Learning to Live with Patents:

Acquiescence & adaptation to the law by the scientific community

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Abstract

Law plays a central, but under-appreciated role in knowledge work. While economic and policy scholars debate the way in which changing legal institutions, particularly expanding property rights, shape the daily lives of knowledge workers, lawyers, with their contracts and concerns, are not key actors on the stage of detailed ethnographies of knowledge work. We reconcile these alternatives arguing that in response to changing legal institutions, knowledge communities acquiesce to but also adapt to and adapt the law. We use our analytical framework to ground an empirical study of the role played by changing legal enforcement of intellectual property rights in shaping exchange in knowledge communities. Using a large-scale quantitative analysis of publications and patents drawn from a period characterized by dynamic changes in property rights enforcement, we econometrically assess whether and how the enforcement of intellectual property rights over scientific knowledge influences the life sciences community. We also examine how different sub-communities acquiesce and adapt to legal changes at differing rates. More broadly, we initiate an agenda incorporating legal institutions into scholarship on communities of practice and knowledge work.

[179 WORDS]

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In the knowledge economy, legal institutions are a pervasive and sometimes problematic aspect of daily life (Jaffe & Lerner, 2004; Heller, 2008). The law provides the institutional backdrop for the knowledge work of individuals, organizations and communities. As part of the "dynamic institutional context" (North 1993, p. 6) of knowledge work – as constituted by material culture, social networks and broader rules and norms – the law shapes the ability of innovators to exchange knowledge rapidly, effectively and with high fidelity (Stern, 2004). Such exchange of ideas between knowledge-workers is critical to knowledge accumulation – building on ideas generated by others, which in turn is a powerful driver of economic growth. However, exchange and accumulation are not inherent properties of knowledge or of knowledge communities (Mokyr, 2002). Instead, it is the institutional foundations of knowledge work that contour these processes. The exchange of knowledge takes place in the shadow of the law. More than any other aspect of legal institutions, property rights increasingly influence knowledge work (Heller, 2008); some deriving from informal norms (Fauchart and Von Hippel 2007, Loshin 2007, Oliar and Sprigman 2998), many are founded in legally constructed property rights, particularly the intellectual property rights governed by patents and copyrights (Dreyfuss, First and Zimmerman 2001, Dreyfuss 1987), yet others mix the two (Raustiala and Sprigman 2006, Murray 2008). By today, more and more knowledge work is undertaken in the shadow of intellectual property rights: patents on research tools concern scientists selecting experiments (Heller & Eisenberg, 1998), copyright infringement suits threaten rap artists sampling music (Perry, 2008), copyright and copyleft licensing requirements lead software developers to make complex design choices (MacCormack et al. 2007; O'Mahony, 2003), the patents undergirding technical standards shape the strategic engineering choices of cell-phone designers (Rosenkopf et al. 200x; Rysman & Simcoe, 2006).

While the salience of the intellectual property law in the knowledge economy is vigorously debated among legal scholars, economists and policy makers (David 2001, 2003; Jaffe and Lerner 2004), for the most part, organizational scholars have been silent on the role of the law in knowledge work (for notable exceptions see

O'Mahony 2003; Marx et al.,2007). The thick descriptions of knowledge work rarely feature patents, non-compete contracts or non-disclosure agreements. For example, in the rich and insightful ethnography of design firm IDEO, using its position as a knowledge broker to recombine and accumulate knowledge (Hargadon & Sutton, 1997: 723), there is no mention of the terms and conditions of knowledge access and reuse, of confidentiality, non-compete agreements, or allocation of patent rights from newly developed ideas. Surprisingly, given the long line of research on the interrelationship between law and organizations, (Edelman& Suchman, 1993), the literature on knowledge communities has mostly extrapolated away from the role and impact of the law.

Lawyers are not key actors on the stage of most knowledge communities; a picture that remains at odds with anecdotal representations of knowledge workers' lives. How should we interpret the seeming paradox between the lack of mention of the law in knowledge work and the widespread debate about the way law is impinging upon knowledge workers (Lessig, 2002). In the extreme, we can interpret the absence of the law in ethnographies as arises from the total irrelevance of the law or its deep, taken-for-granted relevance. On the one hand, law can be so pervasive that it is in the background. For example, an ethnographer of car drivers would likely find no mention of the rules of the road; not because they are irrelevant, but because they are so pervasive that we take them for granted. On the other, it is possible that the transaction costs associated with using the law are so high that the law is simply irrelevant to the daily practice of knowledge workers, and so the same ethnographer driving in the Australian outback might find no mention of the highway code because it is simply too costly for anyone to use. Reconciling these alternative views, we argue that legal institutions, particularly property rights, influence knowledge workers in two ways. First, they do acquiesce to changing intellectual property rights and that this imposes a cost on their communities, but second, they also learn to life with intellectual property rights through processes of adaptation. Thus the law is neither a bludgeon nor irrelevant to knowledge communities. Instead, over time, it is transformed to shape the opportunities and constraints of knowledge workers and ultimately becomes reflected in their daily practices.

This paper considers the inter-relationship between intellectual property rights and knowledge work, building theoretical arguments for the mechanisms through which a knowledge community responds to the introduction of a legally-based barrier to knowledge exchange. Based on our theoretical analysis, we undertake a careful empirical examination of the impact of legal change on the accumulation of knowledge within a community of practice. Our study analyzes a widely discussed empirical puzzle that lies at the intersection of law and knowledge work – whether and how the widespread patenting of scientific knowledge influences communities of scientists (Heller & Eisenberg, 1998; Walsh et al., 2005; Murray & Stern, 2007). More importantly, it initiates a broader research agenda incorporating legal institutions into knowledge work by integrating insights from the literature on law and organizations (Edelman & Suchman, 1993) and law and economics (Heller, 2008; Scotchmer, 2005), into scholarship on communities of practice and knowledge work (Brown & Duguid 1991; Bechky 199x etc.).

Legal Institutional Foundations of Knowledge Exchange

Knowledge accumulation is grounded in the ability of individuals, organizations and communities to learn a about new ideas i.e. disclosure and to access to these ideas so that replication, validation and follow-on innovation takes place. The micro-foundations of knowledge exchange, as developed in the communities of practice literature, highlight the central role of shared language, meaning and objects in allowing for knowledge transfer from one individual (or group) to another. From the early studies of TEA lasers scholars have recognized the important element of tacit knowledge, directing attention to the need for personal (rather than disembodied) relationships in mediating knowledge exchange (Collins 1974, xxx). However, these studies are grounded in the assumption that knowledge workers with the right social networks, personal relationships and shared language will easily participate in knowledge exchange. What of the barriers to exchange imposed by inter-community animosity, organizational boundaries, or geographic competition? While some barriers to exchange are grounded in informal norms; such as those traditionally guiding the exchange of research materials between academic scientists (Kohler, 1994; Biagioli, 2004), legally established property rights also provide potentially powerful barriers. For example, scientists who generated "golden rice' - a rice genetically modified to produce pro-Vitamin worked in academia but have to navigate 70 patent claims on the genes, DNA sequences, and gene constructs from a diverse range of firms including Monsanto and Astra-Zeneca to move to large-scale trials (Kryder et al., 2000). U.S. academics working on human embryonic stem cells must navigate a complex set of contracts established by the Wisconsin Alumni Research Foundation – the technology transfer arm of the University of Wisconsin – if they want to exchange these cells without contravening WARFs intellectual and material property rights over the cell lines, and their methods of production (Murray 2007).

While the nature of property rights makes it possible for knowledge workers to establish a rich repertoire of legally-based strategies for exchange, the literature, as noted above, is puzzlingly silent on the role of law. Do knowledge workers and their ethnographers take these legal strategies for granted to such an extent that they do not warrant mention? Alternatively, are they simply ignored and unused? As we seek to deepen our understanding of the role of the law in knowledge communities, we confront the challenge of disentangling the impact of legal institutions from other institutional elements. How can we, for example, argue that legal requirements drive sharing when it may be the interplay of material culture, history and social norms (Kohler, 1994)? To resolve this challenge, we consider the ways in which knowledge communities respond to a shift in the legal institutions governing knowledge exchange. There are many such examples: Changing enforcement of non-compete agreements (Marx et al., 2007), the expansion of patent rights over business methods (Lerner, 2002; Meurer, 2002; Strandburg, 2008), Supreme Court decisions validating patent rights over genetically modified organisms (Kelves, 2002; Rimmer, 2008; Kaplan & Murray, 2008), the decision by the Recording Industry Association of America to impose copyright over music sharing (Liebowitz, 2003). As we will describe, our focus is on knowledge shifting from the public domain to being subject to intellectual property rights (in the form of patents)[1].

Analyzing the ways in which organizations (and by extension communities) respond to a wide variety of institutional pressures that affect them, the literature articulates a variety of outcomes to pressures from regulatory structures, governmental agencies, laws, courts, and professions (Scott, 1987a: 498; Oliver, 1991). Two are particularly salient in an analysis of legal institutional change. On the one hand, institutional

[1] This may seem puzzling given that patent rights can only be granted on novel and non-obvious ideas that are not previously published. However in our analysis, knowledge publication and patent application is simultaneous however the 3-4 year delay in patent grant means that the knowledge is in the public domain unencumbered by patent rights prior to patent grant and then shifts to being subject to patent rights at some later period.

theorists emphasized the role of acquiescence through conformity with the institutional environment and the desirability of adhering to external rules and norms (DiMaggio & Powell, 1983; Meyer & Rowan, 1977). This approach privileges the importance of high-level institutional change as the key source of pressure whose influence will ripple through an entire community. An alternative approach highlights the potential for organizations and communities to adapt to institutional pressures actively managing their response (Pfeffer & Salancik, 1978), and in doing so engage in resistance and subsequent adaptation, typically at the local level, so as to more effectively live with the institutional change. Examining the literature on the role of law in organizations, we argue that these two different responses may co-exist.

Acquiescing to Changes in Legal Institutions

An important perspective on the role of law in knowledge exchange is grounded in our understanding of patent and copyright law and the rights embodied in these forms of knowledge-based intellectual property. The legal rights that come with patents can be regarded as part of a broader collage of legal (and other) institutions that provide the incentive structures of the knowledge economy (North 1991). The institutional approach to law and knowledge work (more widely referred to as innovation) is grounded in a study of the patent system (Scotchmer 1991; Jaffe and Lerner 2004) as providing the institutional framework for knowledge disclosure and exchange (Mokyr 2002; Stern 2004; Murray and O'Mahony 2007). That law can provide (and inhibit) such institutional support is clear. Notwithstanding recent critiques of the patent system (Lessig 2001), its designers intended the patent system to provide incentives for innovators to invest in and then exchange novel, useful and non-obvious ideas. While exchange in the form of disclosure is crucial to the patent system, its focus is on the incentives for knowledge production provided by the degree to which a researcher can exclude others and so appropriate value rather than exchange *per se* (Nelson 1959; Arrow 1962; Levin et al. 1987; Kremer 1997; Scotchmer 1996). Moreover, classic economic analysis of legal changes assumes innovators immediately acquiesce to shifting legal rules. Most models assume that knowledge workers and knowledge-based organizations respond directly to specific attributes of patent law: what is considered patentable material, the length of patent protection, the scope of patents, the time to patent grant, the probability of patent enforcement (Katz and Shapiro, 1985; Merges and Nelson, 1990; Klemperer, 1990;

Scotchmer 1991; Lemley and Shapiro, 2005). The influence of the law is modeled as unmediated by norms and practices, instead being based on a clear interpretation of, and direct acquiescence to the law. Several examples provide support for the rapid acquiescence of knowledge communities to the law. Using historical patent data from over 100 US semiconductor firms Hall and Ziedonis (2001) showed that following the establishment of the Court of Appeals for the Federal Circuit (CAFC), widely interpreted as being pro-patent, firms rapidly start to patented at higher rates. At an individual level, Marx et al. (2007) show that in the period after the enforcement of non-compete agreements the mobility of inventors in knowledge-based communities gradually declines as the force of the new enforcement practices ripples through the community. These studies assume (and find) that legal shifts have an instantaneous and growing impact the knowledge community. Furthermore, they suggest that legal shifts engender acquiescence to the precise nature of the law at the global-level (i.e. the level at which the law is imposed) with few local variations and a limited sense of the role of local context on institutional change.

Adapting to Changes in Legal Institutions

The prevailing approach to changes in legal rules suggests that the shadow of the law is sharply defined and widely cast over knowledge workers. As such, it runs against the dominant perspective on knowledge communities which emphasizes the importance of local norms and practices (Knorr-Cetina, 1999), shared artifacts (Latour, 1987) and boundary objects (Bechky, 2003; Carlile, 2004). Even the arrangements directly governing exchange appear to be driven by local material cultures (Kohler, 1994) and local norms (Fauchart and Von Hippel, 2007). In the absence of local cultures helping individuals share, replicate and combine distinct pieces of knowledge through local shared meanings (Bechky, 2003) solutions can be sought through the establishment of trading zones that allow for exchange without full mutual understanding (Galison, 1999). But the zones remain local in nature (Galison, 1999). The recognition that the social structures embedding knowledge communities enable (or constrain) their knowledge work also speaks to the role of local conditions in knowledge communities (Van de Ven, 1993; Hansen, 1999; Hargadon and Sutton, 1997; Fleming, 2001; Knorr-Cetina, 1999). For example, an individual or firm's network position may provide significant opportunities for knowledge accumulation through brokerage and by facilitating knowledge exchange (Hansen et al., 2005, Burt, 2004; Uzzi and Spiro, 2005; Fleming, 2007). While these analyses ignore the impact of formal rules particularly the law on knowledge communities, they speak to the importance of local adaptation in responding to the changing conditions of knowledge work.

The notion that communities engage in local adaptation in response to changing legal institutions, rather than simply acquiesce to them, finds direct support in the literature on law and organizations. As Edelman and Suchman (1997) have argued, organizations are "immersed in a sea of law" and yet the organizational response to the law is complex and constituted through the daily practice of individuals (Silbey, xxx). In this conception, the law is embedded in norms and behaviors with individuals interpreting and mobilizing rights in response to legal structures (Fuller, Edelman and Matusik; 2000). Sociological perspectives on the link between law and the employment relationship have pioneered our understanding of the ways in which organizations respond to legal change (Kelly and Dobbin 1999; Dobbin and Kelly 2007). Acknowledging that law has had a profound impact on employer practices, for example in changing maternity leave policies, there is strong evidence that it is not necessarily the strongest legal sanctions that lead to the greatest changes. Instead, legal ambiguity provides ample opportunities for the legal profession to establish its expertise and win corporate resources (Edelman et al. 1992). It has also led to complex compliance activities subject to significant contestation. Thus legislation becomes simply "the beginning of law making" (Kelly and Dobbin 1999, p. 487) and the beginning of law in practice. Adaptation arises as the enactment of legal institutions establishes normative frameworks for behaviors and for meaningfulness – with the law interpreted through the lenses of social practices (Macaulay 1963, Hurst 1964, Mnookin & Kornhauser 1979). A second characteristic that follows from the adaptive response to the law; that the transformation and interpretation of the law may not be immediate. Instead, over time, individuals come to interpret the law in the same way that they learn to operate within a wide range of contractual, moral and social orders (Meyer & Argyris 2004). The adaptive approach is not to deny the potential efficiencies associated with institutions grounded in either a legal or a normative order (North 1991). Instead, it suggests that adaptation to institutional change is likely to be slow and to involve a complex of individual and community-based actions that emerge through the daily life of knowledge workers or other actors (Heimer 1985). A third feature of the adaptive approach is that we will likely see different local variations in response to, and adaptation of changing legal rules. The literature on law and society provides further guidance in this regard, arguing that the law is as malleable and therefore leads to different interpretations and different transformations of practice. As a result, we would expect to see that different communities (or sub-communities) would adapt more or less rapidly and in different ways to shifting legal rules.

The potentially salient role of adaptation in response to legal change is likely to be of critical importance in the case of intellectual property. In Edelman and Suchman's terms (1997), IP rights are facilitative in that they provide their owners with a variety of legal rights that they may (or may not) use in as a setting for action. They do not necessarily modify behavior (of the patent holder or others) but they can do so. Such adaptation arises in part because of the flexibility inherent in IP rights. They can be thought of as a right to exclude others, but they also confer prestige, can be used to control the innovation of others, and they are a source of potential economic rewards (Murray 2008). Of great relevance to the adaptation process is also the recognition that patents have some element of uncertainty that is "especially striking and fundamental to an understanding of the effects of patents on innovation and competition" (Lemley and Shapiro p. 4 2005). As a result, changes in IP rights become constituted by their meaning, implementation and the changing expectations of patent enforcement that arise as communities understand the strength of patent rights and the willingness on the part of IP owners to impose those rights.

Taken together the two responses to legal change - acquiescence and adaptation –constitute a framework within which to consider the role of law in knowledge communities. More precisely, we argue that the effect of any legal transformation is separable into three empirically distinct elements: inception, acquiescence and adaptation. The *inception effect* captures the response of a knowledge community to the initiation of any legal change or change in the implementation of the law. We consider this effect to the initial level of acquiescence to the law at the initial level of adaptation in the first period. For each year after the inception of a legal change, we define an *acquiescence effect* capturing the ways in which a knowledge community acknowledges and incorporates the law. Notwithstanding the cost of acquiescence to a given legal change, we argue that in each subsequent year there will be a positive *adaptation effect* capturing the transformation of the law over time into daily practice by the knowledge community. By analyzing and partitioning the temporal, historically grounded response to changes in legal institutions, we can better understand the role of law on the stage of knowledge work. Paying attention to the ways in which communities respond to the law brings insights into the current role of the law, even when it lies in the background of daily knowledge work, allowing us to disentangle cases where law is irrelevant from those where the commonplace of the law is so taken-for-granted as to be overlooked (Silbey & xxx, 2003).

Law & Knowledge Exchange in the Life Science Community

Among the many legal changes roiling the knowledge economy, the expansion of intellectual property rights designed to protect and encourage knowledge work is now a source of significant controversy, with heated debates over whether or not the breadth, strength and enforcement of IP rights is now stifling the very work it sought to encourage (Lessig, 2002; Benkler, xxxx; Heller, 2008). This argument covers a wide range of knowledge work from software design and hardware engineering, to movie and music making, art and video games, potential shaping the daily lives of knowledge workers in a range of organizational settings from individuals working alone to informal global communities and those in large corporations.

These issues animate debates over the expansion of intellectual property rights in the academic research community (Heller & Eisenberg, 1998; Eisenberg & Nelson, 2002). Largely focused on the life science community, the discussion is driven by the 6,000 life science patents granted between 1989 and 1999 by US Research One universities (Owen-Smith and Powell 2003) and the finding that 25% of U.S. life science faculty members have at least one patent (Ding, Murray and Stuart 2007). A number of factors shape the rise in patents in the life sciences: The expanding promise of biotechnology, reductions in the costs of academic patenting, and increases in the scope of IP over knowledge produced in the life sciences. The rise in useful, inventive knowledge in this field dates back to the early 1970s (Morange, 1990). At the same time, policy shifts encouraged academics to claim IPR over their knowledge. Prior to this time, patent applications filed by universities on behalf of investigators required case-by-case negotiation of the assignment of patent rights and their subsequent licensing. The 1980 Bayh-Dole Act assigned IP (generated using Federal funds) to universities along with a duty to license the patents and facilitate their translation and commercialization (Mowery et al 2001). Finally, there was a significant expansion in the *scope* of patents available in the life sciences. After the 1980 *Diamond vs. Chakrabarty* decision and the granting of the Oncomouse patent in 1988, IP comprehensively covered the domain of genetically modified living organisms – from bacteria to mammals (Kevles 2002). In combination with the developments in the biotech industry, "universities were literally propelled into an awareness of the potential economic value of the technology that was being generated in their research programs" (Bremmer 2001). As a result, many faculty members faced a new set of disclosure choices. Rather than simply document their new ideas as academic publications, they could also file for intellectual property rights on the same ideas. As long as carefully managed the timing of the publication and patent application submission (to fall within the one year bar), they incorporate the same ideas into both a paper and a patent (application). While their paper would be published within a few months (as is the norm in life science publication), the patent would grant approximately three years later, thus instantiating knowledge in a patent-paper pair (Murray, 2002; Ducor, 1999). As a result, a a growing number of ideas traditionally placed in the public domain were now also subject to patent rights and disclosed as patent-paper pairs (Murray and Stern 2007ab, Huang and Murray 2008). To provide a more concrete example of patent paper pairs (taken from the dataset we evaluate in our empirical analysis) consider the following example:

> "A method has been developed for control of molecular weight and molecular weight dispersity during production of polyhydroxyalkanoates in genetically engineered organisms by control of the level and time of expression of one or more PHA synthases in the organisms. The method was demonstrated by constructing a synthetic operon for PHA production in E. coli …Modulation of the total level of PHA synthase activity in the host cell by varying the concentration of the inducer …was found to effect the molecular weight of the polymer produced in the cell." (Snell; Kristi D. (Belmont, MA); Hogan; Scott A. (Troy, MI); Sim; Sang Jun (Seoul, KR); Sinskey; Anthony J. (Boston, MA); Rha; Chokyun (Boston, MA) 1998, Patent No. 5,811,272)

> "A synthetic operon for polyhydroxyalkanoate (PHA) biosynthesis designed to yield high levels of PHA synthase activity in vivo was constructed …by positioning a genetic fragment … behind a modified synthase gene containing an Escherichia coli promoter and ribosome binding site. Plasmids containing the synthetic operon …were transformed into E. coli DH5 alpha and analyzed for polyhydroxybutyrate production… Comparison of the enzyme activity levels of PHA biosynthetic enzymes in a strain encoding the native operon with a strain possessing the synthetic operon indicates

> that the amount of polyhydroxyalkanoate synthase in a host organism plays a key role in controlling the molecular weight and the polydispersity of polymer. (Sim SJ, Snell KD, Hogan SA, Stubbe J, Rha CK, Sinskey AJ , Nature Biotechnology 1997)

As outlined in these brief excerpts, the research described in both documents is based on a specific genetic modification of a bacterium (E. Coli) designed to control the type and amount of particular chemicals (PHA) the bacteria might ordinarily produce. From the scientific perspective, the publication emphasizes that these experiments deepen our understanding of the genes that regulate particular chemical pathways in bacteria. However, as highlighted in the patent, they also provide practical techniques for the manipulation of bacteria and the optimization of their use as a source of useful biomaterials. In other words, this single discovery has been instantiated as both a publication emphasizing its scientific contribution and as a patent disclosure emphasizing its utility.

The rise in patent-paper pairs characterizes the changing nature of knowledge disclosure in academia. However, what lies at the core of the debate regarding the impact of formal IP over scientific knowledge is not the filing of patents but their enforcement i.e. the exercise of property rights by patent owners (or licensees) over those seeking to exchange and use the knowledge in follow-on innovation. It was not until the mid 1990s that the scientific community experienced the real impact of expanding patent rights on their knowledge exchange practices (Blumenthal, 1997; Campbell, 2002; Krimsky, xxxx). Three examples characterize growing implementation of legal property rights: In the early 1990s, mouse geneticists became embroiled with DuPont over their ability to exchange and use transgenic research mice covered by Harvard patents exclusively licensed to DuPont (Murray, 2008). In the mid-1990s, Roche responded to the widespread infringement by the scientific community of process and product patents on the PCR method of amplifying DNA by aggressively assert its intellectual property rights. The company attempted to monitor researchers who were running reactions with unlicensed reagents or thermal cyclers. On May 16, 1995, Roche provided the court with a list of more than two hundred individuals, including researchers working at the National Cancer Institute, the Howard Hughes Medical Institute, Stanford Medical School, M.I.T., and Harvard University who were infringing their patents. In 1998, the Wisconsin Alumni Research Foundation

(WARF) imposed stringent licensing costs and terms on academics who wanted to use their patented embryonic stem cell lines (xxx, Murray, 2007).

We have found contradictory evidence of the influence of expanding IP rights and rights enforcement on the scientific community. On the one hand, Heller and Eisenberg (1998) argue that expanding IP stifles academic scientists in their knowledge work. Their perspective is supported (at a limited level) by quantitative analysis showing that the grant of IP rights over scientific knowledge leads to a reduction in citations to that knowledge (Murray & Stern, 2007; Sampat, 2005). In contrast, survey-based evidence shows that while more than 20% of scientists have been involved in seeking IP, few admit to paying attention to IP rights. Furthermore, only 20% report delays or diversions in their projects because their most recent request for materials had been declined or delayed while they negotiate access to knowledge and materials via Material Transfer Agreements(which may or may not be associated with patents) with colleagues (Walsh et al. 2002, 2003, 2005). In spite of these contradictory perspectives, recent longitudinal qualitative analysis of the role of patents in the life science community is consistent with our theoretical framework, finding that in the mouse genetics community, scientists both acquiesced to and adapted to the patenting of one of their central research tools – the Oncomouse (Murray 2008). In their early response to attempts by DuPont (the exclusive licensee of the Oncomouse) to impose costly contractual terms on mouse exchange, many scientists acquiesced and either left the field or navigated their way slowly through the complex conditions. However, as the mouse genetics community came to realize, adaptation to patent enforcement was possible through the mobilization of powerful organizations such as the National Institutes of Health (NIH), and pressure on TTO professionals, leading to restructuring of licensing provisions and more simplified material transfer procedures (Murray 2008).

Living with Changing Enforcement of Patents: Inception, Acquiescence & Adaptation

On the surface, the two perspectives on the role of intellectual property rights in the life science community appear contradictory. However, our acquiescence-adaptation framework suggests when comparing these studies we must account both for the historical periods under consideration (1998 versus 2005) and for the degree to which the authors sought specific instances where law imagined upon knowledge work or instead ascertained only whether law dramatically shaped scientific practice. If we assume that scientists in the late 1990s initiated in two simultaneous but distinctive responses to changing enforcement of property rights, then we would expect to find that in the late 1990s, intellectual property law was still a salient and frustrating issue for scientists, impinging on their work in costly and complex ways. However, during the next five to seven years, the community would have developed in a variety of adaptation mechanisms so that by 2005 (the timeframe of the survey analysis) it is possible that scientists adapted to intellectual property enforcement to such an extent that it was no longer causing obvious and remarkable headaches. While this resolution is grounded in theory and is supported by recent qualitative evidence (Murray, 2008), our goal is to provide large-scale empirical support for this theoretical framework by testing a series of hypotheses grounded. We frame our hypotheses around the notion of patent-paper pairs. Specifically, we make a series of predictions regarding the way in which patent grant and implementation (of a specific piece of knowledge also disclosed in a paired publication) influences the rate at which follow-on scientists are able to exchange and build upon the knowledge in follow-on publications. We predict that over time, different levels of acquiescence and adaptation will pertain, leading to differences in the rate of exchange and therefore the rate at which follow-on researchers build upon the patented knowledge, as captured in Figure 1. We consider this as a proxy for the way in which changes in patenting and the implementation of patents influence knowledge exchange.

-- Insert Figure 1 about here --

Inception: Regardless of the long-run influence of patents on the knowledge community, we hypothesize that at the inception of patent enforcement, the *inception effect* on knowledge exchange and follow-on innovation will be negative. Our prediction is grounded in a tradeoff between two countervailing perspectives on the role of patents in knowledge work. On the one hand, patents provide incentives for research investment thus potentially increasing the willingness of knowledge workers to exchange and build-upon patented knowledge. In addition, while scientists pursue many discoveries in the absence of IPR, it is possible that patents' enhanced incentives attract the entry of high-quality scientific researchers into specific research fields (Nelson 1959; Arrow 1962). Second, even if there is no impact on the incentive to produce knowledge *per se*, patents may usefully facilitate the commercialization of that knowledge and help to bridge the university-industry divide and therefore spur overall knowledge exchange and accumulation. Alternatively, the granting of IP rights over scientific knowledge traditionally disclosed only through publication imposes potential costs including possible licensing and other contractual agreements. The balance of empirical evidence suggests that in the early period of patent enforcement, individual scientists and their Technology Transfer Office (TTO) professionals had limited experience in gaining access to patented ideas where rights were now being actively exercised[2]. The corporate lawyers who sought to execute their patents on other academic institutions also had limited expertise in this arena and imposed complex contracts that many academics found cumbersome and unreasonable (Einhorn, 2002). Lastly, the pracitce of university-to-university licensing and related material transfer agreements was nascent, leading to clumsy and complex procedures (Mowery & Ziedonis, 2007). Thus, we argue that early in the implementation of IP rights, the net *inception effect* of patent grant will be significant and negative.

Acquiescence: We hypothesize that in the years following patent grant, there will be a negative *acquiescence effect* on exchange and follow-on accumulation building upon the patented piece of knowledge in each year as the patent ages. Several factors drive this effect. First, as argued by the "anti-commons" approach, the imposition of IP rights over areas traditionally maintained in the public commons undermines the process of cumulative scientific discovery (Heller, 1998; Heller & Eisenberg, 1998; David 2003). Because IP can serve to exclude follow-on researchers from exploiting scientific discoveries, the anti-commons hypothesis posits that the privatization of the scientific commons will impose a "tax" on the use of prior scientific knowledge through significant transaction costs (Eisenberg, 1996; Shapiro, 2001; Hall & Ziedonis, 2001). In its precise formulation, the anti-commons is grounded in the proliferation and fragmentation of IP rights (Ziedonis, 2004; Huang & Murray, forthcoming), the associated transaction costs and the potential for royalty stacking. Therefore, for any given patent, acquiescence imposes a tax on follow-on research who seek to build on an

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[2] This is in contrast to the expertise they had gained from 1980 – 2000 in patent filing and in the licensing of patent rights to commercial organizations – both start-ups and established firms. In this aspect of patenting, the universities played a very limited role in patent enforcement, generally relying on the licensee to actively manage infringement by other commercial entities.

individual piece of knowledge which will be increasing in time as related (and fragmented) IP is generated. Growing awareness of the role of IP rights may cumulatively lead researchers to exit a research line in each year following patent grant rather than compete in an area that is fraught with complex licensing requirements. The mouse genetics community characterizes such an effect, with many scientists exiting from transgenic mouse research due to the costs imposed by DuPont through their complex and costly patent licensing agreement. A final factor contributing to the negative acquiescence effect is the expanding reach of enforcement by TTOs and patent licensees.

Adaptation: In the case of patents, we hypothesize that the impact of all patents in every calendar year from the inception year onwards will decline (become increasingly positive) due to an *adaptation effect*. The proposed adaptation of the scientific community to patents is grounded in the idea that while patents provide strong property rights, over time, knowledge workers learn how likely patent owners are to enforce these rights, over whom and for what types of infringing actions. Furthermore, universities implemented a range of of informal or formal agreements to avoid complex individual licensing requirements, most notably the so-called "Universal Biological Material Transfer Agreement" (CITE), thus reducing the idiosyncratic contractual apparatus necessary to deal with patents and licenses, leading to a decline in the associated transaction costs (Meyer & Argyris, 2003).

The Marginal Impact of Patent Enforcement on different segments of the community

Our predictions to this point have focused on the entire scientific community, broadly defined. When we consider the influence of patent grant on exchange and follow-on research, our hypotheses specify the mean impact of patent grant across all members of the scientific community. However, it is more likely that changing legal institutions will differentially affect different sub-communities. Examining the changing legal enforcement of patents, we argue that the marginal *inception*, *acquiescence* and *adaptation* effects will differ for sub-communities defined along four dimensions: academic versus industry scientists, high versus low status researchers, US vs. foreign, applied vs. basic. By analyzing the rate at which scientists in these different, mutually exclusive sub-communities produce follow-on knowledge, we can more clearly elaborate the ways in which adaptation and acquiescence are unfolding.

The differential response of academic versus industry scientists is most straightforward to predict. While enforcement of academic patents on the scientific community was a new phenomenon for academic scientists in the late 1990s, for industrial scientists, infringement suits by industrial patent holders and more recently industrial patent licensees was more commonplace. Several legal suits speak to the frequency with which firms enforced their patent rights against one another. In 2006 lawsuit, Ariad, a Cambridge-based biotechnology company, sued Eli Lily for infringing upon patents it had licensed from MIT and Harvard covering drugs that work by modulating the action of nuclear factor kappa B, or NF-kB, a protein discovered in the 1980s by academic scientists (Pollack 2006). Thus, we would expect the inception and acquiescence effects to be much greater for follow-on academic scientists compared to industrial scientists for whom patent enforcement was already well anticipated. Moreover, up until the Mahey v. Duke decision, most university researchers believed that they had a research exemption from patent infringements, although the decision made clear that they can be sued for making, using, selling or importing patented technologies, even if they have no intention of commercializing the fruits of the research (Yancey and Stuart 2007). Likewise, any adaptation effect is likely to have taken place in a much earlier period as the scope of biotech patents was litigated between firms in the 1980s, thus we would also predict that only academic community members would be subject to an adaptation effect.

The status of community members provides another important margin along which to examine the role of legal change. Within the scientific community, the importance of status hierarchy is well documented as it pertains to returns to achievement (Merton 1963), promotion (Scott Long 19xx) and xxx. While the invisible college provides an important mechanism through which scientists are likely to engage in their adaptive behavior, we predict that the status hierarchy will contour the rate at which different scientists are able to engage in and take advantage of adaptations. High status faculty are more likely to be able to use informal mechanisms as a source of adaptation to complex legal contracting, for example using informal relationships as a conduit for exchange and thus avoiding costly contractual requirements. Thus, we predict that while the inception effect is equal for both high and low status faculty, we predict that high status faculty will exhibit a higher adaptation effect than their low status counterparts. Our predictions on the acquiescence effect are more complex – having accounted for adaptation, we argue that high and low status scientists are equally likely to acquiesce to a given patent, although it is possible that being more high status, and therefore more high profile, the reach of TTOs and industrial licensees would extend more rapidly to high status academics.

Turning to a comparison of scientists affiliated to US versus foreign organizations (public or private), assuming that universities file patent rights within and outside the US, we anticipate that both groups of researchers would suffer from the negative inception effect of patent enforcement. For example, the recent patent infringement lawsuit filed by Biothera and MIT against Biorgin, a Brazilian company, for selling beta 1,3/1,6 gluco polysaccharide ingredients in the U.S. for nutritional supplements and functional foods is not unusual in its international scope. Even among academics, intellectual property rights have been used to established complex international exchange barriers. For example, just as the international scientific community's efforts to treat SARS got underway in 2003, lawyers from the Centers for Disease Control and Prevention (CDC) in Atlanta, the Canada-based British Columbia Cancer Agency (BCCA), and Versitech Ltd., (a for-profit subsidiary of the University of Hong Kong), attempted to patent the virus thought to cause SARS (Yu 2003). The academic agencies justified their actions as securing access and exchange for the scientific community however the potential to shape international exchange was clear and was already evident in the HIV/AIDS patent race initiated by French and US scientists. Nonetheless, we would anticipate that scientists in the foreign sub-community would exhibit a stronger and more rapid adaptation effect as they realize that with a few notable exceptions, few U.S. based recipients of IP licenses are likely to approach foreign scientists for infringement and for contract negotiations. With respect to acquiescence it is not possible to make a strong prediction as to the expanding cost of a given patent on foreign versus US research scientists, except perhaps to note foreign TTOs have less experience with contracts and so the costs from increased enforcement may be higher for them.

Finally, we examine the differential impact of patent grant on researchers engaging in basic versus applied research. We predict that scientists in applied research are more likely to be aware of patents and the requirements of patent licensing, operating as they do at the interface with more commercial research applications. Moreover, scientists who traditionally focus on basic research are likely to have less day-to-day awareness of patents and property rights more generally. Thus, we predict that the inception effect of patent grant is more salient and negative for basic versus applied researchers. However, given the potential for applied researchers to engage in more commercializable follow-on research we would anticipate that they would suffer from a greater acquiescence effect, being increasingly targeted by TTOs and commercial licensees for enforcement on the basis of their follow-on activities. Nonetheless, it is for this group that the potential value of the follow-on research is likely to be highest; it is probably more patentable, more commercializable and more likely to be of interest to future licensees and therefore we would anticipate that this group more rapidly develops mechanisms of adaptation than the basic research sub-community. While we cannot disentangle informal and formal adaptive approaches, we expect the applied sub-community to use formal adaptive mechanisms e.g. lowering the transactions costs to contracting etc.

Empirical Approach

Capturing the Impact of Legal Institutional Change on Knowledge Exchange

The most straightforward context in which to examine the ways in which knowledge exchange varies across different institutional regimes for intellectual property enforcement might be to explore knowledge work in arenas with and without intellectual property rights. However, as noted above, this approach is subject to several potential identification issues. Most critical is that differences shaping the type of knowledge or knowledge community might also lead to variations in the legal institutional environment, making it difficult to disentangle variations in the law from other community- or knowledge-level variations.

Our empirical approach relies on several institutional details of the disclosure, exchange and accumulation of knowledge to overcome these issues. First, we take a sample of very similar “pieces of knowledge” – disclosed in scientific publications - and examine how exchange and follow-on accumulation of this knowledge develops over time. This allows us to examine the knowledge community around these various ideas rather than focus on individual-level analyses. It is consistent with prior research in studies of knowledge that focus on the accumulation of knowledge building on "pieces of knowledge". Since the widespread availability of comprehensive patent statistics, patents have become a staple measurement tool in studies of knowledge and innovation (Hall, Jaffe and Trajtenberg, 2001). Notwithstanding all the caveats associated with patents, many studies use patent data as a starting point for the analysis of knowledge accumulation (Almeida and Kogut 1999, Cockburn and Henderson 1998; Ahuja 2000; Hoeteker and Agrawal 2007; Ziedonis 2004; Fleming and Sorenson 2004). Given our focus on scientific knowledge communities, we focus our attention on publications, which, while less extensively analyzed by organization scholars, are "inscriptions" providing a critical form of knowledge disclosure for academic scientists (Latour and Woolgar 1979), establishing priority, providing a critical "currency" for prestige and promotion, and bringing credit (Merton 1973; Biagioli 1998). Studies in the sociology of science have made widespread use of publication data to measure individual productivity (Levin and Stephan 1991) while organization studies have attended to the production of papers by firms as measure of innovative output in addition to patents (Gittelman and Kogut 2003; Gittelman 2007).

The second aspect of our empirical approach is to take advantage of the fact that scientists choose to disclose some of the pieces of knowledge as patent-paper pairs, rather than simply as peer-reviewed publications. As described above, when knowledge is disclosed as a patent-paper pairs, a piece of knowledge is initially available for exchange in an institutional environment guided by "academic' rules and norms. Then, at a later point, it transitions into a different institutional environment in which intellectual property rights owners (and licensees) can impose on the knowledge community a variety of legally-based restrictions on exchange and follow-on accumulation. This transition allows us to examine exchange and accumulation in the pre- and post-transition periods, therefore controlling for variations in the type of knowledge and specific details of the knowledge community. The organizations and economics literature uses a variety of such institutional shifts to deepen our understanding of innovation processes (Furman and Stern 2004, Rysman and Simcoe 2007, Hoetker and Agarwal 2007, Murray et al. 2008).

A third element of our empirical approach uses forward citations to the academic publications in other publications as a proxy for the rate of exchange among members of the knowledge community. Ideally, we would like to have a direct measure of knowledge exchange among members of the knowledge community. However, particularly for large-scale quantitative research this is impossible to gather in a systematic fashion. While survey data provide a useful snapshot in time, they do not allow for longitudinal analysis of the type that allows for an investigation of the temporal dynamics of knowledge exchange in response to legal institutional change. Instead, we use forward citations as a measure of the rate at which knowledge accumulation (and we assume knowledge exchange) is taking place. This approach follows a long literature using patent and publication citations to trace the flow of ideas and their follow-on use and accumulation by others in their ideas (de Solla Price, 1965; Jaffe & Trajtenberg, 1996). In the case of patents, the inclusion of citations in follow-on innovations is defines legal "prior art" and signals that the patent has been built upon by others (see Hall, Jaffe and Trajtenberg 2001) making it possible to track knowledge accumulation across people, firms, countries, regions, and time (Almeida et al. 2007). We have chosen to use citations of publications in other publications (in distinction to publication citations in patents) because we are interested in the way in which the scientific community exchanges and builds on published knowledge and how this is impacted by intellectual property enforcement, not the exchange and accumulation of patented knowledge in other patents. Unlike patent citations, scientific citations are more informal and are not enforced by the law. We rely on the seminal work of Merton (1973), Hagstrom (1965) and de Solla Price (1965) in articulating the importance of citation in the system of scientific recognition and rewards and noting the importance of publication citations in tracking the rate and direction of scientific progress.[3] They are part of a strongly enforced community norm recognizing exchange in the scientific community (Hagstrom, 1965; Merton, 1988) and therefore provide a useful index of the degree to which an idea is incorporated into follow-on research (Cole, 2000). They also serve to contextualize and frame the contributions of a particular scientific

[3] We recognize that bibliometric analysis is a noisy indicator of scientific progress (see, e.g., Garfield (1979) and Schubert and Braun (1993)): For a number of reasons, small differences in the citation rate of a single paper (particularly early in its publication history) are of limited value in distinguishing the importance of research or its use by the research community. We take care to minimize the impact of these limitations by drawing comparisons among large samples of publications, comparing across control samples, and assessing the impact of policy changes by drawing comparisons within articles across time.

idea (Latour, 1987) and hence have an important meaning in the scientific literature. There is a long history of empirical analysis of scientific citations to measure networks of scientists (Crane, 1969). These citations may represent only the tip of the iceberg of research that builds on a published piece of knowledge but they are a critical element needed by follow-on researchers for continued knowledge accumulation (Murray & O'Mahony, 2007). It is also possible that scientists engage in strategic citing behavior; however, we find little qualitative evidence to support the notion that in the presence of on-going scientific exchange, citation patterns vary in response to patent grant and enforcement.

Identification – Patent Grant Delay

Our empirical framework relies on the fact that institutional change induces changes in the rate of production of scientific articles citing the article in the patent-paper pair relative to pre-patent grant levels.[4] This experimental approach exploits the fact that changes in the legal institutional environment changes does not impact the original "piece of knowledge" but instead (potentially) impacts the ways in which follow-on researchers exchange the knowledge and therefore their opportunities to exploit that piece of knowledge in their own research. The identification embodied in patent-paper pairs relies on the patent-grant delay – a substantial gap between the date of scientific publication and the date at which the associated patent is granted.[5] This empirical technique exploits the insight that while publication in the scientific literature often occurs within six months (or less) after initial submission to a journal, the delay between the initial application and receipt of a patent is often many years (in most cases a 2-4 year time window). It is important to emphasize that patent grant delay is more than simply a matter of the timing of a *pro forma* administrative decision. During the time between application and grant, applicants and examiners undertake detailed

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[4] There are, of course, some important caveats to this approach. First, not all research is disclosed in the scientific literature; indeed, for-profit entities may decline to publish research results either to increase the costs of rivals' research or in the event that such results are disadvantageous for the firm. Second, a increases citations (relative to a baseline) may occur not because of the increased importance of a particular 'unit' of knowledge, but simply because of the ease of its availability relative to alternative pieces of knowledge or for other reasons (such as changes in author prominence or position) that do not reflect changes in the actual use of knowledge. Such problems would average out across the areas we study, unless these changes are closely correlated with the specific policy or institutional changes we study.

[5] The specifics of patent law regarding the timing of disclosure are complex and have been subject to change. Under US patent law, inventors have a grace period of twelve months between public disclosure (for example in an academic publication or presentation) and filing for patenting covering that knowledge. Thus, the timing of the publication submission and patent application can vary among patent applications with some filed before publication and some after.

negotiations about the scope and extent of the patent grant, and so there is significant uncertainty about the extent of IPR prior to grant (Cockburn, Kortum, and Stern, 2002; Jaffe and Lerner, 2004). Perhaps more saliently, prior to the patent grant date, the patent applicant holds no formal IPR, and, in nearly all cases, cannot sue for infringement for activities undertaken during the pre-patent grant period. Finally, until 2001 (and thus for nearly all of the cases within our empirical work), USPTO patent applications remained *secret* until granted. In other words, for any given patent-paper pair, we observe the same "piece" of knowledge in two distinct institutional regimes: one associated with the pre-patent grant period and then a regime shift into the post-patent grant period. Recent research shows that this shift from uncertain to certain property rights is salient in terms of the timing patent licensing (Gans, Hsu & Stern, 2007).

We assume that the impact of intellectual property on the use of knowledge by *follow-on* researchers is (conditionally) independent of the patent filing decision. This is in spite of the fact that the decision to patent a piece of knowledge is endogenous to the specific circumstances of individual researchers, including factors such as their institutional affiliation and their gender (Azoulay, Ding and Stuart, 2007; Ding, Murray, and Stuart, 2007; Markiewicz and Diminin 2004; Agrawal and Henderson 2002). A second critical assuming is that the timing of patent grant is random and is not anticipated by those who use and cite the paper, such that the impact of patent grant on follow-on is observable only in the post-patent grant period. In other words, if patents matter, the *rate* of paper citation before and after patent grant should be different.

In our sampling and analytical strategy, our identification strategy has two elements. First, we investigate the extent to which patent grant induces changes in the production of citations to scientific articles in the pre- and post- patent grant (treatment) period, relative to a set of control articles which are not impacted by the treatment i.e. we compare scientific publications that are patent-paper pairs with scientific articles with no paired patent. To the extent that these differences are exogenous, comparing the citation patterns helps us to evaluate the inception effect, adaptation and acquiescence effects. Second, assuming (and testing) that the timing of patent grant is random and exogenous to any observable article (or patent) characteristics, we use the variation in patent grant to evaluate the precise impact of intellectual property grant on the pre- and post-grant citation rates. This allows us to identifying the patent grant effect exclusively within the sample of patent-paper pairs.

Data & Methods

Patent-Paper Pairs Sample

Our sample is composed of published scientific research articles of roughly similar "quality" which disclose knowledge that is potentially patentable (whether or not the researchers choose to apply for IPR). The scientific publications are drawn from the 340 research articles published in a narrow time window (1997-1999) in top-tier research journal *Nature Biotechnology* previously analyzed by Murray and Stern (2007a). This time horizon allows us to examine the changing impact of patent enforcement in the controversial period 1999 – 2005 (none of the patents in our sample are granted prior to 1999). We contrast this perspective with many excellent studies of the impact of the 1980 Bayh-Dole Act, which examine the rise in academics filing for patent rights in the 1980-2000 period (Mowery et al. 2001). Our analysis examines the impact of changing enforcement of these rights on others in the late 1990s/early 2000. The journal selection is grounded in explicitly editorial goal of featuring research with potential applications to biotechnology: *"[the journal] aims to publish high-quality original research that describes the development and application of new technologies in the biological, pharmaceutical, biomedical, agricultural and environmental sciences, and which promise to find real-world applications in academia or industry. We also have a strong interest in research that describes the application of existing technologies to new problems or challenges, and basic research that reports novel findings that are directly relevant and/or of interest to those who develop biology into technology*." In other words, research published in *Nature Biotechnology* is both high quality and "at risk" of serving as a simultaneous foundation for future scientific studies and commercial exploitation and therefore "at risk" of forming a patent-paper pair.

While the journal publishes scholarly material in a variety of formats, the Murray-Stern (MS) dataset is confined to research articles - defined by the editorial policies of the journal as "a substantial novel research study" (see *Nature Biotechnology*, A Guide to Authors). For each of the 340 articles it was determined whether a patent associated ("paired") with the article had been granted by the USPTO. A number of approaches to this pairing have been devised (Ducor 2000, Murray 2002, Lissoni and Montobbio 2007, Franzoni and Scellato 2007, Huang and Murray 2007). In this instance, the basic search included i) the first, last and corresponding authors for the article and ii) the list of institutions found in the article "address field" in the Web of Science database. Different combinations of authors and/or institutions were used (from the most to the least inclusive) in order to identify all issued patents associated with the authors and institutional affiliations whose research appeared in *Nature Biotechnology*. After establishing the set of patent grants received by individuals and institutions represented in the articles, patent abstracts and claims were read to establish the presence of a patent-paper "pair" i.e. a verification of whether the material described in the abstract of the article was incorporated into the description, claims and/or examples of the granted patent.[6] Using this procedure, 169 of the 340 articles were found to be associated with a paired patent as of October, 2005. In other words, approximately half of all publications in *Nature Biotechnology* are associated with a patent-paper pair within five years of publication.

For the purposes of our current analysis, we sampled only those papers authored by public United States institutions. Under these criteria, the dataset consisted of 174 unique research articles of which 93 (53%) are associated with a granted United States patent. In making this sampling decision, we are guided by the current debate highlighting the ways in which enforcement of patents on academic knowledge transform exchange and accumulation in the knowledge community (Heller 2008). Indeed the surprise for knowledge generated in the private sector is that it is published in the peer-reviewed literature at all –patents are the traditional disclosure the mode for knowledge production in industry (see Gans, Murray and Stern 2008 for an analysis). Second, by focusing on one organizational setting for knowledge -production and patent enforcement we limit the range of possible mechanisms at work as follow-on researchers learn to live with the law. Third, paired patents are generated from searches of the US patent office. We believe that non-US

[6] The criterion used to assign a patent-paper pair was conservative insofar as there had to be a direct connection between the disclosures in the article abstract and patent record. In the vast majority of cases, the presence (or not) of a patent-paper pair was unambiguous. We also developed independent confirmation of patent-paper pair matching from a colleague using an alternative, automated matching method.

researchers may initially file for patents outside the US (or exclusively outside the US) leading to inaccuracies in our characterization of IP rights over non-US authored research.

For each of the 174 articles and 93 patents we gathered variables on observable characteristics: number of authors/inventors, number of institutional addresses/assignees, date of publication/application etc. We also gathered all the forward citations in scientific articles to the 174 research articles. Among the complete set of forward citations we selected only those that were designated as "research articles" according to ISI Web of Science. This amounted to 14,688 forward citations which were then coded for a series of variables: number of authors, the number and type of institutional affiliations (public versus private sector), the rank of institutional affiliation, and the country of institutional affiliation

Empirical Specification

Measuring the impact of scientific research using citations implies that we must account for its form as count data skewed to the right (and likely over-dispersed relative to Poisson). Therefore, except where noted, we employ a negative binomial model of the annual citations for each scientific article in our dataset. Moreover, the impact of a given piece of research, as measured by citations, will vary considerably with the underlying importance of the research discovery, with the time elapsed since initial publication, and with the year for which the citations are being considered. As such, our empirical specifications account for individual publication quality (through article fixed effects), for the effects of publication age and the overall rate of citation in a given year (through age and citation year fixed effects.[7] As an overall measure of the impact of patent grant, the baseline model specified by Murray and Stern (2007a) incorporates a dummy variable - POST-GRANT - equal to one in those years after the patent grant year. By observing citations to a scientific publication before and after the patent is received (and because we observe a control group of similar

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[7] Several subtle issues, including an incidental parameters problem, arise in incorporating multiple fixed effect vectors into a negative binomial specification. We experimented with a range of alternative approaches, including the conditional negative binomial estimator (Hausman, Griliches, and Hall, 1984) and the fixed effects estimator (Allison and Waterman, 2002). All of our qualitative findings are unchanged across these different procedures; building on recent results about the relative size and importance of the small sample versus asymptotic bias arising in count data models, we report fixed effects results using robust standard errors (Allison and Waterman, 2002; Greene, 2004).

publications which never receive a patent) we are able to identify how the temporal pattern of citations to a scientific publication changes as the result of patent grant.[8] Specifically, this baseline estimator is:

$$CITES_{i,j,pubyear(j),t} = f(\varepsilon_{i,j,t}; \gamma_i + \beta_t + \delta_{t-pubyear} + \psi POST-TREATMENT_{i,t}) \qquad (1)$$

where (γ_i) is a fixed effect for each article, β_t is a year effect, $\delta_{t\text{ - pubyear}}$ captures the age of the article, and POST-TREATMENT is a dummy variable equal to one only for years after the knowledge linked to the article is affected by the institutional or policy change. The coefficient on POST-GRANT (□) indicates the marginal impact of the intervention on the set of treated articles. Thus, we test for the impact of patenting by calculating how the citation rate for a scientific publication *changes* following such interventions, accounting for fixed differences in the citation rate across articles and relative to the non-parametric trend in citation rates for articles with similar characteristics.

While this specification provides an aggregate assessment of the impact of the IP rights on forward citations in the years following patent grant it does not provide any insight into the dynamic nature of intellectual property rights as they shape follow-on researchers with different affiliations. In order to tease out these effects we provide a more nuanced baseline specification with three variables capturing the varying forces that contour the impact of patent enforcement on follow-on scientific research. As outlined in our theoretical approach, we identify three distinctive parameters to account for the changing impact of patents on forward citations over time. The first is the "baseline" impact of patent with is the "inception effect" of a piece of knowledge moving into the post-enforcement institutional regime. The next is a "patent acquiescence effect" with identifies the impact of the patent in each year following patent grant and provides an estimate of the trend associated with enforcement of a given patent on publication citations to the paired publication in the years after the "inception" impact. Finally, we identify an "adaptation effect" variable that pertains to the

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[8] This baseline analysis does assume that the age fixed effects associated with citation do not depend on whether a paper receives a patent. In particular, a key assumption of our base model (which we later relax) is that patented articles are not simply "shooting stars" – articles that, for exogenous reasons, experience a high rate of early citation followed by a rapid decline. In part, the "shooting star" hypothesis would be counterfactual to the most well-documented pattern of scientific citation, the so-called Matthew Effect, in which articles with a high rate of early citation tend to continue to receive an ever-higher rate of citation after a favorable early record (Merton, 1973). Also, in our robustness analysis, we actually rely exclusively on a sample of *patented* articles (with varying patent grant lag times), and find a similar pattern of results.

impact of any patent in a given calendar year after 1999 – the initial year in which patents are granted in our sample. This variable is intended to capture the role of adaptation and waning impact of all patents enforce in a given year. Taken together, our more dynamic empirical test therefore:

(2)
$$
\begin{aligned}
CITES_{i,t} = f(\varepsilon_{i,t}; \gamma_i + \beta_t + \delta_{t-pubyear} + \psi_0 POST-GRANT_{i,t} \\
+ \psi_{PatentTax}(t - grantyear_i) * POST-GRANT_{i,t} \\
+ \psi_{Adaptarion}(t - 1999) * POST-GRANT_{i,t})
\end{aligned}
$$

While the preceding analysis focuses on the impact of institutional changes on the overall count of citations to a given piece of knowledge, as we have outlined, the grant and enforcement of IP rights is likely to have quite different implications for different subpopulations in the life science knowledge community. To evaluate these margins, we take advantage of the citation-level data that facilitates detailed coding of the types of citations that are received by *Nature Biotechnology,* breaking them down into subpopulations: academic vs. industry; high status vs. low status; basic vs. applied, US vs. non-US. To estimate the dynamic impact of patent grant on each of these subpopulations, we can aggregate these individual citations into counts of the number of citations received by a given article in a given year by a given subpopulation of citers:

(3)
$$
CITES_{i,l,t} = f(\varepsilon_{i,j,t}; \gamma_i + \lambda_l + \beta_t + \delta_{t-pubyear} + \sum_{l=1,...L} \psi_l \iota_l POST-TREATMENT_{i,t})
$$

In other words, ψ_l is the average impact of the treatment on sub-population *l*, conditional on a fixed effect for each article, and age and citation-year fixed effects.

Results

Our results proceed in several stages. In Table 3, we begin by first replicating the results described in Murray and Stern (2007) using the entire Nature Biotechnology sample of 341 publications. Despite some modest changes in the dataset (we use a "micro" dataset composed of individual citations as opposed to a manual count of citations per article per year), the basic patterns of results accord with the prior findings for the sample period 1997-2002. These results show that when we examine citations through 2002, either focusing on the full sample or only those where a patent is actually received, we observe a significant decline in the rate of citation after patent grant (similar to earlier findings, we find 13% decline for citations through 2002 using both patented and unpatented papers). However, when we extend the analysis to the sample through 2005, we observe a very different "aggregate" result – patents are associated with a modest and marginally significant positive increase in the citation rate. In other words, as we increase the period of time of our sample, our evidence for a modest "anti-commons" effect is reduced, and indeed we find some evidence consistent with the development of a "market for ideas." The remainder of our empirical analysis explores this pattern in a more structured way building on the theoretical framework outlined above. Specifically, in Table 4, we present our main evidence for the role of communitywide adaptation to the impact of patents on cumulative scientific research, accounting for three separate effects:

- The baseline "inception effect" of a patent granted in 2000 for citations during the year 2000
- The patent "acquiescence effect" which captures the increasing impact of a patent as the years since the patent is granted increases
- The patent "adaptation effect" which captures how the "baseline" effect changes over time, relative to the year 2000.

The results are quite striking. First, and most importantly, while the inception effect is quite negative (a 25% decline in the citation rate) and the patent acquiescence effect is also significant (the negative impact of patents increases at a rate of 13% per year since the date of grant). The rate of adaptation is also impressive – with a 19% increase in the "baseline" impact of patents each calendar year. This result implies that, by 2003, the "net" impact of a patent in its first year of grant was actually positive, and that by 2005, the impact of the patent system was a net "positive" for essentially all patent vintages. This effect is documented even more strikingly in the second column where we estimate a "baseline" effect for each year, from 2000 to 2005. The predicted "baseline" impact of patents becomes more favorable in each and every year, going from a 30% reduction in 2000 to more than a 70% predicted increase in citations as of 2005.

Learning in Different Research Sub-Communities

While the results in Table 4 provide useful evidence for our core hypotheses related to the impact of patents over time on the aggregate research community, our detailed micro-data allows us to evaluate these issues more precisely by comparing the impact of patents across different sub-communities. We begin in Table 5-I examining the difference in the impact of patents for public sector and private sector authors. The results accord well with our predictions. Specifically, while patent grant has very *little* impact on private sector behavior, our core results of a negative inception effect and then adaptation between 2000 and 2005 are well captured in the behavior of public sector citation behavior. In other words, while most companies likely have procedures and experience in conducting innovation, public sector researchers seemed to have faced significant costs in managing intellectual property at the beginning of our sample and have become more adept at that over time.

A similar pattern can be observed across the remaining "margins" of the data. In particular, there seems to be significant differences between "high-quality" journal publication versus other journals, and, most striking, our results are particularly salient for research teams located in a single institution. Overall, our pattern of results accords with a model where the impact of patents has changed significant in life sciences research over time, and the "anti-commons" environment of the late 1990s seems to have been mostly replaced by a more productive "market for ideas."

Conclusions

Our findings have some important implications for the debate over IP and knowledge work. In particular, the dynamics of knowledge work suggests that cross-sectional approaches will not capture the range of ways in which communities learn to live with and adapt to the law. This approach suggests a resolution of the current empirical impasse in the anti-commons debate: In the period studied by Heller and Eisenberg (1998), the impact of patents was significant and the rapid rise of patents caused a shock to the academic community and was of growing salience as universities sought to impose their IP rights on many community members. However, by the time of the survey-based analyses by Walsh and co-authors, the life science community had adapted to patents. They continued to file patents, but their impact on knowledge work had become curtailed as the community – through a combination of contractual and normative mechanisms – adapted to limit the deleterious impacts of IP rights and reinforce the traditional practices of the academic sphere (Murray 2008). Such a resolution to the debate over law in the life science community serves as a framework for other studies of law and knowledge work, suggesting a promising research agenda examining the role of law as it shapes the daily lives of knowledge communities across a broad range of sectors and work. Rather than simply document whether or not law impacts knowledge work, this agenda can encompass rich quantitative and qualitative analyses of the ways in which different communities learn to live with the law, the rate of adaptation and the extent of adaptation. Work in areas as diverse as fashion (Sprigman 2007), cuisine (Fauchart and Von Hippel, 2007) and software (O'Mahony 2003) suggest that different communities will develop distinctive adaptive strategies to IP rights.

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Table 1
Variables & Definitions

VARIABLE	DEFINITION	SOURCE
CITATION-YEAR CHARACTERISTICS		
ANNUAL FORWARD CITATIONS$_{jt}$	# of Forward Citations to Article *j* in Year *t*	SCI
YEAR$_t$	Year in which FORWARD CITATIONS are received	SCI
AGE$_{jt}$	YEAR – PUBLICATION YEAR	NB
CITATION CHARACTERISTICS		
CITE ARTICLE$_i$	Dummy variable equal to 1 if citation is a research article; 0 otherwise	SCI
CITE REVIEW$_i$	Dummy variable equal to 1 if citation is a review; 0 otherwise	SCI
CITER TIER 1$_i$	Dummy variable equal to 1 if citation is published in tier 1 journal; 0 otherwise	SCI / JIF
CITER TIER 2$_i$	Dummy variable equal to 1 if citation is published in a tier 2 journal; 0 otherwise	SCI / JIF
CITE PRIVATE$_i$	Dummy variable equal to 1 if *at least* one of the institutions associated with Article *j* is a biotech or pharma company; 0 otherwise	SCI
CITE PUBLIC$_i$	Dummy variable equal to 1 if *at least* one of the institutions associated with Article *j* is a public entity; 0 otherwise	SCI
CITE US$_i$	Dummy variable equal to 1 if *at least* one of the institutions associated with Article *j* is in the U.S.; 0 otherwise	SCI
CITE MULTI0$_i$	Dummy variable equal to 1 if institutional affiliations with Article *j* contain *only* 1 institution; 0 otherwise	SCI
CITE MULTI1$_i$	Dummy variable equal to 1 if institutional affiliations with Article *j* contain *more than* 1 institution; 0 otherwise	SCI
PUBLICATION CHARACTERISTICS		
PUBLICATION YEAR$_j$	Year in which article is published	NB
# AUTHORS$_j$	Count of the number of authors of Article *j*	NB
US AUTHOR$_j$	Dummy variable equal to 1 if *at least* one of institutional affiliation associated with Article *j* is in the US; 0 otherwise	NB
PUBLIC AUTHOR$_j$	Dummy variable equal to 1 if *at least* one of the institutional affiliation associated with Article *j* is a university; 0 otherwise	NB
PRIVATE AUTHOR$_j$	Dummy variable equal to 1 if *at least* one of the institutional affiliation associated with Article *j* is a biotech or pharma; 0 otherwise	NB
TOTAL CITATIONS$_j$	# of FORWARD CITATIONS from publication date to December 2005	SCI
PATENT CHARACTERISTICS		
PATENTED$_j$	Dummy variable equal to 1 if Article is associated with a patent issued by the USPTO prior to October, 2003	USPTO
GRANT YEAR$_j$	YEAR in which PATENT has been granted	USPTO
PATENT AGE$_{jt}$	Age of patent defined as YEAR – GRANT YEAR	USPTO
PATENT POST-GRANT$_j$	Dummy variable equal to 1 if PATENTED = 1 and YEAR > GRANT YEAR	USPTO
PATENT TREND$_j$		USPTO
PATENT TAX$_j$		USPTO
# INVENTORS$_j$	Count of the number of inventors listed in the granted patent associated with Article *j*; 0 if PATENTED = 0.	USPTO

USPTO – United States Patent Office; NB – Nature Biotechnology; SCI – Science Citation Index; JIF – Journal Impact Factor

Table 2

Means & Standard Deviations

VARIABLE	N	MEAN	STANDARD DEVIATION	MIN	MAX
CITATION-YEAR CHARACTERISTICS					
FORWARD CITATIONS	917	11.49	19.39	0	315
CITATION YEAR	917	2001.95	2.09	1998	2005
AGE	917	4.05	2.09	1	8
CITATION CHARACTERISTICS					
CITE ARTICLE	917	8.21	13.77	0	213
CITE REVIEW	917	3.01	5.77	0	97
CITER TIER 1	917	0.37	0.83	0	6
CITER TIER 2	917	0.86	1.62	0	17
CITE NB	917	0.23	0.66	-2	8
CITE PRIVATE	917	1.92	4.70	0	61
CITE PUBLIC	917	10.59	17.29	0	288
CITE US	917	6.40	11.31	0	162
CITE MULTI0	876	5.21	9.01	0	122
CITE MULTI1	876	1.89	3.71	0	54

Table 3

Impact Of Patent Grant:
Difference-In-Difference Estimates Over Different Time Periods

Poisson Specifications	Dep Var = ANNUAL FORWARD CITATIONS [Incident rate ratios reported in square brackets] (Robust coefficient standard errors reported in parentheses)		
	3-1 Cite years 1997-2003 All articles	3-2 Cite years 1997- 2003 Patented articles only (PATENTEDj=1)	3-3 Cite years 1997-2005 All articles
PATENT POST-GRANT	*[0.877]* *(0.065)*	**[0.724]** **(0.075)**	**[1.153]** **(0.083)**
Article FE	Y	Y	Y
Age FE	Y	Y	Y
Citation-Year FE	Y	Y	Y
# Observations	524	337	917
Log-likelihood	-1314.69	-942.91	-2454.28

Table 4

Estimating Temporal Trends In Impact Of Patent Grant

Difference-In-Difference Estimates

Poisson Specifications	Dep Var = ANNUAL FORWARD CITATIONS [Incident rate ratios reported in square brackets] (Robust coefficient standard errors reported in parentheses)	
	4-1 With patent shock, patent tax & patent learning variables	4-2 With annual patent impact variables
PATENT POST-GRANT	*[0.757]* *(0.113)*	
PATENT TAX (ANNUAL)	**[0.876]** **(0.057)**	*[0.875]* *(0.062)*
PATENT LEARNING TREND (ANNUAL)	**[1.190]** **(0.083)**	
PATENT POST_GRANT IMPACT 2000		[0.716] (0.149)
PATENT POST_GRANT IMPACT 2001		[0.984] (0.099)
PATENT POST_GRANT IMPACT 2002		[1.006] (0.085)
PATENT POST_GRANT IMPACT 2003		**[1.301]** **(0.121)**
PATENT POST_GRANT IMPACT 2004		**[1.551]** **(0.288)**
PATENT POST_GRANT IMPACT 2005		**[1.797]** **(0.479)**
Article FE	Y	Y
Age FE	Y	Y
Citation-Year FE	Y	Y

Table 5

Difference-In-Difference Estimates by Institutional Affiliation

Poisson Specifications	Dep Var = FORWARD CITATIONS [Incident rate ratios reported in square brackets] (Robust coefficient standard errors reported in parentheses)	
	5-1 Citations by Public Sector Authors	5-2 Citations by Private Sector Authors
PATENT POST-GRANT IMPACT	**[0.722]** **(0.112)**	[1.054] (0.281)
PATENT TREND	**[1.216]** **(0.089)**	[1.006] (0.109)
PATENT TAX	**[0.864]** **(0.058)**	[1.065] (0.113)
Article FE	Y	Y
Age FE	Y	Y
Citation-Year FE	Y	Y

Table 6

Difference-In-Difference Estimates by National Affiliation

Poisson Specifications	Dep Var = FORWARD CITATIONS [Incident rate ratios reported in square brackets] (Robust coefficient standard errors reported in parentheses)	
	6-1 Citations by US Authors	6-2 Citations by Non-US Authors
PATENT POST-GRANT INCEPTION EFFECT	[0.788] (0.137)	*[0.707]* *(0.141)*
PATENT ADAPTATION EFFECT	*[1.140]* *(0.086)*	**[1.267]** **(0.112)**
PATENT ACQUIESCENCE EFFECT	[0.965] (0.071)	**[0.773]** **(0.062)**
Article FE	Y	Y
Age FE	Y	Y
Citation-Year FE	Y	Y

Table 7

Difference-In-Difference Estimates by Institutional Status

Poisson Specifications	Dep Var = FORWARD CITATIONS [Incident rate ratios reported in square brackets] (Robust coefficient standard errors reported in parentheses)	
	7-1 Citations by Top Tier Authors	7-2 Citations by Low Tier Authors
PATENT POST-GRANT IMPACT	*[0.693]* *(0.142)*	[0.775] (0.131)
PATENT TREND	*[1.177]* *(0.101)*	**[1.202]** **(0.091)**
PATENT TAX	[0.985] (0.083)	**[0.832]** **(0.058)**
Article FE	Y	Y
Age FE	Y	Y
Citation-Year FE	Y	Y

Table 8

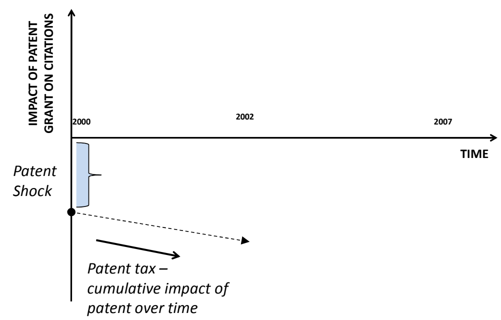
Difference-In-Difference Estimates by Number of Authors

Poisson Specifications	Dep Var = FORWARD CITATIONS [Incident rate ratios reported in square brackets] (Robust coefficient standard errors reported in parentheses)	
	8-1 Citations by Multiple Organization Authors	8-2 Citations by Single Organization Authors
PATENT POST-GRANT IMPACT	[0.822] (0.226)	**[0.745]** **(0.105)**
PATENT TREND	[1.043] (0.126)	**[1.219]** **(0.081)**
PATENT TAX	[1.000] (0.109)	**[0.853]** **(0.053)**
Article FE	Y	Y
Age FE	Y	Y
Citation-Year FE	Y	Y

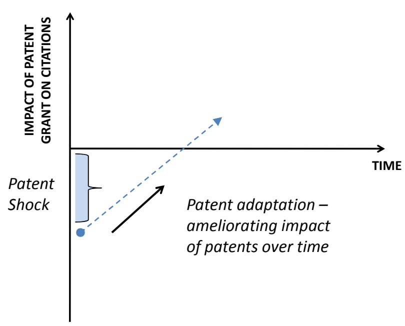
Figure 1

Learning to Live with Patents
Patent Shock only

Learning to Live with Patents
Patent Shock & Patent Tax



Learning to Live with Patents
Patent Shock & Patent Tax & Patent Adaptation



Learning to Live with Patents
Patent Shock & Patent Tax & Patent Adaptation