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Learning to Live with Patents: Acquiescence & adaptation to the law by the life sciences community

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Abstract:
Scholarly studies of how the law affects knowledge work tend to fall between two extreme views. Economists, as well as legal and policy scholars, debate how changes in legal institutions, particularly in expanding property rights, shape the daily lives of knowledge workers. In contrast, ethnographies of knowledge work usually fail to highlight lawyers as key actors. The current study reconciles these views, arguing that in response to changing legal institutions, knowledge communities engage in both costly acquiescence and adaptation to the law. This perspective suggests that while the law may cause significant disruption to knowledge communities, through their adaptation the law becomes commonplace and unremarkable. Our study measures these processes by tracing how changes in the enforcement of intellectual property rights shape patterns of knowledge exchange and accumulation within knowledge communities. Specifically, we conduct a large-scale quantitative analysis of publications and patents drawn from a period characterized by dynamic changes in property rights enforcement, assessing how enforcing intellectual property rights over scientific knowledge influences the life sciences community. Our analysis reveals that initially, IP engenders costly acquiescence on the part of academic scientists, reducing their level of knowledge exchange. Over time, however, adaptation exerts an even larger influence, facilitating exchange even in the presence of IP rights. Consequently, the long-term impact of patent law reflects a balancing act between the processes of acquiescence and adaptation. More broadly, our work suggests that legal institutions play an important, though subtle, role in the structure and practices of knowledge communities and knowledge work.

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Learning to Live with Patents:
Acquiescence & adaptation to the law by the life sciences community

Legal institutions play a pervasive, sometimes problematic, role in the knowledge economy. Through its influence on the speed and effectiveness of knowledge exchange, the law is an essential part of the institutional backdrop of the daily knowledge work of individuals, organizations and communities (Furman & Stern 2008, Murray & O'Mahony 2007). While knowledge exchange among individuals is critical to the process of knowledge accumulation, exchange is not an inherent property of knowledge (Polyani 1965, Mokyr 2002). Instead, it is the institutional context of knowledge work that critically shapes how individuals can build on one another's ideas, driving knowledge accumulation and, with it, growth (Merton 1973, Nelson, 1993, Romer 1996, Mokyr 2002).

Intellectual property (IP) rights are among the most important legal influences on knowledge work. Over the past two decades, formal IP rights have grown in importance in virtually every area of knowledge work (Heller 2008): from the proliferation of patents over research traditionally placed in the public domain (Heller & Eisenberg 1998) to the copyright status of "sampled" music (Perry 2004). What lies at the core of this transformation is not the grant of IP rights *per se* but the expanding enforcement of these rights. For example, the role of IP rights in the development of collaborative technical standards (such as those for cellular phone hardware and software) depends crucially on the legal rules governing patent enforcement after standards are established (Simcoe, Graham & Feldman 2007). Similarly, in academia, controversy erupted over human embryonic stem cell patents, not when patents were granted but when the University of Wisconsin (the patent owner) imposed complex licensing terms on those wanting to use the materials and methods (Murray 2007).

While the legal institutions defining intellectual property in the knowledge economy are the subject of vigorous debate among legal scholars, economists and policy makers (David 2003, Jaffe & Lerner 2004), organizational scholars have been largely silent on the role of the law in knowledge work (with O'Mahony (2003) and Marx et al (2007) as notable exceptions). Contrary to anecdotal accounts of knowledge workers' lives, scholarly studies rarely acknowledge that lawyers are key actors on the stage of most knowledge communities. For example, while the seminal ethnography of design firm IDEO describes the nuanced way in which the firm uses its position as a knowledge broker to recombine and accumulate knowledge (Hargadon & Sutton 1997), its thick description of knowledge work makes little mention of the terms and conditions of knowledge access, reuse, confidentiality, and non-compete requirements. Nor does it examine the contentious matter of how patent rights are assigned from IDEO's collaborative development process. This neglect of the law is particularly surprising given the long-standing recognition that organizations are "immersed in a sea of law" (Edelman & Suchman 1993). While organizational theories of knowledge communities ignore the importance of law in their assumptions, legal institutions likely exert an important influence on the practice of knowledge work.

This paper develops and tests a novel theoretical framework describing the role of the law in knowledge work. Grounded in the sociology of law (Edelman 1992, Sutton & Dobbin 1996, Dobbin & Kelley 1999) and the law and society literature (Black 1976, Selznick 1992), we argue that knowledge workers respond to constraints imposed by legal institutions in two distinct (but potentially co-existing) ways: acquiescence and adaptation. Consider how the exchange practices of a knowledge community respond to the changing legal status of knowledge, as might occur with the granting of formal IP rights. According to our proposed framework, the first consequence of IP enforcement is the imposition of (burdensome) administrative structures and transaction costs that likely reduce the ability of the community to exchange knowledge effectively. In other words, *acquiescence* to legal constraints limits knowledge exchange. Over time, a second force emerges – *adaptation* – as members of a knowledge community learn to live with legal change and develop formal and informal mechanisms to harness the new legal regime to their advantage. For example, licensing practices may become standardized in some areas while enforcement may be eschewed in others through the emergence of informal norms. According to our acquiescence-adaptation framework, the law is neither a bludgeon used to control knowledge workers nor is it irrelevant to knowledge communities. Instead, while legal transformations initially impose behavioral changes on knowledge communities, over time communities mediate the impact of the law, thus shaping the opportunities and constraints of knowledge workers. It is only through the combined influence of both acquiescence and adaptation processes that the legal status of knowledge is transformed, ultimately allowing the law to fade into the background of daily knowledge work (Ewick & Silbey 2003).

As an example of this theory in action, we analyze a widely discussed problem at the intersection of law and knowledge work – how the expansion of patents on scientific knowledge and the growing enforcement of these patents influence knowledge accumulation by the scientific community (Heller & Eisenberg 1998, Walsh et al. 2003, 2005; Murray & Stern 2007). To evaluate the theory we develop a novel empirical framework that employs scientific citations as a measure of knowledge exchange and resulting knowledge accumulation. By taking a sample of scientific papers, some of which have paired patents (covering the same knowledge), we determine how the rate of citation to each paper (in subsequent papers) *changes* by comparing citation rates before and after patent grant in the life sciences, publication is much more rapid than patent grant). Building on a recent stream of research that utilizes scientific citation data to evaluate the causal role of institutions on knowledge work (Murray & Stern 2007, Furman & Stern 2008, Rysman & Simcoe 2008), this empirical approach allows us to disentangle the role of acquiescence from adaptation. Specifically, we argue that while the acquiescence hypothesis implies that patent grant has a *negative* impact on the citation rate of the particular paper, adaptation implies that the influence of *all* granted patents evolves with time to mitigate the negative consequences of acquiescence.

We find strong evidence for both forces in our data. The initial impact of patent grant on scientific citations is negative and increases with the time elapsed from the grant date. However, consistent with the adaptation hypothesis, the impact of all patents declines over time, and they are ultimately associated with an increased rate of scientific citation. Both effects are particularly salient for academic researchers. As the canonical knowledge community relying on informal norms of exchange (Crane 1969), these individuals are likely to be (a) initially unprepared for the enforcement of IP rights (resulting in initially high levels of acquiescence) and (b) able to harness shared norms and informal mechanisms to mitigate the impact of IP rights (resulting in high levels of adaptation over time). Our framework and findings thus shed light on the interactive dynamics between knowledge communities and knowledge law in the process of collaborative knowledge production.

Legal Foundations of Knowledge Exchange

At the heart of knowledge accumulation lies the ability of individuals, organizations and communities to learn from others who disclose ideas, exchange knowledge among members and provide sufficient access to enable replication, validation and follow-on innovation (Rosenberg 1984, Mokyr 2002). The micro-foundations of knowledge exchange, as developed in the organizational literature, highlights the central role of shared language, shared meanings and artifacts in allowing for knowledge transfer from one individual (or group) to another (Star & Griesemer 1989, Brown & Duguid 1991, 2001; Bechky 2003ab). The norms and practices shared within a knowledge community become more salient when we recognize the role of tacit knowledge, directing attention to the need for personal (rather than disembodied) relationships in mediating knowledge exchange (Polanyi 1967, Collins 1974). Moreover, materials play a central role in accumulation (Kohler 1994, Rader 2004, Furman & Stern 2008), providing crucial artifacts that might otherwise be costly and time consuming to replicate and validate (Galison 1997, Carlile, 2004). Recognizing that the terms of trade of any "piece of knowledge" are contingent upon the particular knowledge community (Knorr-Cetina 1999), social networks and the relationships they embody influence the likelihood and effectiveness of knowledge exchange and accumulation over time (Powell et al. 1996, Hansen 1999, Fleming 2001, 2007; Reagans & Zuckerman 2002, Uzzi & Sprio 2006).

While social relationships are central to knowledge communities, are all overtures seeking knowledge exchange fulfilled? If not, what are the origins and influence of exchange barriers between knowledge workers? Some barriers reflect informal norms such as those governing competition and knowledge exchange among scientists (Kohler 1994, Blumenthal et al. 1997, Biagioli 2000, Haas & Park 2007). Recent research expands our understanding of the power of these informal rules to shape exchange in diverse communities ranging from gourmet chefs to comedians and even magicians (Fauchart & Von Hippel 2007, Loshin 2007, Oliar & Sprigman 2008). Formal barriers to exchange such as property rights, privacy laws and trade secrecy also exert a significant influence in knowledge communities. For example, comparing Silicon Valley and Route 128, Saxenian (1996) argues that variations in innovation are grounded in the differential legal status and enforcement of non-compete agreements (Almeida & Kogut 1999). Similarly, the propensity of medical communities to adopt electronic medical records is highly dependent on medical privacy laws; the imposition of these laws has reduced the ability of physicians to share clinical knowledge and practice (Miller & Tucker 2008, Culnan & Armstrong 1999).

To illuminate the role of the law in knowledge communities, we focus our attention on instances in which a knowledge community responds to shifts in the legal institutions governing knowledge exchange. In particular, we draw on institutional theory and the law and society literature to identify two broad responses organizations make when pressures arise from shifting institutional environments, such as regulatory structures, governmental policy, laws and court decisions (Scott 1987, Oliver 1991, Edelman 1992). On the one hand, theory emphasizes the importance of *acquiescence* -- conformity with the institutional environment -- and the desirability of adhering to external rules and norms (DiMaggio & Powell 1983, Meyer & Rowan 1977). Acquiescence behavior privileges the importance of high-level institutional change as the key source of pressure determining the impact of law on organizations. On the other hand, theory highlights the potential for organizations to respond to institutional pressures through *adaptation*, actively managing their response by establishing a "negotiated environment" (Pfeffer & Salancik 1978) and even resisting change (DiMaggio 1988). Through their adaptive processes, organizations are able to live more effectively with the institutional change. In the remainder of this section, we extend these ideas to understand the response to knowledge communities to legal change, motivating specific hypotheses that we evaluate in our study of the impact of patents on the life science community.

Acquiescence

Many analyses of the impact of the law on individuals and organizations essentially assume that social actors acquiesce to the law. Rather than bear the costs of challenging or working around the law, acquiescence is the dominant response to law in many key settings: criminal statutes have a significant deterrence effect on behavior, and organizations are responsive to and attempt to be compliant with changes in legal rules and regulations (Fox et al. 1977, Gibson et al. 2005). While the sources of obedience to law and regulation are long-debated, Oliver (1991) identifies three key processes: habit, compliance and imitation. Habit is blind adherence to taken-for-granted rules. As the common response to many legal arrangements, it is generally linked to rules that have attained the status of a "social fact" and is therefore less likely to apply in situations immediately following a significant legal change. On the other hand, imitation and compliance are plausible responses to a change in the law or its enforcement. Compliance is defined as conscious obedience; it is regarded as conscious and even potentially strategic or self-serving (Meyer & Rowan 1983), and it can be attributed both to the legitimacy of the source of legal change and to the costs of non-compliance. The third source of acquiescence -- imitation – is consistent with the role of mimetic isomorphism described in organizational settings, but of course requires at least some actors to act in compliance and serve as a template for imitation (DiMaggio & Powell 1983).

Acquiescence at the community level is distinct from individual or even organizational acquiescence. By definition, knowledge communities permeate organizational boundaries and even cross jurisdictions, and thus their members are governed by a variety of different legal regimes. However, the cohesion and identity of a knowledge community depends on significant levels of isomorphic behavior among members; practices in which shared knowledge is exchanged must be "taken for granted" for exchange to be easy and effective (Hilgartner 1997). As such, knowledge communities are particularly subject to acquiescence, given that each individual's response to a change in the legal regime needs to be coherent across the community. Thus, beyond the strong forces driving imitation within the community, the pressing need for shared practices may drive acquiescence to legal changes by providing the simplest focal point for a coherent behavioral response. Rapid acquiescence to the "copyleft" licensing contract in the open source software community and its emergent status as a taken-for-granted legal arrangement provides a clear example of the power of acquiescence (Coleman & Hill 2004). Even in cases where the legal change dramatically prohibits knowledge production, there can be immediate acquiescence. For example, when researchers determined that the drug thalidomide led to birth deformities during testing on pregnant women, the FDA imposed rules excluding *all* women of childbearing age from clinical trials. The clinical research community complied rapidly with little resistance. It took 25 years for individuals (mostly outside the research community) to articulate the costs of *not* collecting information from women and then change the rules (Epstein 2007).

The key role of shared practices in acquiescence is particularly salient in considering the response of knowledge communities to changes in formal IP rights such as patents. Broadly speaking, the patent system requires innovators to disclose their knowledge (to the level of enablement) in return for property rights allowing them to exclude others from using the knowledge described in the patent, although rights holders have broad discretion over whether to provide, restrict or prohibit access to engaging in follow-on knowledge work.[1] As reflected in the Appeals Court's decision in *Madey V. Duke University*, even academics doing quite fundamental research without explicit commercial goals can be subject to the enforcement of IP rights and at times, may be required to take a license if they want to access patented materials or methods (Dreyfuss, 2004). Consequently, IP rights may significantly limit all knowledge community members seeking to freely exchange and build upon each other's knowledge.

The introduction of formal IP rights and the concomitant threats of legal enforcement throughout the knowledge community raise a legal challenge to the norms and practices of that community (Lessig 2002, David 2003). Given the importance of clear and consistent terms of exchange in such settings, theory suggests that acquiescence will be the dominant response to legal change. However, this is likely to impose onerous licensing restrictions and contractual burdens on members of the community. As a result, we expect that the introduction of formal IP and the potential for onerous compliance will lead to a reduction in the level and quality of knowledge exchange within a knowledge community. This effect should be even more pronounced for those who are unfamiliar with and unprepared for such changes.

Adaptation

The acquiescence hypothesis implies that the shadow of the law is widely cast and results in rapid compliance. However, institutional theory in general and the law and organizations literature in particular raise the additional possibility that, rather than simply acquiesce, communities respond to legal change through adaptation. Thus, while organizations are "immersed in a sea of law" (Edelman & Suchman 1997), the organizational response to the law is complex and constituted through the daily practice of individuals

[1] Some key exceptions to the right to "refuse to license" occur in the cases of national security, 'march-in' rights (where Federal agencies can insist that ideas they have funded are licensed under particular conditions), and in settings where antitrust is binding (Lewis & Yao 1995, Mackie-Mason 2002, Gilbert et al. 1997)

(Silbey 2005). According to this conception, the law is subject to different interpretations and different transformations of practice (Kelly & Dobbin 1999, Dobbin & Kelly 2007). This plasticity arises because the law, rather than being separate from norms and behaviors, is embedded within them, with individuals interpreting and attempting to secure rights in response to particular legal structures (Fuller, Edelman & Matusik 2000). Opportunities to mediate the law and construct the meaning and degree of compliance depend upon three critical conditions: i) the ambiguity of the meaning of compliance, ii) the variation in the legal construction of compliance by the courts and iii) the strength or weakness of enforcement (Edelman 1992). The adaptation hypothesis implies that under these conditions, legal changes are simply "the beginning of law making" (Kelly & Dobbin 1999, p. 487), and organizations may be quite heterogeneous in their capacity to adapt to the law over time (Meyer & Argyres 2004).

Adaptation to institutional change likely involves diverse responses at both the individual and community levels (Heimer 1985). Organization theory documents several adaptation approaches that knowledge communities might pursue: compromise, avoidance and defiance (Oliver 1991). Compromise is a tactical response that allows for partial compliance, either through active negotiation or through trial and error in anticipation of enforcement (Powell & Friedkin 1986). In contrast, members of knowledge communities may adapt via full or partial avoidance, examining the rule of law and then choosing to ignore its terms in certain areas of knowledge work. This approach is predicated on the assumption that the rules do not strictly apply, the belief that enforcement may be limited or the hope that the community can be buffered from external scrutiny (Pfeffer & Salancik 1978). This form of adaptation is akin to university researchers simply ignoring patents, and neglecting to conduct patent searches (Walsh et al. 2005). Finally, defiance can be the source of more direct challenges to legal change, with knowledge communities collectively fighting the nature of the scope of legal change (Murray 2008). Whatever the adaptive response, relative to the immediacy of acquiescence, adaptation likely takes time and is highly contingent on the local environment, institutional context, and the network structure of the knowledge community (Knorr-Cetina 1999).

Changes in formal IP rights will, we predict, lead to considerable adaptation by knowledge communities. As emphasized by Lemley and Shapiro (2005), patents are *probabilistic property rights* -- the meaning of infringement is ambiguous, the outcome of a particular court cases is highly uncertain, and the cost of patent enforcement (and infringement defense) is extraordinarily high. Moreover, IP rights are facilitative, providing their owners with a variety of legal rights that they may *or may not* use (Edelman & Suchman 1997). IP rights are also inherently flexible: they are rights for excluding others, but they are also a source of prestige, a means of controlling the innovation direction of others, and a source of potential rewards and collaboration with others (Murray 2008). Together, ambiguity in scope and discretion in the use of IP rights mean that the degree and speed of adaptation of new knowledge by a knowledge community depends on collective action, guided by shared meanings, practices and opportunities.

Knowledge communities can and do practice acquiescence and adaptation simultaneously. Understanding both of these behaviors helps in constructing a framework for comprehending and interpreting the role of law in knowledge communities. More specifically, acquiescence and adaptation help explain patterns of knowledge exchange and accumulation over time. While these behaviors have implications across a wide variety of knowledge communities and legal changes, for the purposes of clarity and brevity they are best examined within a specific context.

The Impact of Formal IP Rights on the Life Sciences Community

The remainder of this paper applies the acquiescence-adaptation framework to a specific context – the life sciences community. While the debate over the appropriate role and scope for patents in knowledge work is broad and heated (Merges & Nelson 1990, 1994; Lessig 2002, Scotchmer 2004, Jaffe & Lerner 2004, Heller 2008), nowhere is it more animated than in arguments over the impact of patents on the academic community's open commons (Heller & Eisenberg 1998, David 2003, Kleinman 2004). Largely focused on the life sciences community, the debate centers on the dramatic expansion in IP over knowledge traditionally maintained in the public domain and now published in scientific papers but also patented. For example, between 1989 and 1999 more than 6,000 life science patents have been granted to leading U.S. universities (Owen-Smith & Powell 2003), and at least 12% of U.S. life science faculty members have at least one patent in addition to their publications (Ding, Murray & Stuart 2007).

A number of factors shaped the expansion of life science patenting. First, the rise in useful, knowledge in fields such as molecular biology, dating to the founding of the biotechnology industry in the early 1970s, enlarged the amount of patentable knowledge available in the life science community (Kenny 1986, Colyvas & Powell 2006). Second, key policy shifts such as the 1980 Bayh-Dole Act encouraged academics to claim IP rights over their knowledge, prompting universities to focus on the commercialization of federally funded research ((Mowery et al 2004, Hughes 2002). Finally, landmark court decisions including the 1980 *Diamond vs. Chakrabarty* Supreme Court decision (allowing patents on genetically modified organisms) and the 1988 granting of the Oncomouse patent (extending such protection to genetically modified mammals) resulted in an expansion in the *scope* of patents available for life sciences research (Kevles 2002). With these changes, "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).

A dramatic instantiation of the increasing emphasis on IP was how the growing number of ideas that once might have been in the public domain became <u>additionally</u> embedded within the patent system, thus resulting in what we term patent-paper pairs (Murray 2002, Ducor 2000, Murray & Stern 2007, Huang & Murray 2008, Lissoni & Monttobio 2007). Scientists produce such "pairs" when they disclose the same novel research results in both scientific publications and patent applications. For example, consider the following portions of an actual patent and the abstract of its paired publication:

> *"A method has been developed for control of molecular weight … during production of polyhydroxyalkanoates in genetically engineered organisms by control of the level and time of expression of one or more PHA synthases... 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 affect the molecular weight of the polymer produced in the cell." (Snell; K. D.; Hogan; S. A.; Sim; SJ; Sinskey; A. J.; Rha; C.. 1998, Patent 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)

The rise of such patent-paper pairs is emblematic of the growing production by the life sciences community of knowledge that is simultaneously of scientific and commercial interest, resulting in a heated debate over the role of IP rights on academic research. This debate offers three contrasting perspectives about the potential impact of patents on the structure, practices and productivity of the academic knowledge community.

First, a series of dramatic controversies in the mid-1990s raised the specter that formal IP rights (and the ever-expanding patent thicket) might stifle community members' ability to build on each other's knowledge (Heller & Eisenberg 1998, Campbell et al. 2002, Boyle 2003). For example, having gained an exclusive license on novel transgenic mouse technology developed at Harvard, Du Pont became embroiled in a patent dispute with the mouse genetics community over their ability to exchange and use transgenic research mice covered by the patents (Murray 2008, Murray et al. 2008). Around the same time, pharmaceutical company Roche aggressively asserted its IP rights against instances of widespread infringement of its process and product patents on the PCR method, an essential tool within the molecular biology community. Among other actions, Roche specifically identified more than two hundred alleged infringers, including researchers working at the National Cancer Institute, Stanford Medical School, M.I.T., and Harvard University. Those who emphasize these incidents point out that they are not isolated: the debate encompasses patents on everything from human embryonic stem cells to gene sequencing and genetic tests (Heller & Eisenberg 1998). Indeed, there is some prior empirical support for this perspective; using a sample of patent-paper pairs, the granting of IP rights over scientific knowledge already disclosed in scientific publications is associated with a reduction in the rate of citation to those papers by subsequent researchers (Murray & Stern 2007, Huang & Murray 2008).

Alternatively, a second perspective argues that patents can enhance the use of life sciences knowledge throughout the scientific community. Traditional research on the private use of IP rights highlights the role of patents in facilitating the creation of a market for ideas and encouraging efficient commercialization (Kitch 1977, Arora, Forsfuri & Gambardella 2001, Gans & Stern 2000, Keiff 2005). Indeed, within the university context (particularly university research) IP offers important incentives to move discoveries out of the "ivory tower" and into commercial practice (Hellman 2007). Moreover, patents require disclosure and so facilitate exchange relative to secrecy, even within academia (Nelson & Mazzolini 1998, Gans, Murray & Stern 2008). Finally, some empirical studies suggest that patents may play a very limited role in the life sciences community (Walsh, et al 2003, 2005). Notably, many scientists may believe they are simply immune to prosecution under the so-called experimental use exemption. More specifically, Walsh, Cohen and co-authors have emphasized that many scientists simply ignore the IP system and do not consult patent databases in planning their research agenda. For example, they report that while more than 20% of the U.S. academic biomedical researchers who responded to their survey have been involved in *seeking* formal IP rights (in the two years prior to the survey), very few take a proactive approach to evaluating whether their own research violates others' patents e.g. only 5% report that they regularly check patent databases when designing new projects (Walsh et al. 2003, 2005).

How do we reconcile these contradictory perspectives on how expanding IP enforcement affects the life sciences community? We argue that our theory of acquiescence and adaptation in response to legal change is the appropriate framework within which to adjudicate and synthesize these otherwise competing claims. In the following section, we use the theory to develop distinct, testable predictions of how acquiescence and adaptation takes place in the life sciences community in response to IP and its enforcement.

Acquiescence-Adaptation Predictions

The predictions of the acquiescence-adaptation framework are particularly relevant for the exchange and accumulation of knowledge disclosed in patent-paper pairs -- the canonical setting where the impact of IP and its enforcement are most likely to influence the life sciences community. Specifically, our empirical tests focus on how the annual rate of follow-on accumulation of life sciences knowledge, reflected in the citations to paired papers, changes with the grant of paired patents. As described in the Methods section below, the use of citations is a useful, though imperfect, metric for capturing knowledge accumulation and exchange, particularly when the aim is to evaluate how the rate of these processes changes with shifts in the legal environment surrounding a given "piece" of knowledge. We focus our analysis on the highly contested period from the initiation of patent enforcement in academia in the mid to late 1990s through 2005, and trace out the impact of IP, focusing on three effects: *initial acquiescence, annual acquiescence,* and *annual adaptation*.

Our analysis centers on how the level of citations changes with the grant of a patent over the knowledge covered in each paired scientific article. Our framework suggests there will be an *initial acquiescence* response in the period immediately following patent grant and enforcement. To the extent that acquiescence reduces knowledge exchange, we expect to observe a decrease in the number of citations to the (paired) paper. This initial acquiescence reflects the initial response to the grant of IP (particularly in the late 1990s), when patent owners send "cease and desist" letters to potentially infringing colleagues and university Technology Transfer Offices (TTOs): unwilling or unable to respond to the new requirements, researchers will exit particular research or seek alternative research paths. Indeed, many of the controversies during the mid to late 1990s were based on instances when individual scientists and TTO professionals had limited experience in gaining access to patented materials, data, or tools.[2]. The corporate lawyers who sought to execute their patents on academic institutions also had limited expertise in this arena, imposed complex contracts that academics found cumbersome and unreasonable (Einhorn 2006), and late 1990s suffered the highest rate of DNA patent litigation since the 1980 Bayh-Dole Act (Mills & Tereskerz 2008).

The theoretical framework suggest that the impact of acquiescence will increase over time, as enforcement of a given patent spreads throughout the community and as individual members of the knowledge community learn of the encumbrances associated with a particular knowledge domain. We therefore predict that *initial acquiescence* (in the year immediately following patent grant) will be followed by an annual *acquiescence effect* (an effect that grows in each year after the patent grant). Growing awareness of the role of IP rights may lead researchers to exit a research line in each year following patent grant rather than participate in an area that is fraught with complex legal requirements. This prediction, importantly, relates to

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[2] Contrast this with the expertise universities gained from 1980 onwards in patent filing and licensing to firms. Note, that universities played a limited role in enforcement, relying on licensees to manage infringement by other firms.

individual patents with the acquiescence response by individuals increasing with each year following to the specific patent grant, as the impact and awareness of the new requirements specific to the particular patent grows within the knowledge community.

Finally, the theory also predicts an *adaptation effect* with (all else equal) a positive impact on the rate of knowledge exchange which therefore, we predict, will be manifest as an increase in the number of follow-on citations. Specifically, adaptation will occur as researchers and other community actors implement a range of informal or formal agreements in order to avoid complex licensing requirements for individual patents, that reduce legal complexities (e.g., through the standardization of agreements) and that reduce transaction costs (Meyer & Argyres 2004). Particular contractual mechanisms developed during the period we investigate include the development of the Universal Biological Material Transfer Agreement by university Technology Transfer Offices (TTOs), shifts in the rules imposed by journals governing the exchange and accessibility of underlying data and materials, and the development by NIH of guidelines for patent licensing (NIH 2003, Ristau Baca 2006, Butler 2007, Piwowar et al. 2008). A crucial distinction between acquiescence and adaptation is that adaptation's most powerful mechanisms arise at the community-level and will therefore shape exchange among scientists across a wide variety of research lines and the entire population of granted patents, regardless of their age. In other words, under the adaptation hypothesis, formal and informal mechanisms will emerge over time across the entire life sciences community to dampen and even negate the acquiescence effect. Therefore, while acquiescence may impinge on individual patents from the time of their grant date, adaptation will evolve over time for the entire community of granted patents. Figure 1 summarizes our predictions illustrating how to distinguish the effects of these contrasting forces:

-- Insert Figure 1 about here --

The initial acquiescence effect implies a one-time shift in the citation rate at the time of patent grant (1a). In contrast, the annual acquiescence effect implies that this negative effect will be amplified over time for a given patent (1b). The adaptation effect, on the other hand, is a measure of how citations to the population of patents are shifting over time. For any given patent, then, the acquiescence effect and adaptation effect exert countervailing effects, and the expected level of citations, therefore, reflects a middle ground between the citation levels implied by either theory in isolation (1c and 1d).

We are also interested in the way in which different sub-groups within a knowledge community respond to the impact of patent enforcement. Given the rich and varied practices at work within the life sciences community, it is likely that legal change differentially shapes patterns of exchange and accumulation across identifiable sub-communities. We focus on the *acquiescence* and *adaptation* effects for mutually exclusive sub-communities defined along two dimensions: academic v. industry and high v. low status. Analyzing how researchers within each of these sub-communities produce follow-on knowledge offers insights into how adaptation and acquiescence unfold within sub-populations of a knowledge community.

The differential response of academic and industry scientists is most straightforward to predict. While enforcement of academic patents on the life sciences community was a new phenomenon for academic scientists in the late 1990s, infringement suits by industrial patent holders and (more recently) patent licensees were more commonplace for industrial scientists.[3] If academic researchers were less familiar with IP practices than industrial researchers were, the *acquiescence effect* in our period should be much greater for follow-on academic researchers relative to their industrial colleagues. On the other hand, university life scientists in the same period had many more opportunities to gather (at conferences etc.) and work collectively to resist the enforcement of IP rights and to develop alternative responses (Murray 2008). Their powerful informal norms also made it possible for them to work with journals and funding agencies to shape the limits of enforcement. As such, the *adaptation effect* is therefore likely to be more salient for academic researchers (while industrial researchers likely went through such a process during the 1980s, when IP practices among private biotechnology firms began to be standardized).

The status of community members provides another important dimension when examining the role of changing IP enforcement. Within the scientific community, the importance of status hierarchy is well-documented (Merton 1988, Cole & Cole 1973). Moreover, while scientists are likely to engage in adaptive

[3] Several cases speak to the frequency with which firms enforced their patent rights against one another. For example, Ariad sued Eli Lilly for infringing patents it had licensed from MIT and Harvard; the patents covered drugs that work by modulating a protein discovered by academic scientists (Pollack 2006).

behavior through the tight social ties that characterize by the invisible college (Crane, 1969), we predict a relationship between the status hierarchy and the rate at which different scientists can engage in and take advantage of adaptation. High status faculty members are more likely to be able to use informal mechanisms as a source of adaptation to complex legal contracting. For example, they might use informal relationships as a conduit for exchange and avoid costly contractual requirements. Thus, we predict that while *acquiescence* to patent enforcement is equal for both high and low status faculty, high status faculty will exhibit more rapid *adaptation* compared to their low status counterparts.

Empirical Approach

The remainder of this paper develops and implements a novel approach for evaluating the impact of acquiescence and adaptation within the life sciences community. Building on a recent stream of research which adopts a "differences-in-differences" methodology to evaluate the causal impact of institutions on knowledge accumulation (Murray & Stern 2007, Furman & Stern 2008, Rysman & Simcoe 2008), our approach exploits a number of key institutional features and shared practices characterizing the life sciences community: A sample of scientific papers describing similar knowledge inputs, the use of scientific citations to trace out follow-on cumulative research building on these knowledge inputs, the phenomenon that some scientific papers are disclosed in paired patents, and the variation induced by the grant delay of these patents.

First, our analysis is premised on the construction of a sample of similar "pieces of knowledge" disclosed in scientific papers. We select papers from a single journal to take advantages of the editorial policies, screening, and review processes that are key to the publication process to ensure that our sample of paper papers is broadly similar in type and quality. While less extensively analyzed by organizational scholars, publications, like patents, are a critical form of knowledge disclosure, particularly for academics (Latour & Woolgar 1979); they establish priority claims, come with (informal) property rights and exchange obligations (Merton 1973, Hilgartner 1997). Studies by economists and sociologists make extensive use of publications to measure individual productivity (Allison & Stewart 1974, Cole 1979, Levin & Stephan 1991, Adams & Griliches 1996, Stuart & Ding 2006), while organizational scholars use the production of papers by firms as a measure of innovative output and social networks (Liebeskind et al. 1996, Cockburn & Henderson 1998, Gittelman & Kogut 2003, Lim 2004).

The second element of our empirical approach uses citations by other scientific papers to our sample of papers as a proxy for exchange and accumulation of knowledge within the life sciences community. While it would be ideal to have a direct measure of knowledge exchange, scientific citations offer a useful measure of researchers reliance on prior published work in their own knowledge production. Our approach builds on a long line of scholarship using patent and publication citations to trace the flow of ideas and how they accumulate in the ideas of others (de Solla Price 1965, Garfield 1979, Jaffe, Trajtenberg & Henderson 1993, Cole 2000, Hall, Jaffe & Trajtenberg 2001). More specifically, the sociological literature has articulated the importance of publication citations as a form of recognition for knowledge exchange in the scientific community (Hagstrom 1965, Schubert & Braun 1993). Therefore, citation data facilitates longitudinal analysis allowing us to trace out how researchers exchange knowledge and build upon a publication over time, and how *changes* in the environment governing that knowledge influences their exchange (and citing) behavior.

The third critical aspect of our empirical strategy exploits the existence of patent-paper pairs as not only the instantiation of the expansion of IP rights over life sciences knowledge but also as a concrete empirical starting point from which to identify the impact of such rights on the rate of scientific knowledge exchange and citation. In particular, we take advantage of the substantial gap between the date of scientific publication and the date of patent grant. While papers in the life sciences are typically published rapidly (within 3-6 months), grant of the paired patent takes approximately three years. It is important to emphasize that patent grant delay is more than simply a *pro forma* administrative glitch.[4] Between application and grant applicants and examiners undertake detailed negotiations about the scope and extent of the patent grant, and so there is significant uncertainty about the extent of IP rights prior to grant (Cockburn, Kortum & Stern 2002, Gans, Hsu & Stern 2007). Moreover, prior to grant the patent applicant holds no formal IP rights, and, in nearly all cases, cannot sue for infringement for activities undertaken in the pre-patent grant period. Finally,

[4] Specifics of patent disclosure timing are complex. Under US patent law, inventors have a 12-month grace period between public disclosure (e.g. academic publication) and patent filing.

until 2001 (and thus for nearly all the patents in our sample), USPTO patent applications remained *secret* until granted. Taken together, when a given paper in our sample is published in the scientific literature, the knowledge it embodies is governed by the exchange norms associated the public domain and the "Republic of Science" (David 2003). However, when the patent over the same knowledge is granted the rules governing exchange shift to include the possibility of formal IP rights as well. We can therefore compare how the rate of follow-on citation changes in the pre- and post-patent grant period (controlling for changes in the rate of citation experienced by *all* articles over their life) to isolate the impact of patent grant on patterns of knowledge exchange.

To evaluate the specific hypotheses associated with the acquiescence-adaptation framework, we examine specific types of evidence associated with the "natural experiment" offered by patent grant delay. In particular, the *initial acquiescence* effect is evaluated by measuring the change in citations in the period immediately following patent grant (e.g., in the year after a patent is granted). Similarly, the *annual acquiescence effect* is tested by evaluating whether the impact of patent grant becomes more salient in every subsequent year (i.e. in two or more years since the patent grant). Finally, the *annual adaptation effect* is tested by evaluating whether, with the passage of calendar time, the impact of patents on citations is reduced across the sample of *all* patent-paper pairs. It is useful to note that we can tease out the specific empirical implications of each of the key hypotheses implied by our theoretical framework and identify the three effects separately by taking advantage of the variation in both the patent grant delay the publication year of the articles in our dataset.

Data & Methods

Patent-Paper Pairs Sample

Our sample is composed of 174 published scientific research papers that disclose potentially patentable knowledge drawn from a top-tier journal, *Nature Biotechnology*. They include all research articles authored by at least one U.S. academic, published in the journal in the period 1997-1999. Our choice of period allows us to examine the changing impact of patent enforcement in the controversial period of 1999 – 2005. The journal selection was guided by our interest in knowledge of high scientific impact and commercial relevance. *Nature Biotechnology* is particularly appropriate for our analysis given its high journal impact and editorial goals -- *"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"*. Finally, the decision to sample on academic publications was driven by our understanding of the debate about how patents covering academic knowledge alter the exchange and accumulation in the life science community. A focus on one setting for knowledge production also limits the range of possible mechanisms at work as follow-on researchers learn to live with the law. The choice of U.S.-based researchers follows by our belief that non-US universities likely file for patents outside the US in the first instance leading to inaccuracies in our characterization of IP rights over non-US authored research[5].

For each of the 174 articles it was determined whether a ("paired") patent associated with the article had been granted by the USPTO. A number of pairing approaches have been devised (Ducor 2000, Murray 2002, Lissoni & Montobbio 2007, Huang & Murray 2008). In this instance, the basic search included 1) the first, last and corresponding authors for the article and 2) 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) to identify all possible paired issued patents. We read all patents to verify whether the description, claims or examples of the patent incorporated material described in the paper abstract. Using this procedure, 91 (53%) are associated with a paired U.S. granted patent.[6]

For each of these 174 articles and 91 patents we gathered variables on observable characteristics: the number of authors (# AUTHORS), number of inventors (# INVENTORS). For each publication, we generated a dummy variable PATENTED equal to one if the paper has a paired patent and zero otherwise. We also coded the date of publication (PUBLICATION YEAR) and the date of patent application and grant (APPLICATION YEAR and GRANT YEAR respectively).

[5] This sample is a sub-set of an earlier set of articles analysed by Murray and Stern (2007) also taken from Nature Biotechnology but which includes all 340 research articles (of which 169 have paired patents) published in the same period including those with US and foreign authors as well as academic, joint and solely industry affiliations.

[6] Patent-paper pair assignment is conservative. In most cases, patent-paper pairs were unambiguous. A colleague also provided independent confirmation of patent-paper pair matching with an alternative, automated matching method.

We then collected data on all forward citations to the 174 papers in subsequent "research articles" (defined by Thomson ISI Web of Science) -- 14,685 forward citations -- and coded a rich set of variables. For each forward citation, we then determine whether at least one of the institutions associated with the paper (and listed in the address field in the ISI data) is a public entity (university, research institute or part of a government intramural research organization) and code the citation as CITE PUBLIC. If a citation has at least one institution associated with a biotechnology, pharmaceutical or other for-profit firm, we code the citation CITE PRIVATE. We then code all the institutional affiliations according to whether they have at least one address associated with the top 25 recipients of NIH funding (as of 2005) – CITE HIGH STATUS. We code all other citations as being CITE LOW STATUS.

Finally, we generate a set of citation-year characteristics. First, we define PUBLICATION AGE as YEAR – PUBLICATION YEAR. We then define a dummy variable –PATENT POST GRANT for each paper citation-year observation which =1 for every paper citation year in which the patent is already granted. This is defined by determining if the YEAR – GRANT YEAR is >1. We then develop our dependent variables. The main dependent variable is defined as the total annual number of forward citations (in other research article publications only) received by each paper in every calendar year (YEAR) as ANNUAL FORWARD CITATIONS. We then separate the forward citations into the different citing sub-groups, creating two variables for each paper (that sum to total ANNUAL FORWARD CITATIONS): ANNUAL FORWARD CITATIONS PUBLIC captures all those forward citations to a given paper in a given year that have at least one public sector author. The remaining citations (which have CITE PRIVATE =1 affiliations and CITE PUBLIC =0) are aggregated to create ANNAUL FORWARD CITATIONS PRIVATE. Likewise, we generate ANNUAL FORWARD CITATIONS HIGH STATUS from all the forward citations to a given paper in a given year that are coded with CITE HIGH STATUS =1. All those citations coded CITE LOW STATUS are then aggregated into ANNUAL FORWARD CITATIONS LOW STATUS.

Summary Statistics

As we would expect from a sample of publications drawn from the highly regarded journal Nature Biotechnology, the mean ANNUAL FORWARD CITATIONS are higher than in a randomly selected sample – the average in our sample is 11.49 (std 19.39), with a range of 0 to 315, underscoring the skewed distribution of the citation count for our sample, as is typical in publication (and patent) data. These articles have an average of 6 authors (# AUTHORS). Again, this is typical of the rich collaborations across individuals and organizational boundaries characterizing the life sciences community. In contrast, fewer individual inventors and assignees are found on our sample of 91 patents – the average # INVENTORS is 3. When citations are aggregated at the article level into citation-year characteristics by different types of forward citations, we find that the average ANNUAL FORWARD CITATION PUBLIC is 10.59 (std 17.29) and PRIVATE is 1.92 (std 4.70). The HIGH:LOW STATUS citation breakdown is shows means of 3.204 (std 5.148) and 8.285 (std 14.998) respectively.

An important aspect of our identification strategy lies in the time variation in patent grant. Of the 91 patents in our sample, the average PATENT GRANT YEAR is 2000 (std 1.78), with an average patent grant delay of 1103 days (3.02 years) but with a range of 238 days to 2167 days (5.94 years). In our 917 citation-year observations, the average YEAR that we observe is 2001.95 (std 2.09) and we observe an average of 0.632 observations in the PATENT, POST GRANT period. This provides significant variation across the sample from which to identify and disentangle the adaptation and acquiescence effect.

Empirical Specification

Our empirical specification predicts the annual count of forward citations in publications to each of the 174 papers in our sample over the period 1997-2005. This dependent variable takes the form of count data skewed to the right. Therefore, we use a Poisson model of the annual citations for each publication in our dataset. In the estimation, it is critical to account for considerable variations in the impact of a given paper, as measured by its citations, which correlate with the underlying importance of the knowledge, the time elapsed since initial publication, and the year for which the citations are being considered. As such, our empirical specifications account for individual publication quality (article fixed effects), for the effects of publication age and the overall rate of citation in a given year (age and citation year fixed effects).[7]

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[7] Building on recent results about the relative importance of the small sample vs. asymptotic bias arising in these models, we report fixed effects results with robust standard errors (Allison & Waterman, 2002; Greene, 2004).

As an overall measure of the impact of patent grant (as investigated in Murray and Stern (2007)) 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 grant (and because we observed a control group of similar publications which never receive a patent), this approach identifies how the average pattern of citations to the paper changes with patent grant. Specifically, we estimate:

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

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-GRANT is a dummy variable equal to one only for years after the paired patent is granted[8]. The coefficient on POST-GRANT (ψ) estimates the marginal impact of the intervention on the set of treated articles. Thus, ψ measures the impact of patent grant -- how the citation rate for a paper *changes* following patent grant, 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 temporal dynamics of patent enforcement as it shapes follow-on researcher in the knowledge community. To tease out these effects, a more nuanced baseline specification includes three distinctive parameters, each intended to capture forces contouring the impact of patent enforcement on forward citations over time. The first is the *initial acquiescence* capturing the initial impact of a patent on a piece of knowledge as it moves into the enforcement regime. The next is an annual *acquiescence effect*, which estimates the impact of a given patent on publication citations to its paired paper for each year, after accounting for *initial acquiescence*. Finally, the *adaptation effect* defines impact of all granted patents in each given calendar year after 1999 – the initial year of patent grant in our sample. This variable captures the role of adaptation and the changing annual impact of all patents (regardless of their age) enforced in a given year. Taken together, our core empirical specification is :

[8] This baseline analysis assumes that age fixed effects associated with citations do not depend on whether a paper receives a patent. In particular, a key assumption of our base model 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.

$$(2) \quad CITES_{i,t} = f(\varepsilon_{i,t}; \gamma_i + \beta_t + \delta_{t-pubyear} + \psi_{Acquiescence(Initial)} POST-GRANT_{i,t} + \psi_{Annual\ Acquiescence}(t-grantyear_i) * POST-GRANT_{i,t} + \psi_{Adaptation}(t-1999) * POST-GRANT_{i,t})$$

It is useful to note that we could also estimate the adaptation effect non-parametrically, by estimating an effect for each citation-year.

Finally, as argued earlier, our theoretical framework suggests that patent grant and enforcement are likely to have different implications for different subpopulations of the life sciences knowledge community. To evaluate these subpopulation margins, we take advantage of the detailed citation-level coding of the citations described above, breaking them down into subpopulations: academic vs. industry and high status vs. low status. We 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. We then adapt the specification in (2) to estimate the impact of patents on different subpopulation margins, indexed by *j*:

$$(3) \quad CITES_{i,j,t} = f(\varepsilon_{i,j,t}; \gamma_i + \sum_{j=1,2} \beta_{t,j} + \delta_{t-pubyear,j} + \psi_{Acquiescence(initial),j} POST-GRANT_{i,j,t} + \psi_{AnnualAcquiescence,j}(t-grantyear_i) * POST-GRANT_{i,j,t} + \psi_{Adaptation,j}(t-1999) * POST-GRANT_{i,j,t}))$$

In other words, the coefficients on *initial acquiescence*, *annual acquiescence* and *annual adaptation* (and the age and time effects) are estimated separately for each subpopulation of citers, and we can thus specifically test whether the impact of *initial acquiescence, annual acquiescence, and adaptation* are statistically or practically different than each other across different subpopulations.

Results

All our results employ a conditional fixed effects negative binomial specification with ANNUAL CITATIONS as the dependent variable (in Tables 3 and 4). In each regression we include PUBLICATION AGE, YEAR and ARTICLE fixed effects. By including ARTICLE fixed effects, we fully account for the heterogeneity in the underlying quality of each individual article. We report the results of these regressions as incidence-rate ratios (for which a coefficient equal to one implies no effect on ANNUAL FORWARD

CITATIONS whereas a coefficient equal to 1.20 implies a 20% boost to ANNUAL FORWARD CITATIONS). The first two of these specifications (3-1 and 3-2) replicates an earlier analysis of the entire *Nature Biotechnology* dataset employed by Murray and Stern (2007) (MS). (It is important to note that the dataset employed here may differ in the precise number of citations for individual articles in a given year may differ because the current data is constructed from a "micro" dataset composed of individual citations (as opposed to a manual count by hand of citations per article per year. In addition, it includes a restricted set of US academic authored articles). Restricting the ANNUAL FORWARD CITATIONS in our dataset to the period 1997 – 2002, we can closely replicate the MS analysis and have the same basic patterns of results. Specifically, when we examine citations through 2002, focusing on either the full sample we observe a significant decline in the rate of citation after patent grant – about a 13% decline for citations through 2002 using both patented and unpatented papers. In this specification, the coefficient on PATENT POST GRANT is identified from the change in citations (relative to expectations) after the associated patent is granted. When we further restrict the data to articles for which PATENTED is equal to 1, i.e. only those publications where a patent is actually received (i.e. patent-paper pairs only), we find an even stronger effect of a 28% decline (3-2) which is highly significant.

Extending our analysis of the narrow US academic sample of *Nature Biotechnology* papers over the longer period through 2005 (in 3-3) provides a very different "aggregate" result -- PATENT POST GRANT is associated with a modest and marginally significant positive increase in the citation rate of about 15%. In other words, as we increase the time horizon of our sample but maintain the entire set of PUBLICATION AGE, YEAR and ARTICLE fixed effects, evidence for a modest negative impact of patents on knowledge exchange and accumulation declines. Indeed, the slight positive (and significant) result suggests that patent grant may provide a slight "boost" to exchange consistent with the development of a "market for ideas." The remainder of our empirical analysis explores this pattern in a more structured way following the theoretical framework and hypotheses outlined above.

In Table 4, we present our main evidence for balance of acquiescence and adaptation on the impact of patents on cumulative scientific research. The results are quite striking. First, and most importantly, the baseline *initial acquiescence effect* is negative with a 24% decline in the citation rate in the year following patent grant (significant at the 10% level). Second, consistent with our prediction, the *annual acquiescence effect* that accrues to each patent in the years following patent grant and the initial acquiescence is significant; the negative influence of patents increases at a rate of 13% (sig. at 1% level) in each year after the grant of the patent. However in contrast, and in accordance to our prediction, the rate of adaptation associated with all patents in our sample in a given year and regardless of their age is also impressive, with a 19% average annual increase (significant at the 5% level). If we consider these results in the light of Figure 1, this result implies that for a patent granted in 1999, the initial impact is to decrease the expected level of forward citations by 24% in the following year. In each subsequent year, citations are depressed by 13% because of acquiescence to the particular patent but this is offset by a 19% boost due to overall community-level adaptation. On balance then, there is a net increase in citations from the 24% initial decline of 6% each year (-13% + 19%), so that the impact of patents granted in 1999 is -24% in the first year, -18% in 2001, -12% in 2002, -6% in 2003 and the citations are back to their expected level in 2004 (0% change). If we take the average patent granted in 2000, these results can be traced out for this vintage of patents: their effect in 2000 will be -24 (initial acquiescence) but in the light of 19 (one year of community-wide adaptation) this is only a 6% decline overall in the year following PATENT POST GRANT. These results help up reconcile the apparently conflicting results highlighted in 3-1 and 3-3. By 2003, the "net" impact of a patent in its first year of grant was actually positive and, when we include prior vintages of patents the overall impact remains negative – with acquiescence outweighing adaptation. However, by 2005, the impact of the patent system was a net "positive" for essentially all patent vintages. We document this effect even more strikingly (although with lower significance) in 4-2 -- -- where we estimate a "baseline" effect for each year, from 2000 to 2005. We interpret the baseline to be baseline impact of all patents already enforced in that year. The absolute impact of each patent in that year will depend upon its vintage -- the number of years that it has been enforced. For a patent whose PATENT AGE is 2 years in 2002, its overall impact will be the baseline impact of 2002 (0%) – 2**annual acquiescence* (12.5%) - about a 24% decline in ANNUAL FORWARD CITATIONS. In other words, the analysis in 4-2 identifies the overall adaptation effect that takes place across the entire community over the period of our analysis, while the annual acquiescence allows us to incorporate the effect of individual patents and their enforcement over their lifetime. The predicted "baseline" impact of patents becomes more favorable in each and every year, as the theory predicts, going from a 30% reduction in 2000 to more than a 70% predicted increase in citations as of 2005.

It should be noted that that few patents in our sample show this pure positive "boost" because most patents in that year will have been subject to enforcement and therefore *acquiescence* for several years. Nonetheless, the finding that by the end of the analyzed period (2005), patent grant is associated with a small (but significant) boost in follow-on knowledge accumulation is intriguing. While unexpected from the literature on patents in academia, this finding is consistent with the notion that patents contribute to the effective functioning of the market for ideas (Merges and Nelson 1990; Gans & Stern 2000; Keiff 2005). It may be this efficiency operates through enhanced incentives and efficiency, allowing researchers to more effectively search and match with partners (Jensen & Thursby 2001, Hellman 2007; Aghion et al. 2005).

Acquiescence & Adaptation across Different Community Subpopulations

We now move to a more detailed investigation of the sources of the marginal citations arising from patent grant. While the results in Table 4 provide useful evidence for our core hypotheses related to the impact of patents over time on the aggregate life sciences community, our detailed micro-data allows us to evaluate these issues more precisely by comparing the impact of patents across different sub-sections of the community. We are particularly interested in whether PATENT POST GRANT has a differential impact on different subpopulations of potential citers in the life sciences community. As noted above, we classify each citation to each of our papers according to the author/address characteristics to evaluate how these subpopulations respond to patent grant in terms of *adaptation* i.e. citations and citers responding through a net positive impact on citations and *acquiescence* i.e. citations and citers responding through a decline in citations. For example, we calculate the number of citations to each article by citers affiliated with high status universities and the number by citers with other affiliations. We then specify a stacked regression where the dependent variable is the number of citations received from the subpopulation in that year. Each negative binomial regression includes separate fixed effects for each calendar-year subpopulation, article-age subpopulation and conditional fixed effects for each article. Consistent with our prediction that the academic subpopulation will be most affected by patent grant and will show rapid acquiescence due to their surprise and lack of experience in accessing patent material, we begin in Table 5 by examining the difference in the impact of patents for public sector and private sector authors. The results (5a and 5b) accord well with our predictions. Specifically, while patent grant has very *little* impact on private sector behavior – either adaptation or acquiescence, the negative *initial acquiescence effect* and then a balance of *annual acquiescence* and *adaptation* between 2000 and 2005 is captured in the dependent variable ANNUAL PUBLIC CITES and almost entirely reflects the behavior of public sector authors. In other words, while most companies likely have procedures and experience in conducting innovation, public sector researchers faced significant costs in managing intellectual property at the beginning of our sample and became more adept at that over time. For public sector forward citations, all three effects are highly significant.

Our results for the HIGH STATUS CITERS and LOW STATUS CITERS also provide us with rich insights into extent of acquiescence by each subpopulation for individual patents and of gradual adaptation across the entire subpopulations. The most striking finding, reported in 6a is the dramatic initial acquiescence by high status citing authors, as they are immediately "shocked" by the grant of paired patents in the late 1990s with a 31% negative impact on PATENT POST GRANT citations (significant at the 10% level). However, following this initial shock, adaptation is equally large, with the annual adaptation effect 18% suggesting that life scientists affiliated to high status universities and medical schools rapidly find mechanisms to adapt to the shock of patent enforcement over their previously untouched and cloistered laboratories. Also notable is that after the initial acquiescence, there is no measurable annual acquiescence effect. If we take the first vintage of patents, after the immediate and dramatic shock, there is only community-level adaptation and no on-going acquiescence. For the next vintage, their starting shock is 13% (-31% + 18%) and the entire population of patents becomes positive in their impact after only two years. In contrast, for LOW STATUS CITERS, there is a much smaller noisy initial acquiescence effect (13%) which we interpret to mean that patent owners and assignees are less likely to initiate enforcement on lower status organizations (who are less high profile). However, their ongoing acquiescence is noticeable and is larger (17% significant at the 1% level) suggesting that enforcement continues to "bite" in this subpopulation for specific patents in each year after patent grant. Nonetheless, this sub-population is able to adapt at about the same rate as the high status citers (20% versus 18%); not surprising since many of the adaptation measures are, as we have described, relevant to the entire life sciences community even when they are most aggressively pursued by high status academics.

Conclusions

Our theoretical framework is a dynamic process model which explains the complex and historically contingent impact of legal institutional change on knowledge work. By operationalizing the framework within a longitudinal empirical analysis, we can then tease out the separate institutional processes at work in the knowledge community – acquiescence and adaptation – and the changing balance between them. According to our analysis, two powerful and at times conflicting forces – acquiescence and adaptation -- guide the response to the law by individuals and communities in many areas of knowledge work. By considering the relative balance between the two, and how that balance changes over time, we argue that is it possible to resolve inconsistencies between accounts of the law in a particular organizational setting (Edelman 1992) and, more importantly for our purposes, within knowledge communities. When acquiescence dominates adaptation, the law is a contentious and time-consuming feature of knowledge work. However, when communities begin to adapt in response to the law, it can come to dominate acquiescence, and over time, the law moves into the background of daily knowledge work.

Our empirical study of the life sciences community shows how the theory and analytical framework can resolve existing disputes over the role of patents and their enforcement. Our longitudinal analysis of the citation patterns of a large sample of publications also subject to IP rights supports the view that at different points in time, the competing claims of acquiescence and adaptation by the life sciences community are both correct. Specifically, when placed into their proper historical context, we can disentangle when and to what extent each mechanism is most powerful and for which members of the life science community. Our empirical results suggest that in the mid to late 1990s scientists were only beginning to respond to changing enforcement of IP rights. It is not surprising to find that patents were a salient and frustrating issue for scientists, the initial acquiescence that we document shows the degree to which patents impinged on scientists' work in costly and complex ways, consistent with studies of the period (Heller & Eisenberg, 1998; Merz et al. 1999). Our theory suggests that over the following decade, the life sciences community developed a variety of adaptive mechanisms. The strength of the adaptation response (particularly among academic researchers) that we document is consistent with surveys, undertaken in 2003-2004, capturing the views of scientists so adapted to IP enforcement that when asked, they no longer considered patents salient nor the obvious cause of shifting practices. The inter-temporal dynamics of early acquiescence, later dominated by adaption are also consistent with recent qualitative analysis of the impact of enforcing patents on genetically modified mice for use in cancer research (Murray 2008b). These forces are particularly powerful for academic members of the life science community. While initially ill equipped to deal with the complexities of licensing agreements and threats of patent enforcement, the coherent nature of the life sciences community together with their most powerful organizations – the NIH, the Association of University Technology Managers, and leading journals -- made adaptation rapid and effective. We provide strong evidence that by the end of 2005 the life science community had learned to live with patents.

By demonstrating that legal institutional change in communities is a dynamic and emerging process, our perspective suggest that traditional cross-sectional studies of institutional change – either large sample or qualitative – ignore an important aspect of the change process; the contextually embedded historically grounded dynamics of institutional change. If, as Davis and Marquis (2007) have argued, organizational theory continues to shift towards a problem-based approach, making sense of historical occurrences of institutional change (p. 340), then incorporating the historical context into our theoretical frameworks and our empirical analyses is critical. This means more than simply including the year or age as a variable. Instead, it means taking seriously the ways in which the period being analyzed, including the choice of start date and end date, likely influence the results. Our study of the patent system in academia is certainly not the only case where including observations from later years can uncover changes in the equilibrium outcomes and temporal dynamics. While this may be an obvious statement, too many studies rely on convenience sampling without a thorough grounding in the historical context.

Our theoretical and empirical analysis also has several broader implications for organization theory. By addressing the central role of the law in the knowledge economy, it speaks to the need for organizational scholars to examine legal institutions as constitutive of the modern institutions of power that have critical economic consequences (Davis and Marquis, 2007). While scholars of law and society have examined the implications of employment law and Civil Rights for organizations (Edelman 1992, Sutton & Dobbin 1996), organizational scholars have been silent on many other aspects of legal institutional change. The rise in open source software provides an interesting exception. Perhaps because it reflects knowledge work in what is sometimes referred to as the law's "negative spaces" (Raustiala & Sprigman, 2006) it is a more intriguing phenomenon. We follow O'Mahony and co-authors in arguing that while often used to promote exchange and accumulation, open source communities also engage with the law in their daily work as they select among the bewildering array of licensing conditions that can be appended to their software code. If we consider the case of IP law, its impact spreads well beyond the ivory towers of academia and the legions of software writers, subtly changing the disclosure choices of firms (Gans, Murray & Stern 2008), the commercialization strategies of high-technology entrepreneurs (Gans and Stern 2005), and the mechanisms through which knowledge workers engage with one another (Murray & O'Mahony 2007). However, these issues have not been widely tackled outside the law and economics literature. By extending the organizational analysis of the law to include intellectual property law and by extending traditional scholarship on communities of practice and knowledge work (Brown & Duguid 1991, 2001; Bechky 2003ab) to encompass legal issues, the organizational agenda will be grounded, more strongly, in the central challenges of the knowledge economy.

One of the central tenets of the knowledge economy is the growing participation in knowledge production and accumulation by individuals from diverse countries, organizations, types of organizations, disciplines and backgrounds (Lakhani & Panetta 2007; Chesbrough, 2003; Powell et al, 1996; Rosenkopf et al, 2001). By linking the macro-level changes in IP law and enforcement with their impacts on the ground (Lounsbury & Ventresca 2002), this paper initiates an agenda that highlights the micro-foundations of a diverse range of knowledge work in its macro-level context. In particular, while federal legislation structured the changes in ownership of university-generated ideas, and enforcement choices were made in boardrooms and courtrooms, their consequences unfolded within organizations and communities. Our approach has been to focus on the mechanisms behind this unfolding. Necessarily narrow in its focus on the life sciences community, we believe there is much to learn for other distributed forms of innovation from the micro-foundations of knowledge work presented here. Thus, while some of the features of our empirical set up are setting specific -- for example using publications and citations -- the broad framework is widely applicable to quantitative and qualitative analyses of the ways in which different communities learn to live with the law. By highlighting these mechanisms, we can make sense of legal institutional change in new settings beyond the boundaries of formal organizations. Moreover, by moving beyond the realm of intellectual property law, this agenda can usefully consider individuals and their communities undertake knowledge work in the shadow of many other aspects of the law (and of norms), including the construction of procedures to adjudicate the quality of knowledge work, to establish governance of knowledge validation, and to manage secrecy.

Finally, it is critical that as we examine the micro-foundations of knowledge work, we not only consider how they shape the actual work produced, but also the types of individuals who participate, the structure of the communities that emerge and the nature of the status hierarchies that are constructed. As we have argued, our quantitative approach only examines the degree to which sub-groups of the life science community acquiesce and adapt to the law in terms of their levels of knowledge accumulation. Do changes in IP enforcement cause more profound but hard to measure effects on knowledge communities? For example, do individuals respond to IP enforcement by making distinctive project selections that narrow the scope of their research agenda? Alternatively, it might be that as different community members use collaborations to circumvent the potential costs of the law or to take advantage of expertise in managing transactions costs, in the process they transform the nature of collaboration and the social structure of knowledge work.

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Table 1: Variables & Definitions

VARIABLE	DEFINITION	SOURCE
Publication Characteristics		
PUBLICATION YEARj	Year in which article is published	NB
# AUTHORSj	Count of the number of authors of Article *j*	NB
PATENTEDj	Dummy variable = 1 if Article is associated with a patent issued by the USPTO prior to October, 2003	USPTO
TOTAL CITATIONSj	# of FORWARD CITATIONS from publication date to 12- 2005	SCI
Patent Characteristics		
APPLICATION YEARj	YEAR in which PATENT was applied for	USPTO
GRANT YEARj	YEAR in which PATENT has been granted	USPTO
# INVENTORSj	Count of the number of inventors listed in the granted patent associated with Article *j*	USPTO
Citation Year Characteristics		
ANNUAL FORWARD CITATIONSjt	# of Forward Citations to Article *j* in Year *t*	SCI
ANNUAL FORWARD CITATIONS PUBLICjt	# of Public Forward Citations to Article *j* in Year *t*	SCI
ANNUAL FORWARD CITATIONS PRIVATEjt	# of Private Forward Citations to Article *j* in Year *t*	SCI
ANNUAL FORWARD CITATIONS HIGHjt	# of High Status Forward Citations to Article *j* in Year *t*	SCI/ NIH
ANNUAL FORWARD CITATIONS LOWjt	# of Low Status Forward Citations to Article *j* in Year *t*	SCI/ NIH
PATENT POST-GRANTjt	Dummy variable = 1 if PATENTED = 1 & CITATION YEAR > GRANT YEAR	USPTO
YEARjt	Year in which FORWARD CITATIONS are received	SCI

USPTO – United States Patent Office; NB – Nature Biotechnology; SCI – Science Citation Index; NIH – National Institute of Health

Table 2: Means & Standard Deviations

VARIABLE	N	MEAN	STD	MIN	MAX
Publication Characteristics					
PUBLICATION YEAR$_j$	174	1997.9	0.846	1997	1999
# AUTHORS$_j$	174	5.695	3.09	1	20
PATENTED$_j$	174	0.523	0.501	0	1
Patent Characteristics					
GRANT YEAR$_j$	91	2000.42	1.78	1996	2003
PATENT LAG$_j$	91	1102.91	383.33	238	2167
# INVENTORS$_j$	91	2.967	1.722	1	8
Citation-Year Characteristics					
ANNUAL FORWARD CITATIONS$_{jt}$	917	11.489	19.391	0	315
CITATION YEAR$_t$	917	2001.949	2.088	1998	2005
ANNUAL FORWARD CITATIONS PUBLIC$_{jt}$	917	10.594	17.290	0	288
ANNUAL FORWARD CITATIONS PRIVATE$_{jt}$	917	1.918	4.698	0	61
ANNUAL FORWARD CITATIONS HIGH STATUS$_{jt}$	917	3.204	5.148	0	69
ANNUAL FORWARD CITATIONS LOW STATUS$_{jt}$	917	8.285	14.998	0	246
PATENT POST GRANT$_{jt}$	917	0.632	0.482	0	1

Table 3: Difference-In-Difference Estimates of Patent Grant Impact in 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	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

Significance levels: * 10% ** 5% *** 1%

Table 4: Difference-In-Difference Estimates of Temporal Trends in Impact Of Patent Grant

Poisson Specifications	Dep Var = ANNUAL FORWARD CITATIONS [Incident rate ratios reported in square brackets] (Robust coefficient standard errors reported in parentheses)	
	4-1 With acquiescence-adaptation variables	4-2 With annual patent impact variables
PATENT Initial Acquiescence	[0.757]* (0.113)	
PATENT Annual Acquiescence	[0.876]** (0.057)	[0.875]* (0.062)
PATENT Annual Adaptation	[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
# Observations	917	917
Log Likelihood	-2443.768	-2442.602

Significance levels: * 10% ** 5% *** 1%

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)	
	5a Citations by Public Sector Authors	5b Citations by Private Sector Authors
PATENT Initial Acquiescence	[0.722]** (0.112)	[1.054] (0.281)
PATENT Annual Adaptation	[1.216]*** (0.089)	[1.006] (0.109)
PATENT Annual Acquiescence	[0.864]** (0.058)	[1.065] (0.113)
Article FE	Y	Y
Age FE	Y	Y
Citation-Year FE	Y	Y
# Observations	1834	
Log likelihood	-3570.696	

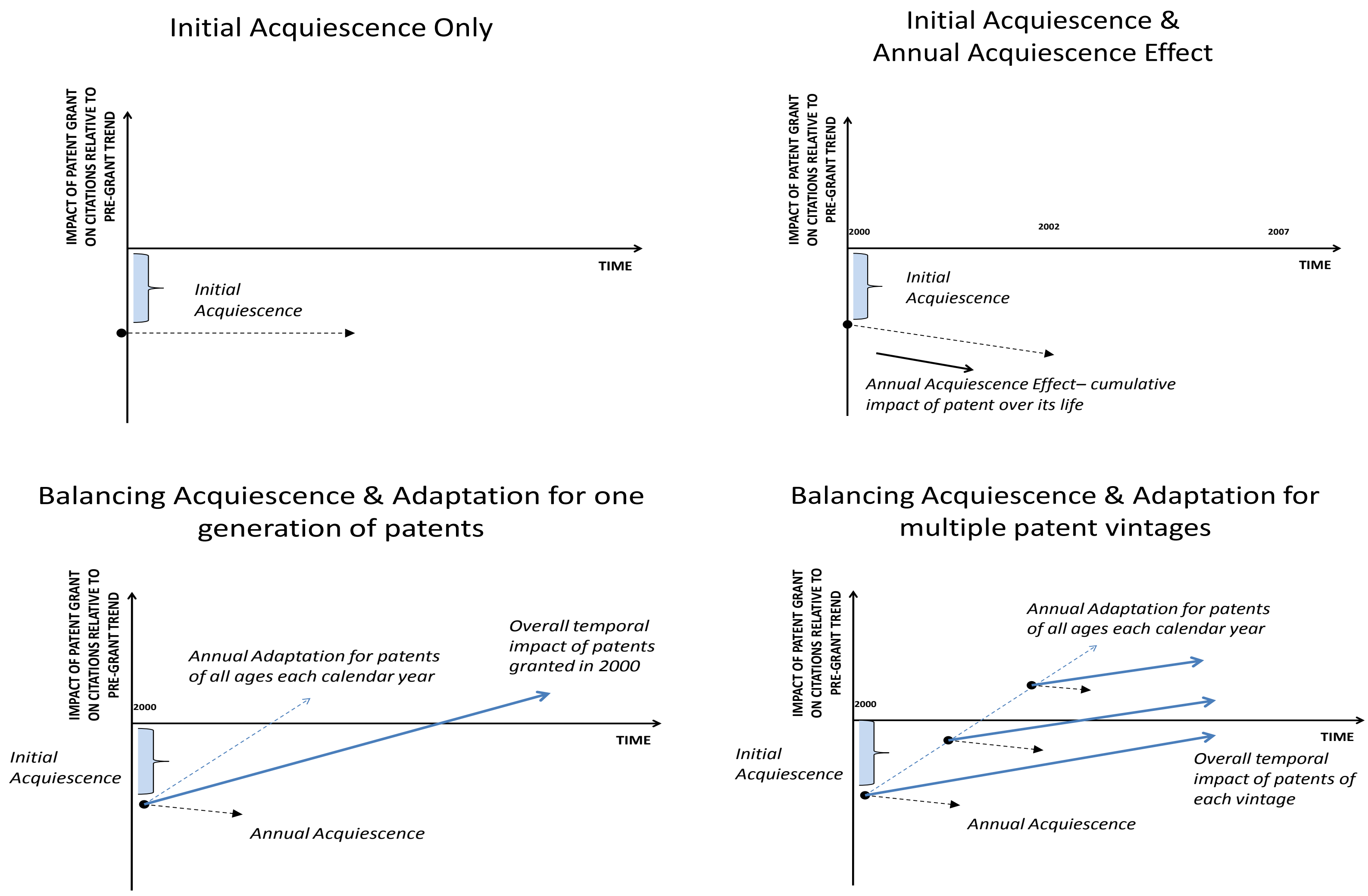
Significance levels: * 10% ** 5% *** 1%

Table 6: 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)	
	6a Citations by Top Tier Authors	6b Citations by Low Tier Authors
PATENT Initial Acquiescence	[0.693]* (0.142)	[0.775] (0.131)
PATENT Annual Adaptation	[1.179]* (0.101)	[1.202]** (0.091)
PATENT Annual Acquiescence	[0.984] (0.083)	[0.832]*** (0.058)
Article FE	Y	Y
Age FE	Y	Y
Citation-Year FE	Y	Y
# Observations	1834	
Log likelihood	-3710.622	

Significance levels: * 10% ** 5% *** 1%

Figure 1


Initial Acquiescence Only
IMPACT OF PATENT GRANT ON CITATIONS RELATIVE TO PRE-GRANT TREND
TIME
Initial Acquiescence
Initial Acquiescence &
Annual Acquiescence Effect
IMPACT OF PATENT GRANT ON CITATIONS RELATIVE TO PRE-GRANT TREND
2000
2002
2007
TIME
Initial Acquiescence
Annual Acquiescence Effect– cumulative impact of patent over its life
Balancing Acquiescence & Adaptation for one generation of patents
IMPACT OF PATENT GRANT ON CITATIONS RELATIVE TO PRE-GRANT TREND
2000
TIME
Overall temporal impact of patents granted in 2000
Annual Adaptation for patents of all ages each calendar year
Initial Acquiescence
Annual Acquiescence
Balancing Acquiescence & Adaptation for multiple patent vintages
IMPACT OF PATENT GRANT ON CITATIONS RELATIVE TO PRE-GRANT TREND
2000
TIME
Annual Adaptation for patents of all ages each calendar year
Initial Acquiescence
Overall temporal impact of patents of each vintage
Annual Acquiescence