cancer Institute facilitated patenting their intellectual property exhibited a higher propensity to start a new firm. This would suggest that the NCI is enhancing scientist entrepreneurship. These findings are consistent with the findings for the more general population that a lack of access to financial resources tends to constrain entrepreneurial activity (Kerr and Nanda, 2009).

The empirical results are not consistent with Hypotheses 1 and 2. In contrast to the consistent findings in the literature for entrepreneurship for the general population (Reynolds et al., 2004), in the case of university scientists, age and gender have no impact on the propensity for the scientist to become an entrepreneur. While both gender and age are consistently found to influence the decision to become an entrepreneur for the population at large (Reynolds et al., 2004), these are not found to have any statistically significance impact for the scientists included in this study.

Similarly, there is no statistical evidence supporting Hypothesis 3. Human capital apparently has no statistically significant impact on the propensity for scientists to start a new firm. This is a contrast to the findings for the more general population (Davidsson and Benson, 2003; Bates, 1995). One interpretation of this disparity may be that this sample consists of scientists with exceptionally high levels of human capital. Variations in human capital for these scientists apparently have no additional impact on the decision to become an entrepreneur. By contrast, studies focusing on the broader population include observations with a much greater variance in levels of human capital, as well as a much lower mean level of human capital, so that human capital has consistently been found to influence entrepreneurial activity.

The main hypotheses focusing on the impact of the institutional context on scientist entrepreneurship, Hypotheses 5 and 6, are not supported by the empirical evidence. Neither the resources of the technology transfer office, as measured by number of full-time employees, nor the share of TTO employees dedicated to licensing and patenting has a statistically significant on the likelihood of a scientist starting a new firm.

None of the control variables have any statistically significant impact on the likelihood of a scientist starting a new firm.

5. Discussion

The empirical results presented in Section 4 from analyzing why some scientists become entrepreneurs, while other colleagues do not, point to the importance of relationships and linkages forged through social capital, and in particular, to other scientists working in industry, as well as experiences gained by serving on a company scientific advisory board. The measures of social capital are found to be the most important influences in the decision of a scientist to become an entrepreneur. Those scientists with higher levels of social capital, in that they are members of a scientific advisory board of a company, or they have co-authored articles with scientists working for a company, exhibit a systematically higher propensity to become an entrepreneur.

Some of the more traditional explanations of entrepreneurship, and in particular, personal characteristics such as gender and age, but also human capital do not seem to play an important role.

Thus, in some aspects, scientist entrepreneurship appears to emulate the entrepreneurial behavior exhibited by the more general population. In particular, the validation of Hypotheses 4 and 7, highlighting the key roles that social capital and access to financial resources play in facilitating entrepreneurship, are also consistent with the empirical results found for the general population (Davidsson and Benson, 2003; Aldrich and Martinez, 2010; Kerr and Nanda, 2009; Gompers and Lerner, 2010). However, in other important aspects, and in particular age, gender and human capital, scientist entrepreneurship diverges from the results found for the more general population (Minniti and Nardone, 2007; Davidsson and Benson, 2003; Bates, 1995). While Blanchflower and Oswald (1998), pose the question, "What makes an entrepreneur?" the answer does not seem to be exactly identical for scientist entrepreneurship.

6. Conclusions

A number of indications suggest that the Bayh-Dole has not had much of an impact on generating entrepreneurial activity by scientists in the form of starting a new firm. Based on the respected and often cited data collected by the technology transfer offices at universities, and assembled by AUTM in a systematic and comprehensive manner, it would appear that even the most entrepreneurial universities generate only a handful of startups by scientists each year.

However, in this study, by asking scientists rather than the technology transfer offices of universities what entrepreneurial activities they actually engage in, a very different picture emerges. In fact, based on a data base of high profile scientists receiving large-scale funding from the National Cancer Institute, we find that university scientist entrepreneurship is robust and dynamic. The empirical results from this study suggest that around one in four scientists has engaged in entrepreneurial activity in the form of starting a new firm.

In addition, while most of the previous literature on scientist has been restricted to focusing on characteristics of the technology transfer offices and universities, due to the nature of the data being aggregated to the level of the university, in this study we are able to analyze the decision of a scientist to engage in entrepreneurial activity at the level of the individual scientist. The empirical results suggest that the decision to become an entrepreneur does not exactly mirror what has been found in the extensive literature for studies analyzing the broader population. Neither personal characteristics nor human capital seem to play an important role in the decision of a scientist to become an entrepreneur, as they do for the broader population. Rather, it is the levels of social capital, as measured by linkages to private industry that increase the propensity of a scientist to become an entrepreneur.

An important qualification of the findings from this paper is that they are based on a special sample of highly successful top scientists in a narrow scientific field. Whether they hold across broader groups of scientists and for other scientific fields is an important issue that needs to be addressed in future research. There is no a priori reason to expect the results from this exceptionally high performing group of scientists in a very narrow, specific scientific field to hold across other scientific fields. Subsequent research needs to identify both the prevalence and determinants of scientific entrepreneurship across a broad spectrum of scientific fields. In addition, future research could make a valuable contribution by analyzing the post-startup performance of scientist startups. For example, do the growth and survival of new firms started by university scientists emulate the growth and survival patterns that have been well documented in the literature for firms more generally? It would also be desirable to expand the analysis to include a third typology of university startups, such as those new companies founded by surrogate academic entrepreneurs, based on university owned technologies without the involvement of the inventor of the technology (Clarysse et al., 2005; Franklin et al., 2001). Thus, while the findings of this study would indicate that scientist entrepreneurship is robust and prevalent in the Bayh-Dole era, and is certainly more prevalent than previous studies have suggested, there are important research opportunities to understand how and why scientist entrepreneurship differs from entrepreneurship for the more general population.

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