The Frontiers of Intellectual Property: Expanded Protection versus New Models of Open Science

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Abstract

The growing salience of intellectual property (IP) rights has reconfigured U.S. science, shifting it from the formerly separate realms of university and commercial science to an increasingly interconnected field of public and proprietary science. We assess both the magnitude and consequences of these developments, first describing the primary tools of IP and the changing nature of their influence on science, and then examining the effects of IP on the roles, rules, and relations of the scientific enterprise. We also consider the emergence of new models of scientific practice that blend both public and private. We debate whether current changes represent a transition or transformation in the relations between science and property. Finally, we argue that just as the public and private spheres of science may be converging, so must future scholarship if we are to answer harder questions about the appropriate balance between traditional logics of open science and the more recent regimes of proprietary science.

> *Humanity needs practical men, who get the most out of their work, and, without forgetting the general good, safeguard their own interests. But humanity also needs dreamers, for whom the disinterested development of an enterprise is so captivating that it becomes impossible for them to devote their care to their own material profit . . . . [A] well-organized society should assure to such workers the efficient means of accomplishing their task, in a life freed from material care and freely consecrated to research.*
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> Marie Curie (1946)

INTRODUCTION

Long gone are the days when the investigator working in his or her lab could embark on a curiosity-driven process of discovery, "in a life freed from material care and freely consecrated to research." As a young scientist who serendipitously discovered radium and polonium in the course of her doctoral research, Marie Curie argued against the idea that scientists should be motivated by the protection and profit that patents often afford. Following 20 years of freely giving away radium for cancer treatments and openly sharing information about the extraction process, Curie found herself forced to rethink her antipatent bias as the financial requirements of maintaining first-class research on radioactivity became burdensome. Although in the end she received financial support and collaboration from industrial patrons such as the Standard Chemical Company, she never accepted ownership of the radium that President Harding deeded her, nor did she patent any processing methods or potential medical applications (Macklis 2002).

With its unfettered model of publication, science has traditionally promoted both disclosure and discovery via the creation of a common corpus of science, bestowing peer recognition and acclaim on those who make significant contributions to public knowledge (Merton 1988, Stephan 1996, Collins 1998). More recently, as ideas and mechanisms of property have been introduced, science has pursued proprietary solutions, viewing research results as entities to be owned and controlled by their creators or licensed for others' use (Powell & Owen-Smith 1998). These cross-currents form the basis of the separate streams of public (often academic and/or basic) and proprietary (often industrial and/or applied) science by creating and maintaining distinctions about what forms of knowledge are produced and used, where, how, and by whom (Merton 1973; Dasgupta & David 1987, 1994).

Since the days of Curie, science has become more restless, transcending the former structural divides between public and proprietary science and spilling across their organizational cultures. Concerns over ownership have flowed into the university at the same time that priorities of discovery have migrated to commercial enterprises (Powell et al. 1996, Kleinman & Vallas 2001). As these previously separate realms of scientific practice and production intermingle with greater frequency, a growing consensus exists that not only are the distinctions between public and proprietary science in flux, particularly at leading research universities and innovative, technology-based firms, but so too are their fundamental definitions (Callon & Foray 1994, Kennedy 2003, Geiger 2004).

Although much has been written on the privatization and commercialization of public science, we see this transformation toward proprietization of science as marked more by complicated bidirectional currents. We posit that science is moving from a binary system of public versus proprietary science to more hybridized arrangements that combine elements of both public and private. These changes are driven in part by the very forces that once threatened Curie's own belief in the openness of public science—the ever-growing need for funding. But we also underscore the powerful effects of novel research techniques and agendas, as well as alternative organizational settings and new professional incentives that are shaping twenty-first century science.

The growing interdependencies between public and proprietary science, and the amalgamation of their respective institutional rules of the game, pose challenges for the immediate conduct of research as well as the long-term character of science (Gieryn 1983, Shapin 1994). Immediate ramifications are manifest, for example, in far-reaching claims to IP rights and the pursuit of income from licensing; the growth of partnerships and contracts between universities and industry; the proliferation of new boundary institutions, such as free-standing quasi-academic research centers; and the emergence of open source and open access models of scientific production and dissemination as both an extension of and a reaction to expanding IP rights. On the horizon, potential long-term implications of these institutional shifts include changes in the financial strategies and fiscal arrangements of universities; the research priorities of academic and industrial science sponsors and practitioners; the institutional relations between producers of scientific research and technological application; the professional practices and career paths of scientists; and the accessibility and availability of results to other potential users of scientific knowledge. Moreover, because these ripple effects undulate differently across research fields (e.g., life sciences, materials science, environmental science) as well as organizational types (e.g., public universities, private universities, for-profit industries), they threaten to fracture the scientific enterprise at the same time that they promise to transform it.

Some analysts view this transformation critically, believing that the integration of academic and industry logics threatens to upset the collegial norms of scientific practice (e.g., Washburn 2005). Others suggest that such views are based on rather mythical historical accounts of science (Vallas & Kleinman 2007), thus biasing our ability to assess objectively the structural and cultural changes associated with a broader transition to a knowledge economy (e.g., Powell & Snellman 2004). The ensuing debates over transformation versus transition have generated much interest in the causes and consequences of evolving IP rights in science.

IP Rights and Science

Robert Merton (1973) characterized science as a social project and a public enterprise guided by the ideals of communalism, universalism, disinterestedness, originality, and skepticism (CUDOS). These aspirations reflected the belief that science depended not on individual advances alone but also on the sharing and elaborating of information, ideas, and research (Barber 1953, Eisenberg 1987, Rai 1999). The goal is to generate new, fundamental knowledge that is widely available, but not necessarily immediately practical or profitable (Merton 1988). This model of public scientific production is based on the concept and provision of public goods, which are understood in the economic sense to be free and nonrival (Olson 1967) and premised on the assumption that producers of scientific knowledge will voluntarily relinquish control of the ideas they have developed and contribute them unconditionally to the "scientific commons" (Eisenberg & Nelson 2002, Nelson 2004).

The values associated with the conduct of science are neither inherent nor intrinsic; such motivations evolve from the institutional context in which inquiry is undertaken. Thus, although Merton's norms of CUDOS may reflect the shared historical view of many working scientists, particularly those in universities and government laboratories, they are not embraced as the guiding principles in commercial and industrial contexts. For scientists in the latter venue, science is a private endeavor, where practice has a stronger orientation toward short-term, applied outcomes and a greater focus on proprietary solutions, with rewards concentrated in financial returns and ownership rights (Heller & Eisenberg 1998). The proprietary science model operates on the normative belief that scientific production and innovation are best leveraged by the incentive of financial profit and protection from free riders (Demsetz 1967, Teece 1986). This incentive-based view assumes that scientists are motivated by the opportunity to retain exclusive control of their ideas, enabling them to reap returns from their research investments (Arrow 1962).

IP rights have traditionally represented the line of demarcation between the realms of communal and commercial research (Sampat 2003, David 2004). But recently this boundary has shifted and in many cases blurred. Stokes (1997) suggested that research in some fields has always had a more simultaneous dual use character, reflecting both scientific discovery and application. In response, Ziman (2000) argued that although, in theory, basic research may be produced in tandem with applied research, science today has a stronger orientation toward short-term, applied outcomes and a greater concern for commercial confidentiality and secrecy requirements. Even with the more "knowledge-plus" orientation of some disciplines and many U.S. universities, an approach firmly ensconced ever since the founding of the land-grant universities in the 1860s, many analysts believe that the contemporary scientific enterprise is undergoing a pronounced shift in which the norms of CUDOS must now coexist with the principles of PLACE—proprietary, local, authoritarian, commissioned, and expert science (Ziman 2000).

This recent joining of science and property is neither inevitable nor necessarily optimal. Only a few decades ago, the very idea of merging these concepts would have been considered unnatural. Numerous challenges and possibilities are prompted by this recombination. On the one hand, science-driven markets have been created, and thousands of companies are contributing to the scientific corpus at little cost to the taxpayer. Projects such as the Human Genome have been completed at record pace, and new job opportunities have enabled students and scientists alike to escape a discouraging academic labor market. On the other hand, the marketization of science has accelerated problems of conflict of interest, patent litigation, and IP disputes (Kennedy 2001, Jaffe & Lerner 2004).

Our task in this review is to gauge the structure and consequences of these changes, as heightened concerns surrounding IP ramify through public and proprietary science and reorganize their institutional relations. To accomplish this goal, we first describe the primary tools of IP rights as they have been introduced in the context of U.S. science. We then discuss the effects of these tools and accompanying changes in the definition of ownership on the reordering of relations between government, universities, and industry in the production of scientific knowledge. We review contemporary research on the consequences of a strong regime of IP, and suggest how the tools of IP influence the process of innovation.

THEORIES AND TOOLS OF INTELLECTUAL PROPERTY

Early objects of property were physical assets, such as land and cattle. The advent of publishing drove the origins of a knowledge economy and the rise of intangible forms of property, including creative and intellectual works. As the production of knowledge generated increasing value, in both social and economic terms, questions arose as to the appropriability of such works and the benefits derived from them. In Western societies, these questions were addressed through the attribution of IP rights (Carruthers & Ariovich 2004, Tuomi 2004).

Legal scholars use the term property in various ways depending on context. For example, definitions include "property interest as cognizable market advantage, property rule rather than liability rule, property privileges that include market alienability and sole dominion . . . " (Boyle 2003, p. 30). From these definitions, a bundle of property rights emerges that may include rights to sell, lend, and bequeath. We use the phrase property to refer primarily to the right of owners to exclude nonowners and the right to extract payment as protections against unwanted trespassing on and/or use of one's goods.

Intellectual rights became known as intellectual *property* rights in the late seventeenth and eighteenth centuries, when legal mechanisms were first being considered in an effort to break up London booksellers' monopolies over authored works and to ensure the future circulation of knowledge. Locke (1690) was one of the earliest writers to argue that ideas should be appropriated by those who originally produced them and thereafter protected for a period of time under the principle of natural law for the benefit of the public. He identified the trade-off between private ownership and the public domain, setting the stage for the enduring tension subsequently taken up by scholars concerned with the balance between individual incentive and collective benefit associated with the production and consumption of a shared resource (Hardin 1968; Rose 1993, 2003).

By the nineteenth century, the idea that a creator possessed natural rights to the products of his or her labor began to mesh with economic arguments about fairness, which maintained that the creators of intellectual works should be compensated by society with exclusive rights to exploit their creation for a limited period of time. The view that state protection was necessary has a long lineage. Hobbes [1651 (1968)], predating Locke (1690), had argued that there was nothing natural about a right. He believed that property rights should not be appropriated and negotiated by individuals through ad hoc institutions, but rather should be determined and monitored by a state body. Bentham (1839) went further, arguing that it was the state's duty not only to protect the inventor through formal means of appropriation, but also to create mechanisms to reward the inventor when others exploited his or her ideas. Bentham contended that it would be immoral to let society freely use the work of inventors without either the latter's consent or compensation (Andersen 2004, Ramello 2005).

These protean philosophical debates laid the foundation for economic and legal debates over how to promote and protect knowledge production. A cornerstone argument was built on the assumption that knowledge is nonrival, nonexcludable, and, most importantly, an indivisible public good. Consequently, inventors will not invest in the creation of new ideas—particularly risky knowledge—without the promise of individual profit and control, even when such investment would yield social benefit and progress (Nelson 1959, Arrow 1962, Nordhaus 1969, North 1981). This concern with market failure underscored a persistent problem in encouraging a socially optimal level of investment in the production of novel science.

Historically, governments have employed policies to ameliorate the impacts of market failure, including public patronage and property rights. The enduring challenge is how to minimize an innovation's social costs (e.g., tax dollars, transaction costs, information asymmetries, deadweight losses) while maximizing its social benefits (Wright 1983, David 1993). Nelson (1992) argues that scientific knowledge is a latent public good rather than a pure public good, as its public and private aspects are largely determined by government regulation. As such, the efficacy of IP turns on the question of balance: Too little protection can dwarf incentives for creation, and too much control can increase social costs associated with limited dissemination and restricted use (Sampat 2003, Frischmann & Lemley 2007).

We turn now to a review of the principal tools of IP—from patents and copyrights to trademarks and trade secrets—and their associated rights. These legal mechanisms for establishing ownership are at the core of debates over the evolving relationship between science and property. These tools may vary in terms of subject matter protected, exclusivity of rights granted, attribution criteria used, and incentives conferred, but they share the critical function of granting the inventor rights over the exploitation of an idea and a certain amount of market control as owner.

Our discussion is largely limited to the United States, and we focus on patents, which have most profoundly influenced the changing nature of knowledge production and shifting patterns of organization in U.S. science.

Patents

In the United States, patent rights are implicit in the federal Constitution, which empowers Congress "to promote the progress of science and useful arts, by securing for limited times to authors and inventors the exclusive right to their respective writings and discoveries" (Article I, Section 8). As established in the patent law of 1793, Section 101 of the U.S. patent code originally limited patent eligibility to "inventions" of a "new and useful process, machine, manufacture, or composition of matter" that has been created, changed, or altered by humans (35 USC § 101).[1] These are the subjects of utility patents, the most common type of patent. The U.S. Patent and Trademark Office (USPTO) gradually extended patent law over the course of the nineteenth and twentieth centuries to cover an increasingly wide array of inventions and discoveries that were previously considered unpatentable. This expansion resulted in the codification of two other primary patent types: design patents and plant patents.[2]

To acquire a patent in any of these three basic categories, inventors must submit an application demonstrating three statutory criteria: (*a*) usefulness, which mandates that the invention have some application and not be simply an end in and of itself (35 USC § 101); (*b*) novelty, which calls for evidence that the invention represents an advancement beyond existing ideas (35 USC § 102); and (*c*) nonobviousness, which requires that any advancement be significant and nontrivial (35 USC § 103). These criteria were intended to ensure that society only bears the social costs of patents for inventions that represent significant technical or scientific departures from existing entities in the public domain (Walterscheid 1998, Barton 2003).

Upon application, inventors are required by U.S. patent law to disclose sufficient technical information enabling skilled practitioners to recreate the invention. The application of that information to new products may be restricted during the patent term to varying extents. Unlike most countries, the United States does not provide research exceptions to patent rights that would allow scientists to further advance knowledge about a patented invention (Samuelson 2003). In exchange for the creation and disclosure of a new idea, successful applicants gain the right to exclude others from commercially exploiting their idea for a specified period of time. When first introduced into law, patents had a life cycle of only seven years. By 1994, in compliance with the Trade-Related Aspects of Intellectual Property (TRIPS) agreement,[3] the United States adopted the longest statutory period allowed: 20 years for utility and plant patents (an extension of three years from the previous patent term of 17 years) and 14 years for design patents. For these specified periods, a patent holder enjoys exclusivity, preventing others from making, using, selling, offering for sale, or importing his/her invention

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[1] The North American patenting system hinges on the concept of utility, which can be applied either to invention or to discovery. By contrast, the European system of patenting is based on the distinction between invention and discovery, allowing only the former to be subject to patentability [Article 52 (2), European Patent Convention].

[2] In 1842, Congress extended the reach of patent statute to cover "new, original, and ornamental design for an article of manufacture" (design patents) (35 USC § 171). The Plant Patent Act of 1930 extended patent protection to "new varieties of asexually reproducing plants" (35 USC § 161–164).

[3] TRIPS was created in 1994 as part of the Uruguay Round of GATT (General Agreement on Tariffs and Trade), with the goal of harmonizing national laws on IP rights. Under TRIPS, 130 signatories to GATT have agreed to enact national laws that establish minimum substantive standards of IP rights protection. The TRIPS agreement covers copyright and related rights as well as trademarks, industrial designs, patents (including the protection of pharmaceutical products, plant varieties, and computer programs), and undisclosed information including trade secrets and test data.

without paying what often amount to hefty rents (35 USC § 133). Only when a patent expires does the idea join the public domain where others can freely use the idea.

In addition to extensions in the period of exclusivity, the past 200 years have also witnessed consequential shifts in the nature of material patents protect. Based on the original intent of Section 101, a number of categories—including facts or pure ideas, natural laws, printed matter, pure mathematical algorithms, formulae or equations, and business methods—were all excluded from the realm of patentability on the grounds that they are objects of natural phenomena, not human productivity. Because these elements of nature were already in the public domain, allowing their commodification through property rights was not considered socially useful. The commitment to ensuring that they remained freely available was sustained in several landmark court cases in the late nineteenth and early twentieth centuries. *O'Reilly v. Morse* (1853) ruled against granting broad rights to a law of nature (the use of power of electric or galvanic current) beyond an immediate and particular application (the telegraph). In *Funk Brothers v. Kalo Inoculant* (1948), the Supreme Court held that a synergistic combination of bacteria for enriching farm soil was a nonpatentable phenomenon of nature. *Brenner v. Manson* (1966) determined that only end products are patentable, arguing that other inventions or innovations—such as chemical processing methods—should stay in the public domain. *Gottschalk v. Benson* (1972) concluded that converting numerical data into binary code in any type of general-purpose digital computer was unpatentable because it was "so abstract and sweeping" that it represented a fundamental idea rather than an inventive process (Dreyfuss 2004, Andrews et al. 2006).

These cases emphasized a clear distinction between downstream products as patent eligible and upstream principles and processes of nature, raw materials, and basic ideas of research belonging to the public domain. More recent cases, however, have overturned these once conventional views, extending patentability to previously disallowed areas, including "non-naturally occurring non-human multicellular living organisms, including animals" (USPTO 1987) (e.g., the oncomouse at Harvard), as well as mathematical algorithms and methods underlying even the most basic software programs and Internet applications in computer sciences. In 1980, in *Diamond v. Chakrabarty*, the Supreme Court distinguished between a product of nature and a patentable genetically modified bacterium cell that did not exist in nature, ruling that live, human-made, or genetically modified microorganisms are in fact patentable (Eisenberg 1987, Jaenischen 1995). In *Diamond v. Diehr* and *Diamond v. Bradley*, both decided in 1981, the Supreme Court allowed the patenting of software algorithms (Merges 1999). In the 1998 case of *State Street Bank v. Signature Financial Group*, a federal court approved the patent on Signature's software system for evaluating and managing mutual funds, thus allowing the patentability of business processes. This ruling laid the foundation for patents on such business methods as Amazon.com's one-click and Priceline.com's reverse auction (Graham & Mowery 2005). Taken together, these decisions represent not only a shift in the parameters of what qualifies as patentable subject matter, but also a step up the ladder in terms of when patentability is allowed in the innovation chain. By affording the patenting of raw materials and basic tools, core features of the basic research enterprise became subject to ownership claims (Rai 2001, Kesselheim & Avorn 2005).

The increase in patenting activity led to legislative and judicial steps to respond to growing IP claims. In 1982, Congress created the Court of Appeals for the Federal Circuit (CAFC), with nationwide jurisdiction for a variety of subject areas, including appeals on cases involving patent infringement and validity. As a unified judicial authority, CAFC was intended to bring uniformity and expertise to patent decisions. In reality, CAFC is widely recognized as having turned out to be a propatent apparatus, bolstering, rather than monitoring, the intensification of patenting (Merges 1992, Henderson et al. 1998, Jaffe & Lerner 2004). Among the many changes CAFC introduced was a new and extended interpretation of the "doctrine of equivalents," which provided patent holders with stronger protection by broadening their prohibitory rights (Jaffe 2000). Above all, according to most observers, CAFC eased the "nonobviousness" criterion, leaving many patent attorneys to declare the obviousness defense dead (Krastiner 1991).[4] Following on the heels of the 1980 *Diamond v. Chakrabarty* decision and the 1987 USPTO ruling that opened up the domain of patentability to any biological material that required human intervention, the regulatory environment of CAFC created fertile ground for patents on discoveries in genetics and biotechnology, including patents on basic research tools and genes. This expansion consolidated the U.S. view of an equivalency between discovery and invention as the non-natural aspect of such inventions stemmed from their human-made attributes, even when the properties they reveal are natural ones (Coriat & Orsi 2002). Many scientists and analysts worry that such potentially broad property claims could stymie future scientific production as well as stifle technological innovation.

Copyrights

Similar to patents, copyright is meant to stimulate innovation by guaranteeing creators the opportunity to exploit the expression of their ideas in the marketplace. Under the Copyright Act (1976), copyright law applies to works of authorship—including literary, dramatic, musical, artistic, and certain other intellectual works (17 USC § 101). Copyright grants exclusive rights to the author to reproduce the work, as well as some form of exclusive right to modify, disseminate, and publicly perform or display the work (17 USC § 106).

Unlike patents, copyright protection kicks in spontaneously, without application or examination but upon fixation of the authored work in a tangible medium (17 USC § 101). Because protection is extended on the basis of a "minimal originality" criterion, copyright only shelters the original expression found in the work at the time of fixation (17 USC § 902). This means that, in contrast to patent law, copyright law is designed to deter direct copying of the author's initial and particular articulation of any set of ideas or significant fragment thereof. Thus, copyright theoretically allows the underlying individual ideas themselves to be freely reused in other forms or representations even during the period of protection. The only exception is that authors retain exclusive rights to prepare derivative works based upon the copyrighted work (17 USC § 106).

By allowing appropriation of the foundational ideas and functional attributes of a work, copyright law grants fewer powers of control to the author over his/her ideas than patent law extends to the inventor. Copyright law does offer longer—and ever expanding—periods of protection than patents do, however. The duration of copyright protection in the United States was originally scheduled as a 14-year term, but it expanded incrementally to 28 years and potentially to well over 100 years (Lessig 2001). The 1998 Sonny Bono Copyright Term Extension Act extended copyright periods to life of the author plus 70 years, and for work-for-hire to 95 years postpublication (these terms apply to works fixed after December 31, 1977) (Samuelson 2003).

Although copyright law is not the primary IP arrangement operating in science and technology, copyright presides over three critical spheres of activity. First, although

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[4] In a recent unanimous decision in the case of *KSR Int'l Co. v. Teleflex Inc.* (April 30, 2007), the Supreme Court overturned the CAFC's "teaching-suggestion-motivation" (TSM) test for finding a claimed invention obvious. The Court's decision calls into question the validity of hundreds of thousands of claims in issued patents and will likely lead to a dramatic tightening of the nonobviousness clause.

software development has traditionally been the purview of copyright law, patent law has permeated this arena over the past two decades (Nalley 2000). The merging of these two regimes has added both complication and complementarity to the protection and, consequently, the application of software innovations as tools of scientific research (Graham & Mowery 2005, Menell & Scotchmer 2007).

Second, copyright law has always covered scientific texts (i.e., reports, articles). In the era of digital infrastructure and a culture of electronic publishing, however, new questions of information management and ownership are testing old copyright rules governing access to, as well as free and fair use of, the growing array of electronic journals used by scientists in their daily work. Most notable here is the 1998 Digital Millennium Copyright Act, which updated the Copyright Act (17 USC) to meet the demands of the global digital era and to conform U.S. law to the requirements of the World Intellectual Property Organization (1996). Among its many provisions, the act imposes rules prohibiting the circumvention of technological measures to protect copyright, heightens the penalties for copyright infringement on the Internet, and provides an update of the rules and procedures regarding archival preservation. Prior to 1998, copyright law made clear exceptions in "fair use" and the right of "first sale" for educational purposes (Lessig 2003).

Lastly, given the burgeoning role of collaborative, synthetic, and cyber-based science (Rhoten & Parker 2004, Rhoten & Pfirman 2007), copyright law offers some weak—but strengthening—protection to the creation, compilation, and dissemination of databases. Although discreet data within a database are generally considered to represent unprotectable facts, the selection and arrangement of those data—in essence, the authorship of the database—may be copyrightable when their assemblage is not dictated by their structure or other technical constraints (Burk 2007). Laws such as the 1996 European Union Directive on the legal protection of databases (Directive 96/9/EC) are significant in this regard. In addition to harmonizing EU member state rules about copyright protection for the selection and arrangement of data in databases, the EU Directive also establishes new rules of IP protection. Not only do database creators in the EU now have 15 years of exclusive rights to control the extraction and reuse of data from their databases, any further investments warrant renewed periods of protection. Such provisions seemingly allow database makers and publishers to enjoy perpetual protection as long as they update or maintain databases. Several bills to provide similar EU-style database protection have been introduced but not yet passed in the U.S. Congress (Reichman & Uhlir 1999, Samuelson 2003). Thus, like patent law, copyright law has expanded considerably in the past century, reaching across new territories and further upstream.

Trade Secrets and Trademarks

Whereas a trade secret is "a formula, pattern, compilation, program device, method, technique, or process" that derives independent economic value from being generally not known (UTSA, §1(4) 1979), a trademark is "any word, name, symbol or device, or any combination thereof" that an inventor uses to identify and distinguish his or her goods or services (15 USC § 1127). Like other IP rights mechanisms, trade secrets and trademarks can also be seen as legal instruments designed to promote innovation, albeit more indirectly than the others. In lieu of granting exclusive ownership over an invention for a limited period of time, trade secrets offer potentially ongoing concealment of the information or know-how pertaining to the production of that invention. Similarly, trademarks indefinitely uphold the reputation and integrity of the invention in the marketplace (Landes & Posner 1987, Menell 1999).

In contrast to the often excessive lead time and considerable expense required to secure patents, the theoretically permanent protection that trade secrets and trademarks offer can prompt some inventors to prefer these rights. Moreover, in contrast to patents, wherein technical information must be disclosed to secure protection, trade secret law carries a nondisclosure clause that helps avoid potential spillover effects by preventing appropriation of underlying knowledge (Bhattacharya & Guriev 2006). Trade secrecy's advantages, however, carry certain risks. Although legal steps can be taken to guard against acts of malfeasance such as industrial espionage or breach of contract, the holder of a trade secret cannot exclude anyone from using his/her knowledge if it is independently discovered or legally acquired through either accidental disclosure or reverse engineering (Friedman et al. 1991). Similarly, trademark law provides an innovator with legally enforceable rights against others' adoption of similar identifying marks, but it confers no privileges to him or her over the underlying innovation, which remains free for anyone to copy and/or sell under a different trademark.

In many scientific, technological, and cultural fields, particularly those in which product innovation is both rapid and cumulative and/or in which inventors are able to conceal their innovation from accidental disclosure and reverse engineering, trade secrets are the primary means of IP protection (Levin et al. 1987, Bulut & Moschini 2006). In high-velocity industries patent protection is of little value, as the speed of the product cycle laps that of the patent office. Similarly, by increasing customer recognition, the licensing of trademarks has become a major profit lever for many scientific firms as well as publishers (Ramello 2006). For example, the publishers Thomson, Reed Elsevier, and Wolters Kluwer now trademark the brand names of all journals in their catalogs. By successfully using trademarks to establish a strong brand identity for their product lines, these big three have also subsequently achieved a high level of control over the international journal market.

Summary

Patents require novelty, copyrights necessitate originality, trade secrets mandate confidentiality, and trademarks compel identity. Over time, the changes in IP protection reflect a pattern: new objects and subjects of property, a shifting locus of enforcement, and longer terms of protection. The implications of this trend bear considerably on the course of science, both positively and negatively. First, expanded IP rights continue to serve utilitarian logics, benefiting both science and society through principles of appropriation, exclusivity, and incentive. Moreover, with the exception of trade secrets, the tools of IP continue to encourage, or require, a certain level of information disclosure, ensuring some dissemination even while sheltering the invention or innovation. Finally, although statutory periods of protection have been lengthened over the past two centuries, U.S. IP (again, trade secrets excepted) sustains traditional values of unrestricted access and sharing of knowledge by maintaining that restrictions on proprietary control be repealed at the end of specified periods.

On the debit side, however, the focus of IP rights has moved further and further upstream over the past century, to the point of now protecting living organisms, basic research tools, and procedural methods as well as mathematical algorithms, databases, and journal articles. Not only were all these items once considered outside the purview of IP, they also represent areas that encompass the most important scientific discoveries of recent decades, as well as some of the most essential raw materials necessary to scientific practice in future years. This incursion may have suboptimal consequences for science from a societal perspective. For example, difficulties in bargaining between upstream and downstream researchers could result in delays in research, a deceleration of innovation, and the delivery of fewer and more costly products to the market (Rai 1999, Shapiro 2001, Boyle 2003). Consequently, although incentives for IP protection are firmly in place and dangers of free riding mitigated, there are new threats to innovation caused by the proliferation of ownership claims and, consequentially, the proprietization of science. We turn now to research on the effects of this new expanded IP regime on the structure and culture of U.S. science.

THE EFFECTS OF EXPANDING IP RIGHTS ON THE LANDSCAPE OF U.S. SCIENCE

The spheres of public and proprietary science, representing the stocks and flows of ideas, have long existed in tension with one another, in a state of fragile equilibrium. Dasgupta & David (1994) made the powerful point that what separated these two realms was neither the law nor the organization of science but the differing normative orientations of these two realms. Rosenberg & Nelson (1994) noted that science in the United States has always had a more practical character than its European counterparts, thus opening the door for proprietary interests to comingle with the public goals of research and development. But after decades of relative stability, former divisions between public and proprietary science have given way to greater intersections between the two spheres and prompted the emergence of practices and organizational arrangements that blend the two domains.

In the aftermath of World War II, U.S. science policy recognized the critical role of the physical and social sciences in the war effort and embraced strong public support for research: "[W]e are entering a period when science needs and deserves increased support from public funds . . . . As long as [colleges, universities, and research centers] are vigorous and healthy and their scientists are free to pursue the truth wherever it may lead, there will be a flow of new scientific knowledge to those who can apply it" (Bush 1945, p. 12). Science in this era enjoyed government patronage in return for the priority of discovery and the disclosure of results—an institutional arrangement between the government and universities referred to as America's "social contract for science." This institutional arrangement was fueled by federal grants from agencies such as the National Institutes of Health or the National Science Foundation, awarded on the basis of peer review, which helped separate personal and financial interests from scientific considerations (Guston 2000).

During this halcyon era of "big science" (Gallison & Hevly 1994), the federal government's share of funding for all U.S. research and development never fell below 50% (Natl. Sci. Board 2006, their table 4.5).[5] Moreover, the government generally opted to place the results of publicly funded scientific research in the public domain and make them freely available to academic researchers or other parties, without requiring licensing rights. The combination of ample funding and open access was consistent with the Mertonian view of communal public science. This era came to a crashing halt in the 1980s, however.

Commercializing Public Science: New Partnerships between University and Industry

The theme of declining U.S. competitiveness, particularly in high-tech markets, echoed throughout the 1980s. Although many reasons were proffered, two common rationales were the failure to move ideas from the lab bench into production, and, paradoxically, the ease of access to U.S. research by foreign firms (Dertouzos et al. 1989, Nelson & Wright 1994). A series of new government policies pursued a shift from a model of science based on the philosophy of the public domain to one leaning toward notions of proprietary ownership and control. These policies represented a deliberate intention to alter the landscape of scientific production and innovation.

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[5] It was not until 1979 that the federal share of R&D funding in the United States first fell below 50%, where it has since remained, reaching as low as 24.9% in 2000 and climbing to 39.9% in 2004 (Natl. Sci. Board 2006).

A key institutional reconfiguration involved new partnerships between industry and universities. Federal policies such as the Bayh-Dole Act of 1980, the Stevenson-Wydler Technology Innovation Act of 1980, and the Economic Recovery Tax Act of 1981 altered university-industry relations by allowing universities to retain the property rights from innovations arising from federally funded research projects and mandating higher education's participation in technology transfer. Empowered with new patenting capabilities, universities were assigned a new role in the capital accumulation process. Simultaneously, several other factors accelerated partnerships between science and industry, notably retrenchment in financial support for higher education (Slaughter & Rhoades 1996), dramatic technological breakthroughs that fostered the emergence of new industries in the biomedical and computer science fields, and the growth of the venture capital industry (Gompers & Lerner 1999).

Debates remain about the degree to which these changes represent a fundamental shift in the institutional norms and logics of university science, away from discovery-oriented research and toward market-driven applications. Additionally, the extent of the influence of policy initiatives and technological innovation remains unclear. Regardless, university patents began to mushroom (Mowery et al. 2004). Before 1980, U.S. universities generated fewer than 250 patents per year. By 1991, that number exceeded 1000, and reached 2500 in 1998 before leveling off. To be sure, the lion's share of this patenting activity came from a very select group of universities (Mowery et al. 1999, Powell et al. 2007). Empirical evidence suggests that as rewards from these universities' involvement in proprietary science feed back and enable further investments, this pattern of patent concentration intensifies an already strong stratification system among research institutions and disciplines and in scientific careers (Owen-Smith 2003). Beyond altering the academic landscape, some authors also contend, the patent upsurge resulted in an overall decline in their quality, i.e., declining impact measured by citations (Henderson et al. 1998). Others argue that, over time, universities have learned to patent more effectively and build productive relations with industrial partners (Mowery et al. 2002, Owen-Smith & Powell 2003).

As new relations were forged between research universities and technology-based firms, individual scientists began to act as amphibious creatures, moving back and forth as consultants and advisors and as founders of university spin-off firms. Studies have demonstrated that by the late 1980s more than half of the life sciences faculty in the United States had consulted for industry and that approximately 7% held equity in a company that was performing work related to their research (Blumenthal 2003). Moreover, as individuals from a select number of universities traverse the former divides between university and industry science, they often receive both federal research support and industry funding (Blumenthal et al. 1996). These trends have had a notable impact on the allocation of professional rewards and the structure of scientific careers, creating a new fault line for stratification (Whittington & Smith-Doerr 2005, Stuart & Ding 2006).

Proprietary-Public Science: New Models of Corporate Science

As the relations between public and proprietary science shifted, the nature of industrial R&D was also changing. Beginning in the 1980s, many of the defining characteristics of most large twentieth century corporations, including job security, a hierarchical division of labor, and geographical stability, began to unravel (Powell 2001). Driven by an increased desire for flexibility in manufacturing, the challenges of inexpensive foreign labor, and pressures from Wall Street to meet demands for quarterly profits and growth, companies began to shrink their work forces and make employment much more contingent and flexible. Broadly speaking, these efforts took two routes. The common low road of sweating labor through outsourcing, offshoring production, and lower wages has had limited impact, thus far, on the world of science and technology. The higher road of more porous organizational boundaries, greater reliance on external sources of R&D, and new collaborative forms of production has, in contrast, introduced a "network logic of production" into a range of technologically sophisticated industries, from biotechnology to semiconductors, design and apparel, and telecommunications (Powell 1990).

This new logic of production involved a transformation in the standard recipes for jobs, organizations, and industries. The change was simultaneously structural and cultural. The structural features included (*a*) shorter product cycles, (*b*) markets in which end users become deeply integrated into the production process, and (*c*) fast-paced learning races with both competitors and collaborators. These developments led participants to turn to new modes of production, just-in-time delivery, and extensive use of alliances to access information and resources. These changes were mutually reinforcing, as reducing internal hierarchy while relying on external sources of expertise pushed organizations to revamp their communication systems and reward structures. These developments were most pronounced in industrial settings where knowledge was developing rapidly and its sources were widely distributed (Powell et al. 1996). In these fields, turning to cheap outsourcing or hollowing out internal capability proved fatal. Instead, companies learned to adjust to sharing information with competitors (von Hippel 1988), developing tools and routines for "studied trust," that is, learning how to work with other parties while carefully monitoring such efforts (Sabel 1994), and deepening their "absorptive capacity" (Cohen & Levinthal 1990). Put differently, to understand the news, companies have to have a hand in making it.

These structural changes, in turn, have pronounced relational and cultural effects. In leading-edge industries, scientists in private sector firms now make significant contributions to the corpus of public science (Evans & Powell 2007). These firms are also tightly coupled with university researchers, government labs, and nonprofit research institutes (Mowery 1999, Merrill & Cooper 1999). Culturally, the accompanying organizational arrangements transform the workplace by altering discourse around what is considered public and private, as well as principles of exchange. In a select but growing number of companies, from Genentech to Google to Nokia, the corporate workplace has become the new home, no longer a place severed from private life, but a place where work and play and even community become intertwined. These changes are important as they recast definitions of exchange and reciprocity, private property and public goods, and forms of production. Indeed, some question how the old-fashioned research university will continue to attract the best research minds in the face of employment options in these more relational corporate settings (Kleinman & Vallas 2001).

These new industrial settings are both enhanced and sustained by the growing interdisciplinarity of work (Gibbons et al. 1994), and a focus on multiple skills deployed in a world of fast-changing, short-term projects (Grabher 2002). Computing and telecommunications networks facilitate mobility across topics and projects, which in turn enable more rapid information decentralization and dissemination. Benkler (2004, p. 1110; 2006, p. 63) dubs this new form of information access and sharing "commons-based production." Below, we explore how these forms of work are possibly transcending the older distinction between public science and private science.

Public-Proprietary Science: Efforts to Recover Openness

As IP rights have expanded and strengthened, a number of analysts have asked whether the cumulative consequences are straining the efficiency and effectiveness of the scientific enterprise (Natl. Res. Counc. 1997, 1999, 2004). Some fear that enhanced IP rights, particularly at early stages of research, may be hindering the circulation of scientific knowledge and thus multiplying the social costs of innovation (Heller & Eisenberg 1998, Rai & Eisenberg 2003, Reichman & Uhlir 2003). Efforts to reverse the trend toward proprietization have generated initiatives to restore, preserve, and/or extend historically communal values of public science. These efforts have ranged from rigorous examinations of IP law to the formation of new paradigms of operation, and have been variably identified under the motives of "defending the public domain" (Lange 1981, Litman 1990) and "creating a new commons" (Benkler 2002). Although these terms vary in their theoretical specifications, they share the common goal of representing the "opposite of property" or the "instantiation of intellectual property's 'outside'" (Boyle 2003, p. 64).

Within these efforts, the open source and open access movements are of particular interest, as both actively resist the extension of monopoly and control through an emphasis on sharing information. Often originating outside of formal organizations, open source initiatives have facilitated the development of new models of production and innovation (Feller et al. 2005, von Hippel 2005, Benkler 2006). Simultaneously, the public and nonprofit sectors have called for alternative approaches dedicated to public knowledge redistribution and dissemination (Esanu & Uhlir 2004, Willinsky 2006). Whereas the first group of activities is more economically motivated, often seeking to circumvent current bottlenecks and overcome obstacles to technological progress, the second can be considered more political in its motivations, working to reduce barriers to entry and democratize knowledge.

The open source movement is based on two innovations: one legal, the other organizational. The first innovation, originally rooted in the free software movement and which much of the open source software movement has adopted, is known as the GNU General Public License (GPL).[6] Essentially, GPL practices allow anyone possessing a copy of free (or open) software the right to use that software, access and alter its source code, and distribute modified or unmodified versions at no cost, provided that subsequent versions comply with the terms of the GPL (see the GNU Library General Public License, available at **http://www.gnu.org/copyleft/library.txt**). Not all open source licenses go as far as the GPL "copyleft" model, limiting requirements on users and modifiers to practices of proper attribution.

The second innovation is steeped in a logic of strength in numbers and the wisdom of crowds. Open source software has primarily depended on the distributed work of thousands of volunteer developers, testers, and users. These volunteers have no proprietary claim but are motivated by a strong personal stake in the ideas, processes, and innovations (Lee & Cole 2003, Lakhani & von Hippel 2003).

Open source software communities have shown that implementing norms of sharing and disclosure in a distributed peer-to-peer setting can result in the creation of complex technological products that approach, and sometimes rival, the scope and quality of similar products produced by proprietary efforts (Feller et al. 2005, Lakhani et al. 2007). Open source software alternatives have achieved a significant or greater market share

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[6] Free and open software have similar licensing practices but differ philosophically in that open source emphasizes the practical benefits, whereas free software focuses on a moral commitment to the practices GPL allows (von Hippel & von Krogh 2003).

than proprietary software in a number of areas. The often cited example is the Linux Apache web server versus Microsoft's Internet Information Services (IIS), with market shares in March 2007 of 59% and 31%, respectively (Netcraft 2007).

The diffusion of open source projects has been attributed to development speed and to the reliability, portability, and scalability of the resulting software. In turn, these characteristics are driven by both open inspection and contributions of numerous interested individuals (Raymond 2001, Weber 2004, MacCormack et al. 2006).

Whether this model is limited to software or could be exported to other fields of scientific production and technological innovation is an open question (Lerner & Tirole 2002, David 2004). Academic analogs to open source models are cropping up in scientific encyclopedias (Giles 2005) and in various biological fields (Rai 2005). As computing and biology converge, there are signs that "in the same way programmers find bugs and write patches, biologists look for proteins ('targets') and select chemicals ('drug candidates') that bind to them and affect their behavior in desirable ways" (Maurer et al. 2004). Moreover, open source biology users can own the patents to their creations that emerge but are not able to hinder others from using the original shared information to develop similar products. Evidence of successful open source biology is appearing in initiatives such as Ensemble Genome Browser, the National Center for Biotechnology Information, the Synaptic Leap, and the Tropical Disease Initiative (Kepler et al. 2006).

Open source represents a sharply different approach to IP, but viewing it strictly from a business perspective elides recognition of open source's close connections to longstanding traditions of open science and the associated rewards of peer recognition and acclaim (Raymond 2001). Von Hippel & von Krogh (2003, p. 209) argue that the open source phenomenon demonstrates an "exemplar of a compound of 'private-collective' model of innovation" that contains elements of both proprietary and public models of knowledge production, which may offer society the best of both worlds under many conditions. But such acclaim aside, it is important to recognize that open source models depend heavily on social authority, whereby particular individuals exert substantial direction over production by dent of their charisma and/or skills (Weber 2004). But the expression and execution of this authority are more ex post than ex ante project development (Lakhani & Wolf 2005). The sociologically intriguing feature of the open source community is the viability of a gift economy based on multiple currencies of reward and multiple status orders.

Alongside open source, there has also been a revival of the image of the knowledge commons by contemporary open access social movements. Most commonly associated with publications, open access science has focused on making peer-reviewed, online research and scholarship freely accessible to a broader population. A number of publishers have now begun to allow authors to contribute their published work to open institutional repositories or eprint archives at their institutions. Some journals make their contents available after a period of months or years. Moreover, large archives such as High Wire Press provide free access to back issues, and approximately 2000 or so open access journals (5% of current peer-reviewed titles) make their content immediately available at no charge (Willinsky 2005). Despite growth in the number of research papers available, it is estimated that only approximately 20% of papers published annually are open access, principally through author self-archiving in institutional archives. Research indicates, however, that open access papers are cited more often than password protected articles, even when controlling for other predictive factors (Eysenbach 2006).

Although the phenomenon has not been studied widely, social networks that emphasize the virtues of respecting a permanent commons in human and plant genetic material are becoming more vocal (e.g., the "no patents on life" movement). The open access movement has been extended to research data and influenced a range of important scientific initiatives, from the Human Genome Project to more recent decisions by private industry (such as Novartis, which made its results of a genomic analysis of type 2 diabetes freely available on the Internet) (Pincock 2007). The willingness of some private firms in the patent-oriented industries of biotechnology and biomedicine to contribute to the public domain provides further evidence that even commercial entities are concerned that a stringent property rights regime may create barriers to subsequent research and product development (Rai & Eisenberg 2003). The identified need for a viable public domain in the area of commercial agricultural research also motivated the negotiation of the International Treaty on Plant Genetic Resources (2001), which created an agricultural commons and a protected public domain in 35 of the world's most important crop and forage plants.

Although the modern state continues to be the primary locus of property enforcement, the pressure for enhanced property rights has expanded from the national to the supranational level in the wake of global markets (Carruthers & Ariovich 2004). The relationship between IP and international trade has emerged as one of the most controversial issues in global negotiations, with the debate focusing primarily on the implications of the TRIPS agreement for the global economy in general and for developing countries in particular (Srinivasan 1998, Maskus & Reichman 2004). The TRIPS agreement was premised on the goal of harmonizing global IP rights laws. By establishing high minimum standards from the outset (with some flexibility in their application), TRIPS has progressed toward global IP norms. In terms of efficiency, this standardization represents a considerable accomplishment (Sherwood 1993). With respect to global justice, the adoption of U.S.-style intellectual property laws is viewed as disadvantageous for developing countries, particularly where patents and exclusive licenses apply to both basic and applied research (Hamilton 1997, Sell 2002).

For developing countries, a key consequence in adopting TRIPS is an increased restriction on access to essential medicines, including AIDS drugs and other patented pharmaceuticals and products. Prior to TRIPS, developing countries could create generic drugs (or other products) using technologies and discoveries now covered by patents. Under TRIPS, however, they are limited by the agreement's 20-year patent term. The potential impacts are enormous, as access to patented medicines comes at a very high price. For example, Bristol-Myers Squibb sold the patented antiretroviral drug, d4T, for more than $1600 per patient per year in South Africa, while the generic form of this drug was sold for $55 per patient per year.[7] In February 2003, the United Nations Development Program (UNDP) released a report that was highly critical of the agreement and urged developing countries to "explore alternative mechanisms for protecting intellectual property rights" (UNDP 2003, p. 11). Increasingly broad and vocal consortiums of nongovernmental actors are challenging the legitimacy of TRIPS, focusing primarily on provisions of the treaty that affect public health, human rights, biodiversity, and plant genetic resources (Helfer 2004). Under this flag, global open access movements to recognize and safeguard those traditionally excluded from

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[7] Developing countries were able to negotiate certain exceptions. Article 31 permits any World Trade Organizations (WTO) member country to license patents to domestic businesses in order to allow countries to manufacture low-cost generic drugs in the face of national health crises or in response to other national emergencies. However, this compulsory licensing exception is limited to the manufacture of generic products for domestic use, thereby imposing hardship on member countries lacking the infrastructure to manufacture generics and also disallowing member countries from exporting generic drugs to another country in need. In 2003, the WTO General Council added flexibility to Article 31, enabling member countries to export pharmaceutical products manufactured under a compulsory license to WTO member countries that do not have the capacity to manufacture the drugs (Lieberwitz 2005).

or disadvantaged by current IP regimes have pushed the question of proprietization of scientific knowledge into the broader realm of international policymaking and fundamental questions of human rights, environmental sustainability, and societal development.

The line between public and proprietary science is just as porous in open source and open access initiatives as it is with new corporate models of science. Consequently, these new organizational forms' place in the older dichotomy of public domain and IP remains unclear. In both instances, the once separate norms and practices of public versus proprietary science are giving way to a single, increasingly interconnected field of public-proprietary science—in Stark's (2001) terms, a heterarchy—marked by multiple anomalies, tensions, and ironies. Just as IP law can be viewed as an impoverishment of the public domain, openness and access can dampen incentives that allow innovations to be created and incorporated into the public domain (Samuelson 2003). Somehow, balance needs to be struck between traditional logics of public science and more recent regimes of proprietary science if new hybrid models are to flourish. We examine this balance in the next section.

CURRENT RESEARCH ON CONSEQUENCES FOR SCIENCE OF A STRONG IP RIGHTS REGIME

The predominant lines of research on the consequences of expanding IP rights for contemporary science draw on three themes: (*a*) policy frameworks (Cole 1993, Cohen & Noll 1994, Leyesdorff & Etzkowitz 1996); (*b*) academic capitalism (Slaughter & Leslie 1997, Kleinman & Vallas 2001); and (*c*) academic entrepreneurship (Zucker et al. 1998, Shane 2004). Each of these rubrics provides useful, albeit partial, accounts of the relationship between IP and the transformation of science. Policy-focused work attends to government-industry relations, whereas academic capitalism arguments contend federal policies have promoted an embrace between university and industry, and the entrepreneurship literature highlights innovative faculty, institutions, and start-up firms. We take up each strand of work in turn, considering its contributions and limitations.

Policy Frameworks

The past two decades have witnessed an ongoing debate in the United States over the effect of federal policies, such as the Bayh-Dole Act, on the incursion of patenting in science. At the heart of the debate are two interrelated questions: (*a*) whether the expansion of a patenting culture undermines the norms of open science, and (*b*) whether the intensification of patenting has accelerated or retarded the development of basic and commercial research.

Proponents of Bayh-Dole argue that the act was necessary because prior to 1980 many federally funded discoveries were not commercialized and the act provided an impetus for federal technology transfer (Cole 1993, *Economist* 2002). Proponents of a "triple helix" between government, industry, and universities argued for a new set of relationships that would catalyze opportunities for both proprietary and public science. The Bayh-Dole legislation authorized universities to pursue technology transfer and enabled active involvement in patenting university research. University technology transfer offices popped up like mushrooms after a good rain, patenting and licensing increased, and considerable revenues were generated. Nonetheless, most technology licensing offices barely break even, fewer than 20 universities garner significant returns to licensing, and only a handful of licenses on any campus generate more than $1 million (Trune & Goslin 1998, Powell et al. 2007).

Critics of Bayh-Dole also question the theoretical and empirical assumptions on which the act was based and argue that the use of patents in such areas as basic biological research frustrate information sharing in the research community (Eisenberg 1996). Former Stanford University president and editor of *Science*, Donald Kennedy (2005, p. 1375), observed: "To those who had worried about technology transfer, it's a huge success. To others, who expressed concern about university/corporate relations or mourn the enclosure of the scientific 'knowledge commons,' it looks more like a bad deal." Leaf & Burke (2005), in a much-discussed *Fortune* article, argue that the strong property orientation ushered in by Bayh-Dole has hindered productive university-industry relations. Sampat (2003) forcefully argues that evidence in support of the view that patenting promotes innovation is weaker than conventionally believed. As universities and firms make IP claims to partial or fragmented knowledge and to early stage inventions, patents can increase the costs of R&D and slow innovation.

Much of the research as well as the claims of pundits and proponents of Bayh-Dole start from an unexamined premise that university involvement in patenting would not have occurred absent legislation (Zacks 2000). Mowery and colleagues have shown, however, that a handful of highly engaged U.S. universities were successfully commercializing university research well before legislation was passed (Mowery & Sampat 2001, Mowery et al. 2004). At Stanford University, three of the most lucrative patents in the history of technology transfer at any university were filed in the 1970s, and arguments with federal agencies were negotiated individually with ease (Nelson 2005, Powell et al. 2007). Thus, despite a growing proprietary imprint on university science, many of the current analyses conflate the source of this trend and assign outcomes as a result of this early legislation. Consequently, although studies in this genre have demonstrated that universities are more active in claiming IP rights, they often fail to identify how institutional policies produced these outcomes, either in chronological time or regulatory effect (Boettiger & Bennett 2006). The detailed review by Phan & Siegel (2006) is a useful first step at assessing the factors that determine the effectiveness of technology transfer practices. Still, little research distinguishes how new, commercially oriented policies interact with traditional, communally based practices of different scientific fields and institutions. One notable exception is work on impediments to sharing biomedical research materials. Walsh et al. (2007) find that academic patenting may not hinder knowledge flow nearly as much as commercial incentives associated with starting spin-off companies and greater secrecy among researchers. Such practical excludability, in their view, presently trumps legal excludability.

Academic Capitalism and Marketization

As proprietary rights have expanded across the scientific enterprise, new financial arrangements between universities and industry have gained currency, extending the reach of private firms into university science. The analytic challenge is to examine how such relationships reshape the character and conduct of science. Critics point to the presence of such new partnerships as evidence of the commercialization and privatization of university-based scientific research and identify the relationships themselves as a profound and deliberate incursion of IP concerns into the university (Rudy et al. 2007).

Academic capitalism arguments explain the rise of new university-industry collaborations by highlighting the economic and political pressures on educational institutions to compete in the research marketplace through protecting and profiting from their investments (Slaughter & Rhoades 1996, 2004; Etzkowitz & Stevens 1998). To be sure, financial pressures are quite considerable, especially at public universities. But few of these arguments regarding fiscal reasons for entry into the research marketplace reconcile the fact that the most prestigious and well-funded universities, such as MIT, Stanford, and UCSF, were the first to commercialize basic research, often far in advance of any legislation. Moreover, the primary reference point for many investigations centers on cases involving the exchange of funding and research results between a corporation and a university, ignoring numerous other forms of academic-industry linkages and their implications for science, training, and research funding. Although notable cases of university-industry partnerships receive considerable press attention (Washburn 2005), overall funding by the private sector for university research has not grown markedly and has even declined in recent years (Rapoport 2006).

This line of work emphasizes that universities took steps in the direction of marketization as a means to offset reductions in government funding. Such market-based calculations have indeed spread throughout many universities, so that managing universities like a business has become commonplace. Although we see this trend apparent in admissions efforts and intercollegiate sports (Bok 2003), evidence that the research enterprise has become more like a business is much less clear. Vallas & Kleinman (2007) are a notable exception, as they document the use of business metrics to evaluate research units within universities as part of the asymmetric convergence between business and the academy. Slaughter & Leslie (1997) voice the concern that universities have lost a privileged position in society as neutral sites of moral authority and are more frequently seen as self-interested actors, clearly a claim that bears merit. Arguments that the reward structure of universities has changed, so that fields located closer to the market are more valued, are more difficult to assess, as disciplines and professional schools in the practical arts have held the favor of campus administrators since the late nineteenth century (Nelson & Rosenberg 1994). Nonetheless, those faculty involved with industry are now rewarded to a significant degree as a result of current commercialization trends (Whittington & Smith-Doerr 2005, Colyvas & Powell 2007).

Academic Entrepreneurship

Another line of work examines the spread of entrepreneurial efforts by faculty and universities, seeking to account for why particular faculty, departments, and universities actively patent and form spin-off companies based on university discoveries (Zucker et al. 1998, Thursby & Thursby 2002). This literature tends to view such entrepreneurial efforts positively, noting that both university science and local economic growth are enhanced in the process. These benefits may come with new structural risks, however. Researchers have identified key attributes, such as research productivity, career stage, and prior experience with collaborative work, which influence whether or not university scientists are drawn into the world of commerce (Shane 2004, Stuart & Ding 2006). Specifically, Whittington & Smith-Doerr (2005) and Stuart & Ding (2006) find that academic patenting has created a new frontier for gender stratification, with male faculty greatly outpacing women.

In the entrepreneurship literature, admiration exists for the successful cases, such as Stanford and MIT, and the propitious relationships these universities have with their surrounding communities. Whether the reference point is Silicon Valley or Kendall Square, efforts at emulating high-status models are now commonplace in the United States and abroad, as politicians, university presidents, and business leaders aim to promote regional economic growth. Such efforts at emulation are challenging, as research has shown that the factors that explain why some disciplines and particular universities have been more conducive to faculty entrepreneurship are highly contingent and tied to local organizational practices (Siegel et al. 2003, Bercovitz & Feldman 2007). Research emphasizes the importance of a wider university culture and supportive administration, a technology transfer office oriented to building relationships rather than bargaining and legal negotiations, and the presence of a research-oriented medical center (Etzkowitz & Stevens 1998, Owen-Smith & Powell 2003, DiGregorio & Shane 2003).

The academic entrepreneurship literature tends to view individual attributes and university incentives as inputs to the process (Lach & Schankerman 2004) and often does not consider the extent to which faculty engagement is the outcome of a larger transformation on university campuses. Careful archival research reveals that basic concepts such as invention and inventor were initially highly contested and unfamiliar and took years to become settled and taken for granted, even on the most entrepreneurial of campuses (Colyvas & Powell 2006, Colyvas 2007). Contemporary ethnographic research, likewise, documents the important role technology licensing officers play in disseminating such concepts and in managing the tensions and conflicts that stem from new actors, relationships, and meanings inherent in academic entrepreneurship (Owen-Smith 2005). More broadly, scant research has addressed how universities are actually sustaining technical advance. Instead, research focuses on indicators—number of patents, number of spin-off companies, revenues generated, etc.—and equates these as proxies for success, despite the numerous limitations associated with these metrics. In an analysis of the evolution of the Boston biotechnology cluster, Owen-Smith & Powell (2004) showed that this productive region was anchored by public research organizations, including universities and research hospitals, and that commercial entities built on key relationships with open science institutions. In this exemplary case, universities and hospitals played an essential role in the creation and expansion of biotechnology precisely because they acted like the traditional university, an open institution where knowledge readily spilled over into the surrounding community.

The new era of university-industry relations raises numerous questions about stratification, access, and scientific careers. We raise these important issues only briefly, suggesting pertinent areas where research is most needed. Little work has considered the ramifications of industry-based scientists becoming simultaneously more active in basic applied research collaborations and publications, both at the corporation and on campus. When commercially based scientists contribute to the corpus of open science, do their contributions have the same impact as university publications? An earlier survey rating research institutions by citation impact in the physical sciences between 1981–1991 reveals that private corporations ranked second, third, and seventh in the top ten (Brown 1995). Research has yet to address how transferable and durable these efforts are or whether publishing is more likely in the early stages of a start-up company's development. In areas where research is easily transferred from basic to applied, does the merger of public and private science transform the criteria by which scientific careers are judged and managed? How will a reconceptualization of professional identity influence scientific career paths, and how will universities reconstruct their teaching and research faculties and priorities? Many universities are already placing bigger and bigger bets in areas with the greatest potential for commercial—as well as reputational—payoffs (Brint 2005).

The changes underway in contemporary science have very divergent outcomes across disciplines, organizations, and geographies (Owen-Smith et al. 2002). For example, poor communities—both within and between countries—may be challenged by the privatization and commercialization of science, as knowledge may become restricted and/or unaffordable and the tools and technologies necessary to use and exploit such knowledge may become less freely available. Although some attention is directed toward the role of industry investments and entrepreneurial ventures in highly patentable areas of research (e.g., the life sciences, material sciences, and engineering), less is understood about these trends in areas with low commercial potential but high social value (e.g., infectious diseases, malaria, clean water, renewable energy).

Traditionally, university settings explored arenas that industry did not pursue. But in the absence of market incentives, it is not obvious where knowledge generation for the public interest and social good may emerge in areas such as vaccines or low-cost technologies. In some circumstances, new models of public and proprietary science have fostered the development of first-to-the-world medicines and affordable communications technologies, but in other realms, such as renewable energy, widely available breakthroughs have not been forthcoming.

A key challenge in understanding the nexus of industry-government-university funding is the historical contingency of different models of research funding. Early in the twentieth century, many institutions rejected federal funds on the basis that they were tainted, and in the 1960s and 1970s defense-related research was highly controversial. Today, the formerly disinterested nature of federal support for research seems to be becoming a historical relic. Increasingly, the government itself is behaving like industry, desiring more influence and control over research topics and outcomes. The embrace of philanthropic donations, gifts, and partnerships from enviable high-tech companies, while currently in vogue, may also prove fleeting.

DIRECTIONS FOR FUTURE RESEARCH

Current research has mapped the shifting boundaries of science and property and begun to track the ramifications of these movements. To date, most studies have separated rather than synthesized potential streams of analysis. Thus, with some significant exceptions, our understanding of the effects of IP on science and our ability to assess these effects as a transformation versus a transition are built on discrete and disconnected bodies of research. The current literature ranges widely, from accounts of the commercialization of university research, to the economic studies of patents, incentives, and innovation, to the growing—and predominantly legal—literature on the value of cultural and scientific commons, to sociological research on fiscal and informational resource flows within scientific cultures. But this expanding body of work is presently fragmented and poorly integrated.

As a result, numerous studies are concerned with the effects of IP on university-based science but do not consider the possibility of reciprocal effects on industry-driven research. Some high-profile meetings on different models of openness and their relationship to existing features of IP law and institutionalized scientific practice have taken place. To date, however, legal, sociological, and economic research on these efforts has largely proceeded in parallel rather than in tandem. Moreover, little is known about how changes in scientific rules, roles, and relations will ultimately trickle down to problem choice, data/information sharing, knowledge values, and professional identity across different social, intellectual, and epistemic contexts in the future. Thus, a full understanding of the causes and consequences of the new public-private system will require analysts to look both vertically and horizontally across scientific fields.

A next step, then, is to tackle the harder questions about where and/or when the IP rights line should be drawn, particularly in instances in which public and private interests collude and where they collide. Research is needed to assess which of the different IP tools can best solve incentive and appropriability problems under different conditions, especially when emerging alternatives exist. The need to clarify the objectives, operations, and effects of the IP rights system is due in part to the arrival of new types of science and technologies, and the changing ways in which IP rights govern and are governed within multisectoral and interjurisdictional systems as both products and processes of science.

Consequently, comparisons of different models of open and proprietary scientific practice are only partial, rendering it difficult to assess fully where the risks and opportunities lie for knowledge production and dissemination under different conditions. Where will the shifts of contemporary science take us, with what costs and benefits, and for whom? What are the long-term distributional consequences of private investment models of scientific innovation versus those of the public domain model or newer versions of open source collaboration? These are fundamental questions that require interdisciplinary analysis.

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