Knowledge Creation and Diffusion of Public Science with Intellectual Property Rights

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1. Introduction

Knowledge, in general, and scientific knowledge, in particular, has characteristics of a pure public good no matter who generates it (Arrow 1962; Nelson 1959; Dasgupta and David 1987, 1994). It is non-rivalrous in the sense that once generated, it is neither depleted nor diminished by use, so the marginal cost of additional individuals or groups using the knowledge is zero. Knowledge is also non-excludable since, once it is made available, in the absence of clearly defined property rights, users cannot be excluded from using it. There are, of course, caveats on availability. It may be possible to keep new knowledge secret, thereby excluding use by others unless they discover it by chance or design, as might be the case if knowledge is embodied in a product that can be reverse engineered. Effective use of scientific knowledge may also be precluded to the extent that publication of a scientific principle, for example, does not fully impart the tacit knowledge needed for its use (Zucker *et al.* 1998).

The non-rivalrous and non-excludable aspects of scientific knowledge imply that private market mechanisms will not provide adequate incentives for knowledge creation. Producers will be hesitant to invest in the generation and commercialization of knowledge if they cannot exclude unauthorized users in order to collect a fee that would compensate their investment. Legal property rights, such as patents, are one means of dealing with this problem. Patronage in the form of government support for research provides another solution, as does a system of prizes, such as the priority system of awarding credit for scientific discoveries to the first to find them (Stephan 1996). All three mechanisms have been employed both in industry and universities, and there is an extensive literature on the costs and benefits of each solution (Arrow 1962; Machlup 1958; Nelson 1959; Stephan 1996; Scotchmer 2005). In the last two decades, there has been is a growth in the relative importance of the use of legal property rights in the university setting, especially in the United States, and with it a growing controversy as to whether the costs may be outweighing the benefits.

In this chapter, we discuss issues and evidence with regard to the ownership and licensing of publicly funded research. Since most of the research on these issues has been in the context of university intellectual property rights (IPR) and, in particular patents and licensing, we will focus largely on university patents and licensing. However, we note that most of what we cover is relevant for patenting and licensing at any non-profit research-oriented organization; indeed, many of the results we cite have combined universities with other non-profits. In addition, most of this research has focused on patenting in the life sciences for the obvious reason that the majority of university patents are in the life sciences as is the bulk of university licensing revenues.[1]

In the next section we provide a general overview of incentives created by the patent system and discuss the ways in which these incentives differ from traditional norms of science. In Section 3, we draw on the legal and economic literatures which distinguish among the incentives to invent, disclose, and innovate, and argue that the rationale for providing IPR for university research stems from the last of these. In Sections 4 and 5, we use these incentives to organize our discussion of the available evidence on the creation and diffusion of academic research under current IPR regimes. Finally, in Section 6 we focus on future directions.

2. Property Rights for Results of Scientific Research

[1] See Rai *et al.* 2006. Rai and Eisenberg (2003) report that about 50 percent of university patents are in biotechnology and pharmaceuticals. In the 1997 Association of University Technology Managers Annual Survey 148 U.S. respondents report $6.73 in life-science licensing revenue for every $1.00 of physical-science licensing revenue. Recent surveys have not included questions on life science versus physical science revenues.

In examining the role of patents in promoting scientific progress (as was their constitutional purpose in the United States), the legal community has emphasized two incentives which are useful in framing the discussion of patents in the context of university research. These are the incentives *to invent* and *to disclose* (Eisenberg 1989). The argument that the patent system provides an incentive to invent comes from the monopoly rights associated with patents. These rights allow an inventor to exclude others from commercial use of the knowledge, thus allowing the inventor to capture rents or appropriate economic returns from her inventive activity (Arrow 1962).

The incentive to disclose follows simply from the fact that an inventor must disclose the knowledge in order to be granted the patent. That is, with monopoly rights comes the requirement that the inventor make available to others the details of the invention or innovation. The rationale for this disclosure is both to prevent others from wasting effort on duplicative research and to allow them to build on the invention. These are clear benefits from patents if, as the courts have argued, they make inventions publicly available which would be kept secret in the absence of patent rights (Eisenberg 1989; Arora *et al.* 2001). According to these arguments, there is a tension between the incentives for invention and disclosure in that without the ability to exclude others from commercial use, the incentive to disclose would be absent.

Although these arguments have long been debated in both the courts and academic literature, their logic applies primarily in the context of scientific progress based on industrial research and development (R&D). Indeed, both the legal and economic literatures on the pros and cons of the patent system rely on cases and evidence related to industrial R&D (e.g., Cohen 2005; Eisenberg 1989; Merges and Nelson 1990, 1994). The applicability of these arguments to university research is not clear, however. For research conducted in the context of the norms of science there is no natural tension between the incentive to invent and the incentive to disclose (Eisenberg 1987).

2.A. The Norms of Science

The traditional norms of science are those associated with the work of sociologist Robert K. Merton, beginning in the early 1940's (Merton 1973). According to Merton, four norms should guide scientific research: universalism, communism (or communalism), disinterestedness, and organized skepticism. Universalism refers to the principle that the veracity of scientific knowledge should be determined by objective, impersonal criteria. As such, scientific principles should be testable and therefore observable or replicable. Communalism is the norm of open science by which scientific knowledge belongs to the community. According to communalism, scientific principles should be "assigned to the community" rather than the scientist and the scientist's claim to intellectual property from her work should be limited to "recognition and esteem." Disinterestedness refers to the ideal that scientists have no emotional or financial attachments to their work so that their goals remain the discovery of truth. As implied by communalism, as well, the scientist's reward for discovery should be recognition. Finally, as with universalism, organized skepticism implies that scientific knowledge should be judged by replicability, with the latter further stating that judgments should be made only "when all of the facts are in."

In her review of the economics of science, Stephan (1996) argues effectively that while the priority reward system that evolved from Merton's norms confers a property right, it differs markedly from the patent system in promoting both invention and disclosure. The reason is that the first scientist to discover a principle receives the recognition and subsequent reputation for the knowledge discovered. The priority reward is exclusionary in that the first to discover captures the reputation, but it requires no separate disclosure requirement. This winner-take-all property sets up a dynamic similar to a patent race, which promotes the incentive to innovate. But the system only works if the research community knows the scientist is first, which promotes the incentive to disclose. A scientist will disclose her discovery as soon as she achieves sufficient evidence of validity, and in fact, in many instances scientists go to considerable effort to prove they are the first (Stephan 1996).

In addition to Mertonian norms, there is considerable evidence that scientists have a taste for inventing (Stern 2004). Much of the incentive to invent comes from enjoying working on, and solving, puzzles (Hagstrom 1965; Levin and Stephan 1991; Stephan 1996). In line with the Mertonian norm of disinterestedness, they prefer the freedom to work on problems of their own choosing (Aghion *at al.* 2005). Thus they are intrinsically motivated to conduct research, quite apart from the ability to earn financial rents from their effort (Hellmann 2007).

It is therefore difficult to argue that proprietary patent rights are needed either to stimulate inventive activity by university scientists or to induce them to disclose their work in a timely fashion. Contingent on the availability of research funding, as long as universities reward their researchers according to the norms of science, there appears to be little reason to patent university research outcomes. To justify such patenting, one needs to rely on another incentive, the incentive *to innovate*.

2.B.University Patenting

Innovation, though not entirely independent of invention, is distinct. Scientific inventions may produce results of enormous scientific merit, but with no economically relevant effect. By contrast, innovation involves “carrying [inventions] into practice….which is a task entirely different from the inventing of it” (Schumpeter 1939). While the norms of science may be sufficient to induce university researchers to invent, they may not be sufficient to induce others to invest in commercial application. Further, as Eisenberg (1989) notes, the incentives to invent and disclose pertain to incentives prior to patent application or award, while the incentive to innovate pertains to incentives after patent award.

Understanding the incentive to innovate is crucial for understanding the rationale for laws that allow patenting of university research, such as the Bayh-Dole Act of 1980 and similar laws introduced in Europe in the 1990s. The Bayh-Dole Act allows US universities to elect to own federally funded inventions made by their employees. In return for this property right, universities are required to file for patent protection on those inventions that are patentable. They may then license the inventions, exclusively or nonexclusively, and they must share any resulting revenue with the inventors. During debate on the Act, proponents argued that science-based incentives were not sufficient to induce firms to invest in developing and improving the types of basic inventions that came from federal funding (Rai 1999, Mowery *et al.* 2004). These inventions tend to be embryonic and need substantial development before commercial application. The underlying argument is that in the absence of intellectual property rights and the ability to issue exclusive licenses to use those rights, any rents associated with commercialization would be dissipated and firms would be unwilling to make the necessary investment. Thus the argument pertains not to *ex ante* incentives for invention, but to incentives *ex post* for downstream users to invest in commercialization of federally funded inventions.

While the debate leading to passage of the Bayh-Dole Act focused primarily on industrial incentives, the legislation also created incentives for university administrators and inventors to engage in commercialization. If finding firms to develop inventions is difficult or costly, IPR owned either by the inventor or the university may be a critical element in promoting commercialization (Hellmann 2007). When inventors have tacit knowledge necessary for subsequent development, the incentive provided by their ability to share in revenue plays a role (Jensen and Thursby 2001).

2.C. Patents and Innovation

The arguments that *ex post* incentives for firms, universities, and inventors are insufficient in the absence of policy rest on the assumption that inventions from federally funded research are likely to require risky and nonobvious (in terms of technique or even direction) further development for successful commercial application. Even if this assumption is correct, however, there are conflicting views as to whether a system of exclusive IPR is the optimal way to support such development. For example, in his prospect theory, Kitch (1977) argues that broad patent protection for the inventor supports efficient innovation, while Merges and Nelson (1990) argue just the opposite.

Kitch’s prospect theory compares innovation to development of mining claims, where there is a well-known commons problem. Communal or free rights to prospect are inefficient because the mineral resources will be depleted too quickly as prospectors will not take into account the costs to others from resource depletion. He argues that exclusive rights allow the patent owner to invest in development without concern that others will also develop it. As well, ownership puts the patent holder in a position to coordinate development by others, thereby avoiding the wasteful duplication of effort.

By contrast, Merges and Nelson (1990) argue that the problem with innovation is not one of overdevelopment, but underdevelopment. In the mining case, there is a finite pool of resources. This is not the case with technical innovation, where no one knows the possible applications of an invention. They argue that Kitch’s theory ignores the limits of cognitive capacity so that while a single patent owner may be expected to develop an invention in some dimensions, she is unlikely to realize as many applications as would many different individuals working on subsequent developments. They therefore argue that uncoordinated efforts by many innovators are preferable.

Both arguments have implications for the scope of patents. Kitch would argue for broad patent rights to maximize the ability of the patent owner to coordinate further development. Merges and Nelson would argue that patent rights need to be broad enough to provide incentives to innovate but should not be broad enough to prevent alternative development paths.

Heller and Eisenberg (1998) present a different reason for underdevelopment. Where applications of patented inventions require combining rights to use multiple patents, an "anti-commons" may emerge. They argue that the development of drugs or diagnostic tests based on biomedical research is particularly susceptible to the "tragedy of the anti-commons" as patents have been awarded for gene fragments without identifying biological function or potential commercial products. Where multiple patents are needed for tests or downstream product development and these patents are owned by different institutions, with differing goals, there may be substantial transaction costs associated with combining patent licenses. This problem is also identified by the term patent thickets.

To summarize, there appears to be little need for patents to provide public-sector scientists the proper incentives to invent or disclose, as the rewards associated with the norms of science encourage both invention and public disclosure. The incentive to innovate is a different matter and valid arguments can be made that patents provide needed incentives for firms, universities, and inventors to participate in commercialization. It is clear, however, that depending on the nature of development possibilities and the objectives of the parties involved, IPR may or may not provide the socially optimal commercialization effort.

3. Incentives to Innovate: Empirical Evidence in the Post Bayh-Dole Era

In this section we discuss the IPR associated with the Bayh-Dole Act and the extensive empirical literature examining the extent to which it has promoted commercialization of university research results.

3.A. The Changing Patent Environment and Growth in University Patenting

Around 1980 a number of changes took place in the United States that had the effect of strengthening patent rights and thus, it is often argued, the incentive to innovate.[2] The most significant effects were arguably on university patent policies. The event most cited by observers was passage of the Bayh-Dole Act, which directly affected the ability of universities to patent and license discoveries made from federally funded research. However, nearly simultaneous with passage of this Act was the important 1980 Supreme Court case, *Diamond vs. Chakrabarty*, which upheld the validity of a broad patent in biotechnology. The case established the ability to own certain living organisms – in this case genetically engineered bacteria – by patenting them. This extension came at a time when research in biotechnology was expanding as was federal support of biomedical research.

Further, in 1981 the Supreme Court in *Diamond vs. Diehr* extended patent rights to software though software patents were limited to that which was a part of "physical elements or process steps." However, a series of court decisions in the 1990s eliminated the need for a

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[2] See, for example, Jaffe (2000) and Cohen (2005). Some of these effects are changes in incentives and others might be best described as changes in the "opportunity set" of patenting possibilities.

physical machine or process. As patenting options opened for software, copyrights became less attractive (Rai *et al.* 2006).

An additional major change came about from efforts to bring uniformity and predictability to patent litigation, culminating in the creation of the specialized Court of Appeals of the Federal Circuit. This Court has proved to be considerably more supportive of patent holders than was the earlier judicial system. Hence it has provided an incentive for patenting since infringement suits are now more likely to be resolved in favor of the patent owner (Cohen 2005; Gallini 2002). Further, and more subtly, Mowery and Sampat (2001) note that in the 1970s many universities that had previously distanced themselves from patenting began to be directly involved in patenting.

Gallini (2002) provides a review of both theoretical arguments on the relation between patents and innovation (see also Gallini and Scotchmer 2001) and empirical evidence on the effects of these particular legal reforms. Particularly relevant is Kortum and Lerner's (1998) study which shows a surge in patenting between 1983 and 1991. They show that these data cannot be explained by either the more supportive court or the extension of patenting to biotechnology and software. They further suggest that the most likely explanation of the surge is a change in the management of R&D during this period. Based on this and other studies which question the effectiveness of patents in providing incentives to innovate (Schankerman 1998; Lanjouw 1998; Cohen *et al.* 2000), Gallini concludes that while patent activity has increased markedly in the past few decades, it is clear from the available evidence that the connection between patents and innovation is far from a settled matter. It is important to note, however, that the bulk of this literature abstracts from industrial innovation based on university research.

3.B. Evidence on Commercialization

In this section we consider the evidence on commercialization activities of US universities. Within the scope of commercialization we include patenting, licenses executed, and license income. We also include a discussion of factors that might differentiate technology transfer offices (TTO) according to their effectiveness in commercialization operations.

3.B.1. Growth in University Patenting

As did patenting in general, patenting and licensing by U.S. universities increased dramatically over the decades of the 1980s and 1990s. Henderson *et al.* (1998) report that in 1965 only 96 patents were granted to 28 universities. By 1992 this had grown to 1500 patents granted to over 150 U.S. universities. In 2004 the 158 universities answering the annual Association of University Technology Managers (AUTM) survey reported 3,090 domestic patents issued and 9,247 new patent applications. Patent grants changed from about 3.4 per patenting university in 1965 to 10 per university in 1992 and about 20 per university in 2004.

While a number of (often casual) observers attribute this growth in patenting to passage of the Bayh-Dole Act, the multiple events discussed above in section 3.A. confound the problem of verifying the impact. Mowery *et al.* (2001) and Mowery and Ziedonis (2002) claim that the increases in patenting and licensing by US universities observed in the 1980 and 1990s can be traced to these other factors as well as the Bayh-Dole Act. Henderson *et al.* (1998) also point to the increase in the number of universities with organized licensing offices (which may have been related to passage of the Act). Mowery *et al.* (2001, 2004) and Henderson *et al.* (1998) argue that more patenting and licensing at U.S. universities likely would have occurred in the absence of Bayh-Dole, though they recognize that it has had an effect by facilitating the license process through simplifying the patent landscape.

Further, evidence from multiple studies suggest the post Bayh-Dole growth in patent activity can be viewed as the continuation of an upward trend dominated by biotechnology patenting which accords with the incentives generated by the *Diamond vs. Chakrabarty* case and the overall growth in biotechnology research (Mowery *et al.* 2001; Henderson *et al.* 1998; and Mowery and Sampat 2001). An alternative view is presented by Shane (2004) who provides evidence that the rise in patenting is not related to a shift in biomedical research but a shift in the distribution of university patents across lines of business. He examines pre- and post-Bayh-Dole patenting and finds that in the latter period universities focused their activities in areas where licensing is more effective. His measure of effectiveness is based on Likert scores from the Yale Survey on Innovation as to how effective lab directors consider licensing as a means of acquiring technical knowledge about new processes and products. These results notwithstanding, it remains unclear why the Bayh-Dole Act would have changed the propensity of universities to patent in lines of business where licensing is effective since patenting prior to the Act would have occurred only with an intent to license.

Several studies have examined whether the growth in university patenting was associated with a concomitant change in the *nature* or *importance* of university patents. Henderson *et al.* (1998) explored the possibility of changing importance of university patents. Their focus was on citations made by later patent applications to university patents compared to a random sample of industry patents. The higher the number of citations the greater is the revealed quality of the initial patent. They conclude that, while the rate of university patenting has increased, the average importance of those patents has decreased. This implies that the growth in transfer of knowledge from universities through patent licensing has been less than the increase in patenting.

However, Mowery and Ziedonis (2002), in a study of patent strategies at Stanford and the University of California System, found that no change in patent quality had accompanied the growth in patenting. Further, Sampat *et al.* (2003) find no decline in patent quality, in contrast to the Henderson *et al.* (1998) results, when the period of time for citations to accrue is extended. They show that university patent citation lags are much longer than industry patent citation lags. As well, Mowery and Ziedonis (2002) find no evidence of a decline in patent citations for universities that had actively patented prior to the Bayh-Dole Act. For universities that began patenting after passage of the Act they find patent quality improved over time.

In spite of these conflicting results on the impact of the Bayh-Dole Act, there have been efforts to generate a similar legal environment in other developed countries in the Organization for Economic Cooperation and Development (OECD) in order to foster university-to-industry technology transfer. Mowery and Sampat (2004) address the notion of extending the Bayh-Dole Act internationally and conclude that only modest success is likely elsewhere given the institutional differences between the United States and most other OECD countries. In particular, they point out that university-industry collaboration has a long history in the United States with much of the 19th and 20th century university research devoted to practical problems in agriculture, public health and industry. Furthermore, the prevalent university structure in the United States is different from that in Europe and Japan. The larger scale of U.S. universities, coupled with financial autonomy and both state funding and federal grant support, provided incentives for research with commercial, and frequently regional, benefits. Schmiemann and Durvy (2003) discuss the cultural, legal and regulatory differences between the United States and Europe with regard to technology transfer and note the move by some countries to reform "professor's privilege" which permits faculty members to own their inventions (see also Breschi *et al.* (2005)).

In January 2001 Denmark passed its Law on University Patenting, which was inspired by the Bayh-Dole Act. Valentin and Jensen (2006) argue that this law had a largely negative effect. They hypothesize that the Danish law may have reduced industrial collaboration with academic researchers since property rights that previously would have been assigned to industry were assigned to universities. They find that, indeed, Danish academic patents owned by industry fell after its implementation without an offsetting increase in the number of university-owned patents. Their work is particularly interesting since over the same period of time they do not observe the same pattern of patent activity in Sweden, a similar country but one that did not change from a system of professor's privilege to one of university "privilege" or ownership.

3.B.2. Growth in University Licensing

So far we have focused on the relationship between IPR policy reforms and patent activity. A discussion of university patenting would be incomplete without a treatment of licensing since it is the mechanism by which universities transfer the rights to practice their patents to firms. Thus, the potential for licensing provides the incentive for universities to take advantage of patents and changes in the patent environment.

Comprehensive data on licensing are not available before 1991 when AUTM began yearly surveys of its members' licensing activity. Thursby and Thursby (2002) report that for the 64 universities or university systems responding to the survey in each of the years 1994-98, invention disclosures, new patent applications and licenses executed grew annually by 7.1 percent, 17.1 percent and 8.4 percent, respectively.[3] In 1998 132 U.S. universities responded to

[3] Invention disclosures are the documents faculty researchers file with their TTO when they believe they have results with commercial potential.

the survey and reported for that year a total of 9,555 disclosures, 4,140 new patent applications and 3,078 licenses. By 2004, the 150 respondent universities reported 3,824 licenses, 14,208 disclosures and 9,241 new patent applications. While the rate of licensing, as measured by licenses per respondent technology office, remained fairly constant from 1998 until 2004, the disclosure and patent application rates continued to rise.[4]

In an attempt to sort out the sources of this growth, Thursby and Thursby (2002) construct a three-stage model of university licensing. In the first stage invention disclosures are produced, which are an input in the second stage in which patent applications are submitted. Licenses are the final output. Inputs to the production of disclosures are the number of licensing professionals in the TTO, federally sponsored and industry-sponsored research funds, the number of faculty and an unobserved propensity for faculty to disclose. Inputs to the production of patents are the disclosures produced in the first stage, the number of professionals in the TTO, the research quality of faculty and an unobserved propensity for university central administrators to patent. Inputs in the last stage, the production of licenses, are disclosures, patents, the number of professionals in the TTO, the research quality of the faculty, the unobserved knowledge and aggressiveness of the TTO and unobserved market demand for university inventions. Removing the portion of growth due to changes in observable inputs in each stage yields measures of total factor productivity (TFP) growth for disclosures, patents and licenses executed For the period 1994-1998, they find a yearly TFP growth rate of 2.7 percent for disclosures, 12.1 percent for patent applications, and a negative rate of TFP growth for licenses executed.

The fact that the rate of TFP growth for patent applications far exceeds that for disclosures or licenses leads the authors to two general conclusions. First, noting that disclosures

[4] It is possible that the licensing rate remained fairly constant because of the entry of new universities into licensing and the lag before licensing catches up with disclosures. See also Mowery and Ziedonis (2002) on learning by doing for new university entrants to patenting.

largely reflect faculty behavior and patent applications reflect university administration decisions, they conclude that an increased propensity of university administrators to promote patent licensing has been the primary driver of increased licensing. This conclusion is bolstered by a survey they conducted of industry executives who claimed the most important reason for their increased licensing from universities was changes in university receptivity to technology contracts and research agreements rather than a change in the orientation of faculty research.

Second, the fact that TFP growth is positive for both disclosures and patent applications but negative for licenses executed suggests a conclusion similar to that of Henderson *et al.* (1998). Universities are clearly delving more deeply into the pool of inventions, which would naturally lead to a decline in the marginal value of disclosures and patents. Thursby *et al.* (2001) come to a similar conclusion based on their estimates of the elasticities of licenses executed and royalties received with respect to invention disclosures. They find that a one-percent increase in disclosures is associated with less than a one-percent increase in either licenses executed or royalties received. If there were not a decline in the marginal value of a disclosure, then percentage changes in licenses and royalties should equal those of disclosures.

3.B.3. Profitability of TTOs and Incentives for Licensing Efforts

The 144 US universities and university systems that reported income in the AUTM 2004 survey received $1.42 billion in royalty income, net of payments to other institutions and of legal fees. Research funding tied to licenses accounted for $222 million of this total. This is about $7.2 million per responding office, $47,722 per active license (22,311 in total) and $118,229 per license that actually generated income (8,817 licenses). The average office employed 4.4 licensing professionals and 4.7 additional staff members. These figures suggest that, on average, TTOs generate profits for their universities. However, licensing revenues are highly skewed across universities with the median income, net of payments to other institutions and net of legal fees, being only $1.3 million, and 40 percent of the respondent TTOs earned less than $600,000. An AUTM survey of salaries suggests that a TTO with the median number of employees would have a wage bill of about $638,000 (Stephens 2005; Thursby and Thursby 2007b).

If income for most offices is low, what might account for the fact that so many universities have TTOs? One simple possibility is that universities may hope to "hit the jackpot" with a single valuable invention. A recent example was the sale of an anti-AIDS drug by Emory University for $525 million. That this may be explained by a "jackpots" model is suggested by the fact that in 2004 only 0.48 percent (109 of 22,311) of all active licenses at 144 US universities and 1.24 percent (109 of 8,817) of all licenses generating income yielded $1million or more in revenues (AUTM 2004).

Other explanations explored by Jensen and Thursby (2001), Thursby *et al.* (2001) and Jensen *et al.* (2003) are that universities have other goals in licensing. They surveyed 62 major university TTOs regarding the importance they attach to various licensing outcomes as well as how important they perceive these outcomes to be to the central administration and faculty of their universities. The outcomes were revenues generated, inventions commercialized, licenses executed, sponsored research and patents. While revenues were most important to the TTO and the central administration, sponsored research was most important to the faculty. Most importantly, no respondent viewed income as the sole motivation for licensing. Link and Siegel (2005) find in interviews with university administrators that most view revenue as the most important goal of their licensing operations.

We conjecture an additional motivation for licensing. Given the emphasis on licensing, and the pervasive presence of university TTOs across the United States, any research university would be something of an “odd duck” if it did not have a licensing office. This attitude could be most detrimental to public universities, where there are widespread expectations that research activities will have beneficial effects on the local and state economies. This claim would be difficult to test, but we note that 16 university respondents to the 2004 AUTM survey reported less than $30 million in total research expenditures. This small figure indicates that these are clearly not science and engineering research universities, where the presence of TTOs makes sense. Eleven of these 16 low-scale respondents were public universities.

3.B.4. Relative TTO Performance

A number of studies examine the performance of TTOs relative to each other. Thursby and Kemp (2002) take a multiple-input, multiple-output linear programming approach and use the AUTM data to measure production frontiers over the period 1991-1996 for university licensing. The inputs to the process are the number of professionals in the TTO, federally sponsored research funds and faculty size and research quality. The measures of commercial outputs are industry sponsored research funds, royalty income and the numbers of disclosures, patents and licenses executed. Those universities with combinations of inputs and commercial outputs that place them below the frontier are said to be inefficient. With this framework, they show that the rate of growth of commercial outputs exceeded the rate of growth of inputs over this period. More to the point, they find that more than half the sample of 111 universities were inefficient compared to other universities over the entire time period, but that there were clear increases in overall efficiency over time.

A number of studies examine the relative performance of TTOs in terms of the types of contracts they use in licensing. For example, Feldman *et al.* (2002) note that universities are increasingly willing to take equity positions in start-up firms based on intellectual property owned by the university. While most respondents mention that this willingness facilitates the formation of start-ups since those entities are frequently "cash-poor," the authors argue that equity positions are also important in aligning the interests and goals of both parties, making it easier to write contracts. Di Gregorio and Shane (2003) find that university willingness to make equity investments in lieu of royalties, along with providing the inventor a share of patent royalties, are the two university policies most closely associated with start-up activity.

Siegel *et al*. (2002) focus on organizational factors. Based on interview data, they hypothesize that the most important organizational factors in determining the relative productivity of universities in licensing are rewards to faculty and TTOs and actions taken to ease the barriers between universities and potential licensees. Sine *et al.* (2003) offer evidence that past success at licensing affects current licensing and also that institutional prestige matters. Elfenbein (2007) finds a similar effect, in that prestige of inventors increases the visibility of the TTO, thereby attracting potential licensees. That prestige, however, does not translate into greater willingness to license inventions.

Shane and Somaya (2007) is one of the few studies to examine relative performance as a function of the university's willingness to defend their patents. They show that increases in university licensing over the past 20 years have been accompanied by an increase in patent litigation pursued by universities. Based on interviews with university technology licensing professionals and data on licensing activity and lawsuits, they conclude that patent litigation has had an adverse effect on university licensing volumes. Litigation imposes significant time costs on TTOs and has reduced the number of licenses executed in the year following lawsuits. However, there appears not to be an effect on patent applications and invention disclosures.

3.C. The Intended Role of the Bayh-Dole Act and Empirical Evidence.

As discussed earlier, the Bayh-Dole Act was designed to increase commercialization of U.S. university inventions and the growth in patenting and licensing observed over the past several decades seems in line with that intention. In this sub-section, we address the literature that examines this growth in the context of arguments that proprietary rights to university inventions were needed to spur that growth.

Prior to Bayh-Dole, patent policy covering university research was at the discretion of federal funding agencies. However, the general rule was that universities should issue nonexclusive licenses. The argument for streamlining this cumbersome process was occasioned by concerns in the US Congress that nonexclusivity hampered development of commercial applications of federally funded research. In part this concern was based on evidence that only a small percentage of almost 30,000 patents owned by the federal government had been commercialized by the late 1970s. Eisenberg (1996) has pointed out, however, that these patents were largely related to research performed under defense contracts and that ownership had reverted to the federal government only after federal contractors elected not to retain rights ceded to them by the Department of Defense. Thus, the evidence cited in support of the Act was not a random sample of federally funded research or patents.

Nonetheless, the conceptual arguments for allowing university ownership and exclusive licensing remain relevant to the extent that commercial application requires substantial downstream investments. This possibility raises three questions. To what extent are university inventions early-stage inventions? How extensively are exclusive licenses used? To what extent are strong property rights necessary for downstream investment and commercialization?

3.C.1. Stage of Development

The generally embryonic nature of university inventions is clear from surveys of both TTOs and licensing executives (Thursby and Thursby 2004a, 2005b). In the university licensing survey by Thursby *et al.* (2001) respondents indicated that 82 percent of all university licenses are either of a proof of concept or only a laboratory-scale prototype. The comparable figure reported in the industry survey by Thursby and Thursby (2004a) is 74 percent. The two surveys report, respectively, that only 12 percent and 14 percent of licenses are granted for inventions that are ready for practical or commercial use. In contrast, the case study by Colyvas *et al*. (2002) of eleven Stanford University and Columbia University technologies finds that four of the eleven were "off the shelf" technologies.

3.C.2. Exclusive versus Nonexclusive Licensing

If the need for exclusivity for downstream investment is the primary argument for university IPR, then one would expect the majority of licenses to be exclusive. However, the data show that the majority of licenses are nonexclusive. In the 2004 AUTM survey, 212 United States and Canadian institutions reported more nonexclusive licenses (2,715) than exclusive licenses (2,277). Note this is not the same as a comparison of the number of *inventions* that are exclusively licensed versus nonexclusively licensed because the same invention can be nonexclusively licensed many times. On the other hand, it is common to exclusively license a technology by field of use or exclusively by geographic area. Thus, a particular technology can also be exclusively licensed multiple times.

The important point is that, as Colyvas *et al.* (2002) argue, proof-of-concept and laboratory-scale technologies do not necessarily map perfectly with the need for exclusivity supporting further development. As an example, they mention that the Cohen-Boyer patented technology, which was certainly embryonic, was almost immediately useful to industry and nonexclusively licensed.[5] Further, Rai *et al.* (2006) note that patents on improvements made by firms and the availability of absorptive capacity within firms may reduce the need for exclusivity.

It is also important to note that need for patents and exclusive licenses is much less apparent for software than biotechnology inventions. Development costs in software are very likely low in relation to other fields (and, in particular, the biopharmaceutical industry). In addition, in open-source software firm revenues are derived from support services and complementary hardware rather than from IPR (Rai *et al.* 2006).

Thus while the IPR associated with Bayh Dole allows exclusive licensing, it is not necessary for many technologies. It is also clear that in both university and policy circles that an understanding is evolving as to when exclusivity is and is not needed. A prominent example is the National Institutes of Health guideline that research tools be nonexclusively licensed. Other examples include the Public Intellectual Property Resource for Agriculture and the Biological Innovation for Open Society, which both promote nonexclusive licensing on favorable terms for developing countries or to protect the commons (Benkler 2004; Boettinger and Bennett 2006). These approaches essentially use price discrimination, a strategy that can benefit both the private and public interests in licensing (David 2004).

3.C.3. Appropriability

The argument for IPR under Bayh-Dole is that exclusivity associated with patents improves the ability of downstream innovators to appropriate or capture the returns to their investment. But it is well known that patents may not be particularly effective in this regard and

[5] This is the basic gene-cloning technique developed at Stanford, which received a patent on products using that technology in 1984.

hence unnecessary for commercialization (Levin *et al*. 1987; Cohen *et al*. 2000). Unfortunately there is little empirical research looking at this link.

An exception is Dechenaux *et al.* (2006) who examine the relationship between commercial success, or failure, of innovations and various means of appropriating returns to commercialization. They consider a university invention that has been exclusively licensed to a firm and requires further development prior to possible commercialization. They model both the technical and commercial uncertainty associated with the invention. In each period the firm decides whether to continue or terminate development. If there is technical success in achieving a useful outcome, the firm must decide whether to commercialize the invention. Based on a sample of 805 exclusively licensed MIT inventions, they examine how the hazard of termination and commercialization is affected by patent scope, as well as the Yale measures of the effectiveness of patents, secrecy, learning, and lead time in appropriating returns (Levin *et al*. 1987). Stronger appropriability, in the sense of wider patent scope, better patent strength and more effective business secrecy, reduces the probability of termination in each period. Interestingly, the effectiveness of lead time in appropriating returns is an important determinant of commercialization.

3.C.4. Role of Faculty

Research faculty play the most important role in university patenting and licensing since they are the inventors. However, their role clearly extends beyond that point since faculty must take the step of disclosing any potentially commercially valuable inventions to their university. Indeed, many universities require their faculty to make such disclosures. However, Thursby *et al.* (2001) provide interview evidence suggesting that university TTOs see only a fraction of disclosures (possibly less than half) of the inventions with commercial potential (see also Sine *et* *al.* 2003 and Link and Siegel 2005). This might be because faculty do not always recognize the commercial potential of their inventions. Further, they may not want to spend the time it takes to further develop the invention to make it ready for the market, as we discuss below. Some researchers may resist participation in commercial development because they believe the proper role of university science is for its results to remain open and not proprietary. In addition, a clear disincentive to faculty is that license agreements often include delay-of-publication clauses. In a survey of industry licensing executives Thursby and Thursby (2003a) found that 27 percent of university licenses include clauses that allow for deletion of information. Moreover, 44 percent allow for publication delays, with an average delay of nearly four months. Some licensing firms require as much as a year's delay.

Based on interviews Owen-Smith and Powell (2001) argue that most TTOs do not have the resources to canvass laboratories to find potentially marketable inventions. Thus, the success of an office in obtaining disclosures depends on faculty perceptions of both the value of potential patents and the costs of interacting with the TTO.

After invention and disclosure the inventor is frequently involved in helping to identify potential licensees. This role follows in large part because university inventions are primarily early-stage technologies and the inventors are often best situated to know their potential uses and the licensees who might be interested. Jansen and Dillon (1999) report that 56 percent of the primary leads for over 1,100 licenses executed at five universities and one national laboratory were inventors. This is consistent with evidence from surveys of university technology managers and business executives conducted by Thursby and Thursby (2004b, 2005b), who find that personal contacts of the inventor are the most important source for industry to find relevant university technologies to license, eclipsing publications, patent searches and presentations at professional meetings.

The most important post-invention role of faculty, however, is their frequent efforts at further development of licensed technologies (Agrawal and Henderson 2002; Colyvas *et al.* 2002; Jensen and Thursby 2001; Thursby *et al.* 2001; and Thursby and Thursby 2002). In their survey of university licensing professionals, Jensen and Thursby (2001) and Thursby *et al.* (2001) find that 71 percent of licensed inventions use faculty in further development after the license is signed. Thursby and Thursby (2004a) utilize their industry survey to explore this role in more detail. They asked respondents the percentage of time that faculty were involved in further development for licensed inventions in different stages of development. For technologies that were only a proof of concept, respondents indicated that faculty were used 55 percent of the time. The comparable figure was 54 percent for technologies for which a laboratory-scale prototype (the next stage of development after proof of concept) was available. However, research faculty were used much less frequently for late-stage technologies. If the technology was ready for use or its manufacturing feasibility was known, professors were involved only 15 percent of the time. In those cases where faculty were important for further development, respondents were asked why this was the case. Not surprisingly, the specialized knowledge of faculty inventors was given as the most important reason, cited by 66 percent of respondents. In contrast, only 17 percent claimed that employing professors in development activities was cheaper than in-house development.

Agrawal (2006) examines the extent to which firms engage the inventor in further development of an acquired early-stage development rather than develop the technology in-house. The technologies he describes were licensed from universities. His hypothesis is that firms that engage the inventor more, and thereby avail themselves of the inventor's tacit knowledge, will be more successful at commercializing the technology. He measures commercial success as a binary variable, indicating whether or not the invention was commercialized, and he calculates the degree of success using royalties per year. His key explanatory variables are the number of hours spent on development after the license is signed and before revenues begin to flow, and the number of researchers from the inventor's laboratory who are recruited into the firm's research facility. He concludes that both the likelihood and degree of commercial success are related positively to the extent to which the firm engages the inventor and his graduate students.

4. Incentives to Innovate: Theoretical Frameworks

Despite the inability of researchers to definitively link increased commercialization of university inventions to IPR legislation, it is apparent that the post-1980 environment appears to have facilitated university-industry technology transfer. As noted earlier, part of the difficulty in identifying the sources of increased commercialization is the multiple contemporaneous policy changes. But another part of the problem is the lack of theoretical structures that formally link empirical results to the incentive mechanisms in play. In this section, we describe the few studies that attempt to fill this need.

4.A. The Rationale for TTOs

Empirically there has been a dramatic organizational response by universities to the ability to own and license patents. The number of universities with organized technology transfer offices grew from 25 in 1980 to over 230 in 2004. While a number of studies examine the performance of these offices, scant attention has been devoted to theoretical analysis of the rationale for establishing such offices. Hoppe and Ozdenoren (2005), Macho-Stadler *et al.* (2007), and Hellmann (2007) are notable exceptions. In all three studies, uncertainty about either the profitability of inventions or the identity of firms that can successfully deploy university inventions provides a rationale for a TTO to serve as an intermediary between inventors and developers.

In Hoppe and Ozdenoren (2005) uncertainty about the profitability of inventions prevents firms from licensing them unless a TTO invests in acquiring information to reduce this uncertainty. They examine equilibria in which it is worthwhile for the TTO to make this investment and for firms to adopt and invest in developing inventions. With its investment the TTO develops private information, which it cannot credibly reveal to potential licensing firms. Nonetheless, the authors show that the use of success-based payment terms, such as royalties or equity, signals to firms that the TTO is interested in choosing the best match of inventions with firms. When the number of inventions available to the TTO is sufficiently high, these payments support an equilibrium in which the TTO performs an intermediary function.

The model in Macho-Stadler *et al.* (2007) is similar in that firms have incomplete information about invention quality and contracts take the form in which universities receive a share of licensee profits. Their analysis differs in considering the incentives for an infinitely lived TTO not to license under some circumstances. The TTO, with private information about true invention quality, may shelve a portion of the inventions in order to establish a reputation for offering high-quality inventions. As in Hoppe and Ozdenoren, whether it is worthwhile for the TTO to invest in establishing such a reputation depends on a sufficient supply of inventions. Unfortunately, neither study addresses the role of IPR in providing incentives for the creation of a licensing office. Moreover, by taking the supply of inventions as exogenous they also abstract from the role of the TTO in providing incentives for university scientists either to invent or disclose inventions or to participate in further development.

Hellmann (2007) examines the role of patents in a model where scientists (inventors) are unaware of which firms can use their discoveries and firms are unaware of which academic discoveries would be useful to them. Central to the model is a costly matching process in which inventors and firms find each other. If a match is successful some portion of firm profits are transferred to the inventor. The existence of a patent raises the transfer payment to the inventor. He shows that patents increase the incentive for inventors to search for firms that could use their discoveries, but dampen the incentive for firms to search for discoveries made outside their own laboratories. Thus patents for academic inventions may or may not increase their *ex post* development, depending on the elasticity of scientist and firm search activity. Hellmann's model also provides a justification for delegating searches for compatible firms to a TTO, which may be more efficient at searching than the inventor. This delegation frees time for inventors to focus on research. With complete contracts such delegation is optimal with or without IPR, while with incomplete contracts, IPR are required for this delegation to occur.

4.B. IPR, Contracts, and Innovation Incentives

Kitch's (1977) argument that patents provide an incentive for the original inventor to coordinate subsequent innovation efforts does not take into account the possible separation between the inventor and the patent owner. Under U.S. patent law the inventor is the original owner of patent rights, but under employment policies in the majority of U.S. universities, an employee is obligated to assign these rights to her employer as long as university resources are used in the research. If scientists, particularly those in universities, are motivated by their love of solving puzzles or reputation, then the university's interest in revenue and the faculty inventor's incentives may not be aligned.

While most of the literature on inventor incentives abstracts from this distinction, the Bayh-Dole Act recognizes the problem and requires that the university share a portion of any license revenue with the inventor. Jensen and Thursby (2001) construct a theoretical model that takes this requirement into account and show that this section of the Act has merit. They also demonstrate the need for license contracts that tie expected revenue to successful commercialization. They consider the development of an invention that has been disclosed to a TTO, which has the responsibility of licensing inventions owned by the university. As suggested by the survey results reported earlier (Thursby *et al*. 2001), the invention is likely to be so embryonic that commercial application requires further development with collaboration between the inventor and licensee. The TTO decides whether or not to license the invention and the terms of a contract to offer a potential licensee. If a license is offered and accepted by the firm, the inventor then can choose to spend effort in development. While the inventor in their model benefits from license revenue, she prefers engaging in research and therefore also suffers a loss from efforts spent in *ex post* development. There is, therefore, a moral-hazard problem in this setting and a financial return tied to commercial success, such as shared royalties or equity participation, is necessary to induce inventor effort.

This work suggests a role for royalties in university license contracts that differs from the rent-extraction, risk-aversion, or signaling rationales in the earlier theoretical literature on licensing (Kamien 1992; Gallini and Wright 1990). It also accords with recent survey evidence on contracts struck by US universities. In the Thursby *et al.* (2001) survey of university TTOs, 97 percent of the respondents reported that royalties were included in license contracts either "almost always" or "often". Notice, however, that many contracts also include other terms. For example, 92 percent reported the same frequencies for upfront fees, 89 percent for annual payments, and 72 percent for milestone payments, which are made as the technology is developed through various stages.

In an effort to explain the use of milestones and annual payments, Dechenaux *et al* (2007) highlight the role of contracts in framing both licensee and inventor incentives. Their model is similar to Jensen and Thursby (2001), except that they exploit the fact that many inventions must go through multiple stages of development before they can be commercialized. They assume two stages, a first in which inventor and licensee effort are both needed to determine technical success, and a second in which the licensee can invest in commercialization. Thus, in addition to inventor moral hazard, there may be adverse selection since firms may "shelve" inventions either because their intent in licensing was simply to block other firms from developing them or simply because by the time development is completed expected profits are less than originally anticipated. Neither inventor effort nor licensee investment is contractible and the licensee has private information about its intent.

They show that milestones address the problem of inventor moral hazard without the inefficiency inherent in royalties. Royalties are optimal only when the licensee is risk-averse. Neither royalties nor a milestone paid at the end of the technical development stage can address the shelving problem. Annual fees address the problem of unintentional shelving, where the licensee learns after technical development that, while the invention may be useful for other firms, it is not worth its own investment in commercialization. In situations where the TTO is concerned that the licensee may be licensing with the intent to shelve, an upfront fee is needed. The model provides conditions under which such fees deter shelving in equilibrium. Thus in their model upfront fees serve a different purpose than in an environment in which shelving is not regarded as a problem where such fees merely extract rents or spread risk. Finally, their analysis shows that in situations where the incentives of the licensee and the inventor are questionable, complicated contracts, such as those observed in practice, may be optimal.

These results contribute to policy debates on the “march-in” provision of the Bayh-Dole Act. This provision allows the federal government to take back ownership if there is a failure to undertake reasonable commercialization efforts, making university ownership state-contingent. The fact that the government has never exercised these rights has contributed to the view that this provision of the law should be strengthened (Rai and Eisenberg 2003). Dechenaux *et al*. (2007) contribute to the debate by showing that certain contract terms and a willingness of universities to terminate licenses may provide a market mechanism to minimize shelving.

Two other points should be noted. First, the conditions under which shelving is deterred in equilibrium rest on an assumption that the TTO finds it worthwhile to terminate licenses and search for alternative licensees. Dechenaux *et al.* (2007) motivate this assumption by referring to university survey results that TTO personnel frequently state their mission in terms of the Bayh-Dole provisions. Thus, it may not be necessary to strengthen the “march-in” rule, the provision itself may serve the purpose of framing TTO objectives in licensing. Second, shelving is only a potential problem when licenses are issued exclusively to a single development firm. Where the deterrence conditions in Dechenaux *et al* are not met, shelving concerns reinforce the arguments of those who suggest that exclusive licenses should be the exception rather than the rule (Rai and Eisenberg 2003; Colyvas *et al.* 2002; Merges and Nelson 1990).

Finally, the need for success-based payments discussed here pertain to inventions requiring further development for commercialization. For inventions that are ready for use, the optimal way to extract rent from the licensee is an upfront fee or auction. While many university inventions require further development, some, such as transgenic mice and other research tools, do not. Thus, the argument that reach-through royalties, which are license payments made by users of all products that rely on the basic research tool, should not be charged has economic merit as well as social welfare benefits (Rai and Eisenberg 2003; Merges and Nelson 1990).

4.C. Innovation and Social Welfare

Even if awarding IPR to universities increases commercialization, this increase may or may not represent an improvement in social welfare. If downstream products based on university inventions in the public domain can be patented, it is not clear that patents on the upstream input are needed for firms to innovate based on them. By contrast, if downstream products based on university inventions in the public domain cannot be patented, IPR for the upstream inventions may improve welfare. In the former case, awarding IPR to universities may simply redistribute rents from downstream firms to universities (Hellmann 2007), while in the latter, IPR can alter the nature of competition downstream. Given this inherent ambiguity there is surprisingly little rigorous analysis of the welfare effects of awarding IPR to universities.

An exception is Mazzoleni (2005) who examines social welfare in terms of the net total surplus from downstream product development with and without patent protection for the downstream products and with and without IPR upstream. His model is an adaptation of Dasgupta and Stiglitz (1980) which examines the welfare effects of R&D competition in terms of the number of firms that compete in equilibrium and the expected time for product introduction.

When the downstream product can be patented, the introduction of IPR upstream restricts the number of firms which develop a downstream product and in the context of this model, delays product introduction. As a result, consumer surplus is lower with IPR upstream. In this case, welfare can increase only when the number of firms who compete in the absence of IPR is greater than or less than the socially optimal number.

When downstream products cannot be patented, whether IPR upstream increases or decreases welfare depends on the threat of imitation. In the extreme case where imitation is impossible, upstream IPR and licensing reduces the number of firms investing in downstream products. This unambiguously decreases welfare and delays product introduction. At the other extreme, if imitation is costless and sufficiently rapid, then IPR and licensing is necessary for downstream product development. In intermediate cases, which are arguably the most realistic, upstream IPR is more likely to increase welfare the lower is the likelihood of imitation.

Mazzoleni's model can be criticized for its simplicity. For example, it assumes free entry into R&D, and the time to develop a product, as well as time to imitation in the regime without downstream patents, are exogenous. Nonetheless, his work provides a clean analysis of welfare tradeoffs in some of the hotly debated cases. His analysis of welfare when downstream patents are possible captures the essence of the argument that patenting research tools can be harmful. His analysis of welfare when imitation is costless and upstream inventions are in the public domain captures the basic arguments for Bayh-Dole.

5. Patents and Incentives to Invent and Disclose

Whatever their merits, the arguments for patenting university research rest on incentives for innovation rather than for invention *per se.* As discussed in Section 2, traditional norms of science promote both invention and free disclosure regardless of commercial results. The natural question is whether the incentives created by university IPR undermine the norms of science (Eisenberg 1987). With the dramatic growth in patenting and licensing, one might expect the potential financial returns to faculty inventors to affect their research, either raising the time spent in development or skewing research toward topics with commercial potential (Krimsky 2003; Washburn 2000). Another concern is that the ability to perform research has suffered because exclusivity provisions or license fees limit the access of follow-on researchers to basic knowledge (Argyres and Liebeskind 1998; Heller and Eisenberg 1998).

5.A. Research Effort

Jensen and Thursby (2004) and Thursby *et al.* (2007) develop theoretical models in which a faculty researcher chooses the amount of effort to devote to basic research, which is freely disseminated, and applied research, which can be both licensed and published. Both models incorporate the notion that faculty derive utility from solving puzzles and gaining a subsequent reputation, which is consistent with the priority system that has evolved from the norms of science, and from receiving financial rewards. They also allow for the possibility of research in the so-called "Pasteur's Quadrant" where research need not be basic *or* applied but rather has dual uses. Thus use-inspired research can make fundamental contributions, and curiosity-driven research can have immediate applied uses, being both patentable and publishable (Stokes 1997).

Jensen and Thursby (2004) show that whether the researcher specializes in basic or applied research, or spends time on both, in any period depends on the marginal rate of substitution of applied for basic research. In a one-period problem, this merely takes into account the utility associated with each type of research. However, in a two-period model, this marginal rate of substitution also incorporates the productivity of research types in adding to future knowledge stocks, and so also to the faculty member's income and prestige. Although it seems likely that an increase in income associated with patent licensing would induce her to reallocate time to applied research, this outcome is not necessary. This reallocation would both increase the future stock of patentable knowledge produced and reduce the future stock of scientific knowledge and its associated prestige. Thus, it could reduce overall utility from research *per se*.

Thursby *et al.* (2007) examine the total amount of time spent in research, as well as the mix between applied and basic research, throughout the inventor's life cycle. Their model also takes into account the effect of the researcher's choices on the stock of knowledge over time. They show that, with or without patent licensing, and whether or not the faculty member works in a tenure system, she devotes more time to research early in her career, so that leisure rises over time. In that sense, licensing does not alter the life-cycle pattern of research. Nonetheless, they find that licensing yields a higher ratio of applied to basic effort and lower leisure throughout the life cycle.

Thus, as suggested by Lach and Schankerman (2004), faculty researchers respond to economic incentives. Importantly, however, this diversion does not mean that research effort is reduced. In all specifications of Thursby *et al.'s* (2007) model leisure is the activity most compromised, so that total research effort rises. In most of the specifications they consider, basic research effort actually rises with the possibility of licensing. The stock of knowledge may or may not suffer depending on the publishability of research. In specifications where only basic research is publishable, the introduction of licensing reduces the stock of knowledge. However, as long as the results of applied research efforts are published and licensed, the stock of knowledge is higher with licensing than without.

There is also a growing body of literature that empirically addresses the impact of patenting or licensing opportunities on scientific research. Despite concerns over changing research practices suggested by surveys of university researchers (Blumenthal *et al*. 1996;

Krimsky 2003), early studies show a positive relationship between publishing and patenting (Murray 2002; Agrawal and Henderson 2002; Fabrizio and DiMinin 2005; Stephan *et al*. 2007). These studies do not directly address the extent to which the nature of research is affected by commercial activity.

Thursby and Thursby (2007a) and Azoulay *et al*. (2007) construct longitudinal databases of faculty publications and other characteristics, which allow them to examine the research productivity of faculty over their life cycle. Both find a pattern of life-cycle productivity consistent with the predictions in Thursby *et al.* (2007). Thursby and Thursby's study examines the behavior of 3,241 faculty researchers at six major US universities from 1983 through 1999. Their data include information on publications, as well as whether a faculty member disclosed an invention to her university's TTO in each year, and other individual characteristics such as gender and proxies for age. Their data also include Narin's citation-based basicness index for the journals in which the faculty published (Narin *et al.* 1976). This index is based on the notion that basic journals are more likely to be cited by applied journals than vice versa, so that a journal is considered more basic the more it is cited by other journals. They find that while the probability a faculty member disclosed an invention to her TTO increased tenfold over the period they examine (from 0.01 in 1983 to 0.10 by 1996), the portion of research published in "basic" journals remained constant. They also find that both publications and disclosure activity rise and then fall with age (with publications peaking before disclosure). Not surprisingly, faculty in the biological sciences are more likely to disclose than those in physical sciences, and, controlling for field, age, year of PhD, as well as university characteristics, faculty who are more prolific publishers are more likely to disclose.

Azoulay *et al*. (2007) examine the life-cycle patenting behavior of 3,884 scientists in biomedical fields from 1967 to 1999 and find that patenting peaks in mid-career years. They develop a measure of the latent patentability of each scientist's research by relating areas identified by publication titles to a measure of the extent to which other scientists working in these areas patented their discoveries. Using hazard-rate and logistic models, they find that patent applications follow flurries of publication, holding constant latent patentability. This suggests that, rather than diminishing or shifting in response to returns from patentable research, research creates opportunities for patenting. From the perspective of an individual researcher, then, academic patenting and entrepreneurship might be a natural consequence of moving along a particular research trajectory rather than a diversion away from more fundamental research.

Azoulay *et al.* (2006) employ the same database to examine related questions in terms of the quality and content of publication. As do Thursby and Thursby (2007a), they find that scientists who patent are more prolific publishers than those who do not, controlling for other characteristics. Interestingly, however, the quality of publications, as measured by the impact factor of the journal of publication in a given year, as well as the proportion of publications in which the scientist appears first or last in the authorship list, is not significantly different between scientists who patent and those who do not.

In summary, the theoretical and empirical literature that focuses on university invention *per se* finds little if any evidence to suggest that patenting or licensing has compromised research agendas, either in terms of the rate of output or subject areas addressed.

5.B. Diffusion and Invention: the Anti-commons Problem

The anti-commons hypothesis focuses on the cumulative nature of research. While Jensen and Thursby (2004) and Thursby *et al.* (2007) consider the cumulative nature of research, they do so in the context of a single researcher building on her knowledge base. The anti-commons problem goes beyond this, hypothesizing that by restricting access of others to inventions, either by excessive fees or coordination costs, as well as delayed or denied access, university IPR may limit the incentive or ability of future researchers to cumulatively build on prior research (Heller and Eisenberg 1998; Campbell *et al.* 2002). The anti-commons problem is an increasing concern, as universities increasingly patent research tools and faculty report an increasing reliance on access to multiple research technologies (Walsh *et al.* 2003a, 2003b).

Several studies address the anti-commons problem empirically. Walsh *et al.* (2005) provide survey evidence suggesting that, while the preconditions for an anti-commons effect are prevalent, researchers do not appear (with the exception to access to tangible property) to be delayed or diverted from their research interests. Only one percent of a random sample of 398 university respondents report having to delay their research more than a month because of patents on knowledge inputs needed to pursue the work. None of the respondents stopped pursuing a line of research because of third-party patents on research inputs. This result is qualified by the fact that respondents tend not to be aware of existing patents on the knowledge they use. The situation is different for material-transfer agreements, where 19 percent of respondents reported an inability to obtain materials. Roughly 40 percent of respondents said they were asked to sign material-transfer agreements. In contrast to the one percent of cases when a patent was involved, eight percent of requests for tangible materials involved at least a one-month delay.

Murray and Stern (2006, 2007) examine the anti-commons problem in the context of research that lies in Pasteur's Quadrant. They construct a sample of 169 patents associated with papers published in *Nature Biotechnology* over the period 1977 to 1999. They exploit the fact that patents are granted with a lag so that the initial knowledge disclosed is through publication. They examine whether there are different publication citation patterns before and after a patent is granted. They find that the citation rate declines by between 10 and 20 percent after a patent grant, particularly for researchers with public-sector affiliations. In other words, one potential cost of academic patenting may be a reduced ability of subsequent scientific researchers to draw upon that knowledge in an unrestricted fashion.

Rosell and Agrawal (2006) focus on a different dimension of the anti-commons, specifically whether knowledge is disseminated to a narrower spectrum of users. They use the National Bureau of Economic Research patent database, as described by Hall *et al.* (2001), along with a report of university patents[6] to compute a Herfindahl-type measure of the concentration of patents awarded to particular assignees and estimate the extent to which patented university inventions are more widely disseminated than those of firms. They find that the degree to which citations of university patents are more widely dispersed across assignees than those of firms declined by more than half as university patenting increased from the 1980s to the 1990s. They also find that the extent to which citations in university patents are more widely dispersed than those of firm patents declined by more than half.

The extent to which there is an anti-commons as a result of university IPR begs for much more analysis, particularly theoretical. For example, while results of the Walsh *et al.* (2005) survey suggest that research may not have been hampered by patent thickets, an important question is why. The fact that few respondents to their survey regularly conduct patent searches may explain their results, but there could be other explanations involving the likelihood of litigation for infringement. While theoretical models are starting to address such issues in the context of industrial competition, there is none to our knowledge in the context of university

[6] Compiled in U.S. Patent and Trademark Office, Information Products Division 1969-2000.

patenting and research.[7] While the Walsh *et al*. results suggest that the *Madey v Duke* decision has had little impact on the propensity of researchers to check for patents, the precedent set could mean that the possibility of litigation may factor more into researcher's decisions in the future.[8]

To our knowledge, the only theoretical analysis of invention and disclosure is that of Mukherjee and Stern (2005). They examine an overlapping-generations model of cumulative research that highlights the tradeoffs facing researchers when their work lies in Pasteur's Quadrant. In their model, researchers decide whether to access information produced by the previous generation, the level of their research investment, and whether to disclose the knowledge their investment produces. They show that both open science and secrecy can be equilibria, as well as alternating paths, depending on the costs of accessing prior knowledge and the private benefits from secrecy. There are few general results from their analysis. Nonetheless, they highlight that the ability to sustain open science as an equilibrium depends not only on the ability to access prior knowledge, but also researchers' benefit from the ability of future generations to use the knowledge they produce. Finally, patents in this model can produce an anti-commons effect, as in Murray and Stern (2006, 2007), since they raise the private benefits from restricting dissemination. However, if secrecy is the equilibrium benchmark, then the public disclosure requirement of patents could mitigate the negative effects of that restriction.

6. Future Directions

[7] For theoretical treatments of various aspects of patent thickets in the context of firm competition, see Lerner and Tirole (2004), Noel and Schankerman (2006), Galasso (2006), and Shapiro (2006).

[8] In Madey v Duke, the Federal Court of Appeals ruled that Duke University infringed two of John Madey's patents. The university's defense had relied on the experimental use exemption which allows for non-infringing use of patents for curiosity-driven, as opposed to business-driven, research. The Court ruled that research within the university furthered the legitimate business of the university so that the research exemption could not be used as a defense.

In this chapter we considered IPR for university inventions in the context of *ex ante* incentives for scientists to invent and disclose their inventions and *ex post* incentives for innovation based on those inventions. As is clear from the literature summarized in Section 2, the norms of open science appear much more appropriate for promoting invention and disclosure. Providing incentives for innovation is another matter, and there are arguments both in favor of patents and against them in this context. Taken as a whole the body of work presented in Section 3 is consistent with the view that changes in patent laws and judicial standards in the early 1980s in the United States put in place a set of rules that allowed for dramatic increases in commercialization of university research. What is not so clear, however, is whether IPR were necessary for this increase. Further, many scholars now question whether these changes have endangered further invention and innovation. Here, the message from recent research is less clear. While the studies summarized in Sections 4 and 5 show that the academic research enterprise appears to have remained healthy, and to some extent may have benefited from patenting, the few papers that examine dissemination patterns find evidence of some negative effects.

The overarching issue that is largely ignored in this work is whether increased commercialization of university inventions is socially desirable. Put simply, from society's point of view is there too-little provision of innovative market goods and technologies derived from university inventions (Mazzoleni 2005)? This is an area that requires extensive and careful research. Somewhat related, and more specific to the Bayh-Dole type of laws that have been implemented, it is not clear whether a system that gives ownership to the university is more efficient than one investing ownership in the inventor (Crespi *et al.* 2006). While work is beginning on this issue, the answer is far from clear at this time.

Our discussion has focused primarily on IPR in the form of patents and publicly funded research at universities. It is important to recognize that many of the issues we address also pertain to other forms of IPR, such as copyright and trade secrets, and other types of publicly funded institutions, such as federal laboratories (Dam 1999; David 2004; Reichman and Uhlir 2003; Jaffe and Lerner 2001). Our decision to focus primarily on patents was a function of two things: the paucity of rigorous research in these other contexts and the perception that copyright protection does not prevent access to information in the same way as patents.

There is, however, growing controversy over the potential deleterious effects of changes in copyright law. Covering all of the issues is beyond our scope, but two examples illustrate. First, copyright law carries a "fair use" provision that allows some use of material without infringement, hence the perception that copyright protection is not particularly restrictive. For several reasons this perception may not be valid. As David (2004) points out, in the case of software US copyright protection can be obtained without disclosing source code. Moreover, advances in digital technology now allow copyright holders to prevent access through encryption and the 1998 Digital Millennium Copyright Act (DMCA) prohibits attempts to circumvent encryption. While there are limited exceptions for libraries and academics, the extent to which the Act restricts research is an empirical issue.

The second example is the 1996 European Union Directive on the Legal Protection of Databases which created a *sui generis* property right for non-copyrightable databases. Under the directive, the database compiler is given the exclusive right to control uses of the data as long as the compiler can show a "substantial investment" in its creation or maintenance (Reichman and Uhlir 2003). This property right clearly jeopardizes the scientific community as it confers a property right on the information *per se*. As pointed out by Eisenberg and Rai (2006), in the

United States neither patents nor copyrights confer exclusive rights on information or data.[9] As with the DMCA, the extent to which property rights on data are asserted is an empirical issue and one of great importance given the prevalence of publicly funded data bases.

[9] Rather patents confer rights on products or processes that result from novel ideas and copyright confers rights on new expressions.

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