Learning to Live with Patents:
A Evolving Norms in Response to Legal Institutional Change

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In accounts of the daily practice of scientists significant disagreement arises as to whether and how law, specifically institutions support intellectual property (IP) rights, shape scientific work. On the one hand, patents are considered to be intrusive legal instruments. On the other, it has been argued that collective social norms emerge to manage intellectual property rights and other access-related issues. In this paper we examine the role of social norms and ask whether they serve as a complement to or substitute for formal legal institutional arrangements. We posit that in response to legal change, two key mechanisms – acquiescence and adaptation – arise both of which require a shift in social norms: acquiescence arises rapidly at the level of individuals and organizations while adaptation operates over the long run, at the community-level, and only becomes the dominant response with time. In a quantitative analysis of this thesis we examine the causal impact of expanding IP rights on participation in the life sciences knowledge community. We find that while IP initially engenders rapid acquiescence, over time adaptation exerts an ever larger influence, facilitating participation through the development of norms that outweigh the specific details of IP rights.

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 daily knowledge work (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 1967, 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, Dasgupta & David 1994, Romer 1990). Among the most important legal influences on knowledge work is the granting of intellectual property (IP) rights (North 1991). What lies at the core of this influence is not the grant of IP rights *per se* but their enforcement. For example, the role of IP in the development of collaborative technical standards (such as those for cellular phones) depends crucially on the legal rules governing patent enforcement after standards are established (Simcoe, Graham & Feldman 2007). Similarly, in academia, controversy over human embryonic stem cell patents, erupted not when patents were granted but when the patent owner imposed complex licensing terms on those wanting to use the materials and methods (Murray 2007).

Organizational scholars have been largely silent on the role of the law in knowledge work (with O'Mahony (2003), Marx et al (2007) and Murray & O'Mahony (2007) as notable exceptions), despite the growing presence of the law in knowledge work and the debate among legal scholars, economists and policy makers (David 2003, Jaffe & Lerner 2004) over the role of legal institutions in the knowledge economy. While organizational and institutional scholars have expanded their focus to consider the knowledge economy (Powell & Snellman 2004), the current literature lacks a theory explaining the response to legal change of knowledge workers and their broader intra and inters organizational knowledge communities. Take, for example, the seminal ethnography of design firm IDEO. While describing 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. The laboratory life of scientists articulated by Latour and Woolgar similarly neglects legal change: even as the ethnographers were in the laboratory, scientists filed patents over their research, thus changing its legal status and yet no mention is made of this salient legal transformation (Latour & Woolgar 1979).

The neglect of the law in organizational scholarship, especially in the area of knowledge work, is particularly surprising given the long-standing recognition that organizations are "immersed in a sea of law" (Edelman & Suchman 1997). Nonetheless, while institutional theory includes the law as a key institution (Friedland & Alford 1991, Scott 1994, Stryker 2003), the nexus of extant organizational and institutional theory only includes a narrow slice of the law -- as it pertains to employment, discrimination etc. The profound role of legal property rights on knowledge work within and across organizations is neglected. Beyond simply articulating the link between knowledge work and legal institutions, organization theory must develop a deeper understanding of how legal institutional change shapes organizations and broader communities (DiMaggio & Powell 1983, Scott 1994, Rao et al. 2003). While current scholarship elucidates a variety of responses to institutional change (see for example Oliver 1991) – many of which are salient when we consider the impact of legal change on knowledge work -- what is lacking is a dynamic theory that explores the ways in which knowledge workers, both individually and as part of communities, construct and combine these different responses over time (Van de Ven & Poole 2005). The need for such a dynamic process model of the response to institutional change is particularly pressing when we consider that the response to legal institutions is contoured by the dynamics of how law is translated into policies and practices (within organizations and across communities) and the dynamics of precedent as it emerges from law suits and other enforcement actions (Fuller, Edelman & Matusik 2000). For example, over the past two decades, the meaning and enforcement of formal IP rights has expanded 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). Thus, while organizational theories of knowledge communities ignore the importance of law, legal institutions likely exert an important, dynamic influence.

To develop a dynamic process theory of how knowledge communities respond to legal change, we focus specifically on the causal impact of enforcing IP rights on participation in knowledge work. We then develop and test our theory and its predictions in the context of the life sciences knowledge community. By knowledge community we invoke the image of the invisible college provided by Crane (1969) but more broadly, we consider knowledge communities as individuals collaborating, problem solving and disseminating knowledge both within and across organizations (van Maanen & Barley 1984, Brown & Duguid 1991, 2001; Bechky 2003a, Tushman & Rosenkopf 1992, Van de Ven & Garud 1989). A better understanding of the dynamic role of law is critical not only because it reconciles theory with the practice of knowledge work on the ground where law is salient, but also because laws (and property rights more broadly) constitute a powerful institution in many areas of organizational life; well beyond traditional knowledge work such as engineering (Rosenkopf et al. 2001) and science (Murray & Stern 2007) to encompass, among others, programmin (Benkler 2004), music (Perry 2004) and designers (Raustiula & Sprigman 2006). Understanding the dynamic relationship between property rights and knowledge work is also critical to outcomes of scholarly interest including the structure and performance of knowledge networks (Flemming, Mingo & Chen 2007, Uzzi & Spiro 2005), the effectiveness of intra- and inter-organizational knowledge work (Hansen 1999; Ahuja 2000), and the nature of knowledge communities (Hargadon & Bechky 2006, O'Mahony & Bechky 2008).

We develop a dynamic process theory that explains not only the generative mechanisms driving the response of knowledge workers to legal change but also their temporal order and sequencing (Hargrave & Van de Ven 2006). While our work takes a dialectical view of the response to legal change with the motor of change driven by contestation and conflict (Van de Ven & Poole 2005), we focus on two responses identified by Oliver (1991): acquiescence and adaptation. Grounded in the sociology of law (Edelman 1992, Sutton & Dobbin 1996, Kelley & Dobbin 1999), the law and society literature (Black 1972, Selznick 2003), and historical narratives of the role of IP in knowledge communities (Hughes 2001, Owen-Smith 2005, Murray 2008) acquiescence and adaptation, we argue, represent distinctive ways knowledge workers respond to constraints imposed by legal institutions. While Oliver simply posits these as possible responses, we place them in a dynamic process theory with time as an important explanatory variable, elaborating the relative timing of the two generative mechanisms (Tsoukas 1989). We argue that acquiescence to the law takes place rapidly and is driven as individuals respond to the enforcement of a specific legal property rights right. In contrast, adaptation takes longer and arises as the knowledge community responds to all salient property rights, thus the passage of time plays an important role in adaptation.

In this view, a critical differentiating factor lies in the difference between specific property rights relevant to a knowledge worker's own project and the broader set of rights imposed on other members of an individual's community (while not necessarily influencing their work directly). This distinction is well known in analyses of the power of law suits as a deterrent to, for example, patent infringement: Not only does the outcome of a patent law suit influence the defendant, it also shapes the behavior of all those in the broad community of the defendant whose assumptions about the scope and strength of property rights is now changed (Hall & Ziedonis 2001).

Our core argument rests on a rich and historically grounded understanding of the ways in which legal change have impinged upon knowledge communities placed in the context of existing theories of the organizational response to institutional change (Oliver 1991, Scott 2001). More specifically, consider how the 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 dynamic process theory, the first consequence of IP enforcement is the imposition of 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 and thus limits participation in knowledge work. Over time, a second force emerges – *adaptation* – as members of a knowledge community learn to live with legal change and develop 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. According to our dynamic acquiescence-adaptation theory, the law is neither a bludgeon used to control knowledge workers nor is it irrelevant to knowledge communities. Instead, while legal transformations initially impose 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).

To test the predictions of our dynamic process model, and 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). We develop a novel empirical framework that employs scientific citations as a measure of knowledge exchange and resulting participation in knowledge accumulation. By taking a sample of life sciences 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* before and after patent grant. Building on a recent literature utilizing scientific citations 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 acquiescence and adaptation. Specifically, the acquiescence hypothesis implies that in a period when enforcement becomed strict and widespread, patent grant has a *negative* impact on the citation rate of the particular paper. Over time, however, adaptation implies that the influence of *all* granted patents evolves to mitigate the negative consequences of acquiescence leading to their neutral (or slightly positive) influence on participation.

Our empirical analysis differs from much past research in knowledge communities by virtue of being quantitative and strongly guided by a clearly articulated set of predictions about the ways in which the rate of participation in knowledge work changes due to the causal impact of legal change. The theoretical basis of our research is also distinctive because it aims to build a dynamic model of the response to (legal) institutional change that is not only grounded in a rich historical narrative, but that also articulates the key motors driving the response. By putting these two elements together, we shed light on the interactive dynamics between knowledge communities and law in the process of collaborative knowledge production. More broadly, we can narrow the gap between theory and data, by taking the complex and contested processes that shape the response to institutional change and incorporate them into a testable, dynamic process theory that not only encompasses both acquiescence and adaptation but also articulates the changing balance between the two.

LEGAL FOUNDATIONS OF KNOWLEDGE WORK

At the heart of knowledge accumulation lies the ability of individuals to learn from others who disclose ideas, exchange knowledge among members and provide sufficient access to enable replication, validation and follow-on innovation (Collins 1974, Mokyr 2002). The micro-foundations of knowledge exchange within intra and inter organizational knowledge communities, 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 to another (Star & Griesemer 1989, Brown & Duguid 1991, 2001; Bechky 2003ab). Shared norms and practices 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, Fleming et al. 2007; Reagans & Zuckerman 2003, Uzzi & Sprio 2005).

While social relationships are central to knowledge communities, are all overtures seeking knowledge exchange and participation in knowledge communities fulfilled? If not, what limits exchange between knowledge workers? Some limits reflect informal norms such as those among scientists governing competition and knowledge exchange (Kohler 1994, Campbell et al. 2002, Biagioli 2000). Recent research expands our understanding of the power of these informal rules to shape diverse communities (Fauchart & Von Hippel 2007, Feldman 2006, 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, scholars argue that variations in innovation are grounded in the differential legal status and enforcement of non-compete agreements (Saxenian 1996, Almeida & Kogut 1999). Similarly, the propensity of medical communities to adopt electronic 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 organizational responses to pressures arise from shifting institutional environments, such as regulatory structures, governmental policy, laws and court decisions (Scott 1987, Oliver 1991, Edelman 1992) and then explore the implications of these responses for communities. 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 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 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 knowledge communities and in doing so develop a dynamic process model of the response of 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 to Legal Change

Many analyses of the impact of the law on individuals 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 (DiMaggio & Powell 1983).

Acquiescence at the community level is distinct from individual or even organizational acquiescence. By definition, knowledge communities permeate organizational boundaries (Crane 1969, Tushman & Rosenkopf 1992, Powell et al. 1996, Van de Ven & Garud 1989) and even cross legal 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 is most effective when 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 a 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 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] Starting in the mid-1990s and reflected in the later Appeals Court's *Madey V. Duke University* decision even members of the academic community doing quite fundamental research without explicit commercial goals can be subject to the enforcement of IP rights on tools and materials and, at times, may be required to take a license if they want to access patented inputs for their experiments (Dreyfuss 2004).

The introduction of formal IP rights and the concomitant threats of legal enforcement throughout the knowledge community challenge the norms and practices of that community (Lessig 2004, David 2003). Nonetheless, given the importance of clear terms of exchange in such settings, and the potential power of legal property rights over informal norms, theory suggests acquiescence will be the dominant response to legal change. Strong qualitative evidence suggests that initial

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[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)

acquiescence will be rapid as IP owners send "cease and desist" letters to potentially infringing individuals and their organizations (Murray 2008): unwilling or unable to respond to these requirements, knowledge workers rapidly reduce their participation in the community. In the life sciences community, initial acquiescence reflected the response of scientists and Technology Transfer Office (TTO) professionals to the new enforcement of IP rights in the mid 1990s. With limited experience gaining access to patented materials, data, or tools (Owen-Smith 2005) many universities sought rapid acquiescence. The corporate lawyers who sought to execute their patents on academic institutions also had limited expertise, imposed complex contracts that academics found cumbersome (Einhorn 2006), and, in the late 1990s incurred the highest rate of DNA patent litigation since the 1980 Bayh-Dole Act (Mills & Tereskerz 2008). Not only rapid, theory also suggests that IP will be linked to specific legal events i.e. the granting of particular property rights or the signing of specific contractual agreements changing the legal status of knowledge e.g. incorporating patents into technical standards (Rysman & Simcoe 2008) or signature of an open access agreement over research mice as occurred between DuPont and the National Institutes of Health (Murray et al. 2008). As a result, we hypothesize that:

> **Hypothesis 1**: The introduction of specific formal IP into a knowledge community will lead to immediate acquiescence and result in declining participation in the knowledge community.

Within the broader context of legal change, not only will acquiescence rapidly follow a particular legal event, it will also be increasing in the time from that event as enforcement of a given patent or other form of property rights spreads throughout the community and as individual members of the knowledge community learn of the encumbrances associated with a particular knowledge domain. For example, evidence from the life sciences again illustrates that as patents were increasingly widely enforced, more and more research organizations and their scientists received cease-and-desist letters or were the subject of law suits. We therefore hypothesize that:

Hypothesis 2: The introduction of specific formal IP into a knowledge community will lead to an annual acquiescence and an annual decline in participation.

Adaptation to Legal Change

The acquiescence hypothesis implies that the shadow of the law is widely cast and results in rapid and growing 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 (Silbey 2005). Within 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 conditions: i) ambiguity of the meaning of compliance, ii) variation in the legal construction of compliance by the courts and iii) strength or weakness of enforcement (Edelman 1992).

While the adaptation response to the law implies that legal changes are simply "the beginning of law making" (Kelly & Dobbin 1999 p. 487), the mechanisms of adaptation are likely to be diverse and arise at the individual, organizational and community levels as beliefs about the law interact with "law-related actions" through a dynamic process (Fuller, Edelman & Matusik 2000 p. 201, Heimer 1985). Organization theory documents several motors driving adaptation that are relevant to knowledge communities: 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 (Edelman, Petterson, Chambliss, & Erlanger 1991). This form of adaptation is akin to university researchers simply ignoring patents, and neglecting to conduct patent searches (Walsh et al. 2005). The response is predicated on the assumption that enforcement may be limited, or the hope that the community can be buffered from external scrutiny (Pfeffer & Salancik 1978). It may also be grounded, as in the case of the response of academics of IP law enforcement, that the rules may not strictly apply to them (Walsh et al. 2003, and more generally Fuller, Edelman & Matusik 2000). 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).

Several important characteristics of formal IP rights raise the possibility of considerable adaptation (rather than simply acquiescence) by knowledge communities to changes in the formal legal status of knowledge. 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 (Kleinman 2004, Colyvas & Powell 2007, Murray 2008). Taken together, these elements suggest that adaptation may allow for increased participation in knowledge work (relative to acquiescence).

A crucial distinction between acquiescence and adaptation is that adaptation's most powerful mechanisms arise at the community-level and will therefore shape participation in knowledge work for individuals in a range of organizations, and impacted by the entire range of legal changes i.e. by the collective response to all enforced patents rather than a specific patent. In other words, in the adaptation response, formal and informal engines will operate over time across the entire community to dampen and even negate the acquiescence effect. Specifically, adaptation will occur as knowledge workers and other community actors implement a range of informal or formal agreements in order to avoid complex licensing requirements for individual patents reducing legal complexities (e.g. through the standardization) and transaction costs (Meyer & Argyres 2004). In the life sciences community for example, these included the Universal Biological Material Transfer Agreement, 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). Therefore, from a temporal perspective, adaptation and the concomitant increase in participation in a knowledge community that it drives, can be linked to the passage of time, from the first events in legal enforcement, and relative to the immediacy of acquiescence, takes time. Therefore we hypothesize:

> **Hypothesis 3**: The introduction of specific formal IP into a knowledge community (all else equal) will lead to a slow increase in participation in a knowledge community linked to the timing of the introduction of the all formal IP changes not the specific IP rights.

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. It is therefore highly contingent on the local environment, institutional context, and the network structure of the knowledge community to structure a response (Knorr-Cetina 1999). We therefore predict:

> **Hypothesis 4**: Adaptation and therefore participation will take place at a higher rate in the context of communities with a longer tradition of collaboration and exchange.

Compare for example, those engaged in knowledge work in academia and industry. Academics, with many opportunities to gather and work collectively to develop alternative responses to the enforcement of IP rights, will likely develop a strong adaptation effect relative to those in industry. The status of knowledge community members provides another important dimension when examining the role of changing IP enforcement. Within the scientific community, the importance of status hierarchy has been well-documented (Merton 1988, Cole & Cole 1973) and status will, we suggest, positively contour rate at which different scientists can engage in and take advantage of adaptation. Thus, while acquiescence to patent enforcement is likely to be equal across the status hierarchy, high status members of a knowledge community will exhibit more rapid adaptation compared to their low status counterparts.

Not merely distinctive responses to legal institutional change, the dynamic process model we propose illustrates that knowledge communities can and do acquiesce and adapt simultaneously. Understanding the temporal dynamics these behaviors -- the speed of acquiescence and the relatively slower pace of adaptation -- as well as the level at which they operate – acquiescence linked to individual contracts or patents and adaptation to the entire set of contracts and patents imposed across the knowledge community, helps construct a richer theory. Taken together, this dynamic process model builds on the historical narrative of the law as it shapes knowledge work, but also allows us to interpret the causal role of law and explain the complex patterns of participation in knowledge exchange and accumulation over time.

RESEARCH SETTING:
FORMAL IP RIGHTS IN THE LIFE SCIENCES COMMUNITY

The remainder of this paper applies our dynamic process theory to the response of the life sciences community to changes in the granting and enforcement of intellectual property rights. While the debate over the appropriate role and scope for patents in knowledge work is broad

(Merges & Nelson 1990; Lessig 2002, Scotchmer 2004, Jaffe & Lerner 2004, Heller 2008), it is animated by discussions of the impact of patents on the academic community's open commons (Mowery et al. 2004, Heller & Eisenberg 1998, David 2003, Kleinman 2003). 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 were granted to leading U.S. universities (Owen-Smith & Powell 2003), and at least 12 percent of U.S. life science faculty members have at least one patent in addition to their publications (Ding, Murray & Stuart 2006).

Expanding Legal Rights

A number of factors shaped the expansion of life sciences 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 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 2001). Finally, landmark court decisions such as the 1980 *Diamond vs. Chakrabarty* case (allowing patents on genetically modified organisms) and the 1988 grant of the Oncomouse patent (extending such protection to genetically modified mammals) expanded the scope of patents available for life sciences research (Kelves 2002).

A dramatic instantiation of the emphasis on IP was the growing number of ideas once placed solely in the public domain now additionally embedded within the patent system, thus resulting in what we term patent-paper pairs (Murray 2002, Ducor 2000, 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).
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> "A synthetic operon for polyhydroxyalkanoate (PHA) biosynthesis designed to yield high levels of PHA synthase activity in vivo was constructed …. 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 life sciences community's expanding production of knowledge that is simultaneously of scientific and commercial interest. Patent-paper pairs are also the focal point for many of the specific instances in which life science patenting has roiled the life sciences knowledge community. Such pairs challenge the knowledge community because they initiate a dynamic process that changes the legal status of knowledge. While publications and patents are filed simultaneously, publication is rapid (3-4 months) and with disclosure in a journal, the knowledge is subject to informal norms (for exchange and follow-on use). With the grant of private property rights (an average of 3 to 4 years later) the knowledge is subject to the formal legal rights associated with IP's legal institutional foundations. While the right to enforce IP rights against all members of the knowledge community is not always exercised, such enforcement is possible and can include academics as well as their industrial counterparts.

Against this backdrop, scholars have taken three contrasting perspectives on the impact of patents on knowledge work among life scientists. First, a series of dramatic controversies in the mid-1990s raised the specter that formal IP rights might stifle community members' ability to build on each other's knowledge (Heller & Eisenberg 1998, Boyle 2003, Benkler 2004). For example, having gained an exclusive license to novel transgenic mouse technology developed at Harvard and disclosed as a patent-paper pair, 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 limits on knowledge work extend to patents on everything from human embryonic stem cells to gene sequences and genetic tests (Heller & Eisenberg 1998).

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 (Mazzolini & Nelson 1998, Gans, Murray & Stern 2008).

Third, 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 percent 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), few proactively evaluate whether their own research violates others' patents e.g. only 5 percent report that they regularly check patent databases when designing new projects (Walsh et al. 2003, 2005).

To test our dynamic process theory of the impact of IP in the life sciences community, we grounded our approach in the historical narrative underlying these three competing claims regarding IP's influence on the life sciences community. Given the subtle temporal interplay theorized to exist between acquiescence and adaptation we adjudicated the dynamic response of the life sciences community to legal change using a longitudinal, quantitative model. This allowed us to test more precisely the hypotheses of our model and the temporal dynamics of knowledge communities. The following section describes our empirical approach.

EMPIRICAL APPROACH

A well-established research design to test dynamic process theories links the theoretical framework with a rich understanding of the historical context (e.g. Barley 1986). To test our hypotheses on the impact of legal change on participation in life sciences communities, we followed this approach but integrated historical qualitative evidence into a quantitative empirical setup. The quantitative approach drew on recent advances in the program evaluation literature that pay careful attention to identifying the causal impact of institutional changes on a variety of actors, particularly disentangling temporal dynamics from broader changes arising with the passage of time. More specifically, using a sample of scientific papers that are linked to specific patents, we implemented a differences-in-differences estimator to evaluate how the level of participation by members of the knowledge community changed after the grant of specific paired patents (in the period 1995-2002).

Within this framework, we translated the four core hypotheses of our dynamic process model into distinct, testable predictions of how acquiescence and adaptation takes place in the life sciences community in response to IP and its enforcement. These predictions focused on changes in the annual rate of follow-on accumulation of life sciences knowledge, reflected in the citations to paired papers, with the grant of paired patents (some time after publication). In other words, how the citation level changes with the grant of a patent over the knowledge covered in each paired scientific article. As described below, the use of citations was a useful, though imperfect, metric for capturing participation in knowledge work and the underlying exchange it depends upon, particularly when the aim was to evaluate how the rate of participation changes with shifts in the legal environment surrounding a given "piece" of knowledge.

Testable Predictions

We focused our analysis on the late 1990s through to 2005; a period that encompasses the initiation of patent enforcement in the academic life sciences community. Against this backdrop, we traced out the impact of IP on participation in the life sciences community, focusing on the three effects described in our hypotheses: initial acquiescence, annual acquiescence, and annual adaptation.

Hypothesis 1 predicts an initial acquiescence response in the period immediately following changing legal practice around patent grant and enforcement at the start of our sample. In empirical terms, to the extent that acquiescence reduces knowledge exchange and broader participation in the knowledge community surrounding the patented paper, we expect to observe a decrease in the number of citations to the (paired) paper. Hypothesis 2 predicts 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). In other words, enforcement leads researchers to exit a research line in each year following patent grant rather than participate in an area fraught with complex legal requirements. This prediction, importantly, relates to individual patents with the acquiescence response by individuals increasing with each year following to the specific patent grant. Hypothesis 3 predicts an adaptation effect which (all else equal) will be manifest as an increase in the number of follow-on citations over time. As noted above, a variety of contractual mechanisms were developed as part of the adaptation response over the period 1998-2005. Moreover, adaption is relevant for all patents, its impact on participation will be linked to the timing of the first patent granted and will be increasing with the calendar years from that event and will impact the population of all patents granted and enforce for any subsequent year.

Our predictions are summarized in Figure 1(a-d), illustrating how to distinguish the effects of these strongly contrasting forces: 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, acquiescence and adaptation exert countervailing effects, and the expected level of citations, therefore, reflects the changing between them (1c and 1d).

-- Insert Figure 1 about here --

Moving to consider how the balance of acquiescence and adaption pertains to different sub-groups, following the intuition in Hypothesis 4, we capture the predict that different participants in the knowledge community differentially respond to the impact of patent enforcement by capturing variations in the citation patterns for citations made by those in academia v. industry on the one hand and by those in high v. low status institutions on the other.

Empirical Model

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 for evaluating the impact of acquiescence and adaptation within the life sciences community exploited 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; and the fact that some scientific papers are also disclosed in paired patents whose grant comes several years after publication.

First, our analysis was premised on the construction of a sample of similar "pieces of knowledge" disclosed in scientific papers. We selected 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 papers was 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, Levin & Stephan 1991, Adams & Griliches 1998, 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).

The second element of our empirical approach used citations by other scientific papers to our sample of papers. This measure is captures exchange and accumulation of the knowledge disclosed in the paper as a proxy for participation in the knowledge community. While it would be ideal to have a direct participation measure, scientific citations capture researchers' reliance on prior published work in their own knowledge production. This approach builds on scholarship using patent and publication citations to trace the flow of ideas and how they accumulate 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). Citation data thus facilitated our longitudinal analysis, allowing us to trace out how researchers exchanged knowledge, built upon a publication and thus participated in a knowledge community.

The third aspect of our empirical approach exploited the existence of patent-paper pairs as a concrete starting point from which to identify the impact of IP rights on the rate of participation in scientific knowledge work. In particular, we took 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. It is not until patent grant that the application holds formal IP rights and can use them to change participation in knowledge work, including the treat of infringement lawsuits.

The delay in patent grant provides a "natural experiment" to evaluate how changing legal rights change participation in knowledge work. By comparing the rate of follow-on citation in the pre- and post-patent grant period (controlling for changes in the rate of citation experienced by all articles over their life) we can isolate the impact of patent grant on knowledge exchange and participation. In particular, initial acquiescence was 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, annual acquiescence was 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, annual adaptation was tested by evaluating whether, with the passage of calendar time, the impact of patents on citations across the community was reduced for all patent-paper pairs regardless of patent age. It is worth noting that by taking advantage of the variation in the patent grant delay and the publication year in our sample, we were able to separately identify the three effects implied by the dynamic process theory.

Empirical Specification

Our empirical specification predicted the annual count of forward citations in publications to each of the papers in our sample over the period 1997-2005. This dependent variable took the form of count data skewed to the right. Therefore, we used a Poisson model of the annual citations for each publication in our dataset. In the estimation, it was 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 were being considered. As such, our empirical specifications accounted 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). 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 the model incorporated 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 specification identified how the average pattern of citations to the paper changes with patent grant. Specifically, we estimated

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

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[2]. The coefficient on POST-GRANT (ψ) estimated the marginal impact of the intervention on the set of treated articles. Thus, ψ measured the impact of 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 provided an aggregate assessment of the impact of the IP rights on forward citations in the years following patent grant, it did not provide any insight into the temporal dynamics of patent enforcement as it shapes follow-on researcher participation in the knowledge community. To tease out these effects, a more nuanced baseline specification included three distinctive parameters, each intended to capture forces contouring the impact of patent enforcement on forward citations over time. The first was the initial acquiescence capturing the initial impact of a patent on a piece of knowledge as it moves into the enforcement regime. The next was an annual acquiescence effect, which estimated 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 defined the impact of all granted patents in each given calendar year after 1999 – the initial year of patent grant in our sample. This variable captured the role of adaptation and the changing annual

[2] 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.

impact of all patents (regardless of their age) enforced in a given year. Taken together, our core empirical specification was:

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

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

Finally, as argued earlier, our dynamic process theory 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 took 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 aggregated 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 adapted the specification in (2) to estimate the impact of patents on different subpopulation margins, indexed by *j*:

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

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

Patent-Paper Pairs Sample

Our sample was composed of 174 published scientific research papers disclosing potentially patentable knowledge drawn from a top-tier journal, *Nature Biotechnology*. They included all research articles authored by at least one U.S. academic, published in the journal in the period 1997-1999. Our choice of period allowed us to examine the changing impact of patent enforcement in the period 1999 – 2005 that is the source of discussion in the theoretical perspectives outlined above. The journal selection was guided by our interest in knowledge of high scientific impact and commercial relevance. *Nature Biotechnology* was 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 patents covering academic knowledge. A focus on one setting for knowledge production also limited the range of mechanisms at work as follow-on researchers learn to live with the law[3].

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

[3] 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.

procedure, 91 (53 percent) are associated with a paired U.S. granted patent. 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).

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) was a public entity (university, research institute or part of a government intramural research organization) and coded the citation as CITE PUBLIC. If a citation had at least one institution associated with a biotechnology, pharmaceutical or other for-profit firm, we coded the citation CITE PRIVATE. We then coded all the institutional affiliations according to whether they had at least one address associated with the top 25 recipients of NIH funding (as of 2005) – CITE HIGH STATUS. We coded all other citations as being CITE LOW STATUS.

Finally, we generated a set of citation-year characteristics. First, we defined PUBLICATION AGE as YEAR – PUBLICATION YEAR. We then defined 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 was defined by determining if the YEAR – GRANT YEAR is >1. We then developed our dependent variables. The main dependent variable was 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 also separated 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) were aggregated to create ANNUAL FORWARD CITATIONS PRIVATE. Likewise, we generated 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. The remaining cites were 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 were 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 (see Table 1 and 2).

-- Insert Table 1 about here --

-- Insert Table 2 about here --

These articles had an average of 6 authors (# AUTHORS). Again, this was typical of the rich collaborations across individuals and organizational boundaries characterizing the life sciences community. In contrast, fewer individual inventors and assignees were found on our sample of 91 patents – the average # INVENTORS was 3. When citations were aggregated at the article level into citation-year characteristics by different types of forward citations, we found that the average ANNUAL FORWARD CITATION PUBLIC was 10.59 (std 17.29) and PRIVATE is 1.92 (std 4.70). The HIGH:LOW STATUS citation breakdown had means of 3.204 (std 5.148) and 8.285 (std 14.998) respectively (meaning that there are more low status than high status citations).

An important aspect of our identification strategy lay in the time variation in patent grant. Of the 91 patents in our sample, the average PATENT GRANT YEAR was 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 observed was 2001.95 (std 2.09) and we observed an average of 0.632 observations in the PATENT, POST GRANT period. This provided significant variation across the sample from which to identify and disentangle the adaptation and acquiescence effect.

RESULTS

All our results employed a conditional fixed effects negative binomial specification with ANNUAL CITATIONS as the dependent variable (in Tables 3 and 4). In each regression we included 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 percent boost to ANNUAL FORWARD CITATIONS).

-- Insert Table 3 about here --

The first two of these specifications (3-1 and 3-2) replicated an earlier analysis of the entire *Nature Biotechnology* dataset employed by Murray and Stern (2007) (MS). Restricting the ANNUAL FORWARD CITATIONS in our dataset to the period 1997 – 2002, we closely replicated the MS analysis and had the same basic patterns of results. Specifically, when we examined citations through 2002, we observed 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 was identified from the change in citations (relative to expectations) after the associated patent was granted. When we further restricted 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 found an even stronger effect - a 28 percent 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) provided a very different "aggregate" result -- PATENT POST GRANT was associated with a modest and marginally significant positive increase in the citation rate of about 15 percent. In other words, as we increased the time horizon of our sample but maintained the entire set of PUBLICATION AGE, YEAR and ARTICLE fixed effects, evidence for a modest negative impact of patents on knowledge exchange and accumulation declined. Indeed, the slight positive (and significant) result suggested that patent grant may provide a slight "boost" to exchange consistent with the development of a "market for ideas." Taken together, these results suggest that the overall balance of the impact of IP changes over time. The remainder of our empirical analysis explores this pattern in a more structured way following the theoretical predictions outlined above and focusing on the changing balance of acquiescence and adaptation.

Acquiescence & Adaptation

In Table 4 we present our main evidence for balance of acquiescence and adaptation on the impact of patents on cumulative scientific research.

-- Insert Table 4 about here --

The results are quite striking. First, and most importantly, consistent with Hypothesis 1, the baseline initial acquiescence effect was negative with a 24 percent decline in the citation rate in the year following patent grant (sig. at 10 percent level). Second, consistent with our prediction in Hypothesis 2, the annual acquiescence effect that accrues to each patent in the years following patent grant and the initial acquiescence was significant; the negative influence of patents increased at a rate of 13 percent (sig. at 1 percent level) in each year after the grant of the patent. However in contrast, and in accordance to Hypothesis 3, the rate of adaptation associated with all patents in our sample in a given year and regardless of their age was also impressive, with a 19 percent average annual increase (sig. at 5 percent 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 percent in the following year. In each subsequent year, citations were depressed by 13 percent because of acquiescence to the particular patent but this was offset by a 19 percent boost due to overall community-level adaptation. On balance then, there was a net increase in citations from the 24 percent initial decline of 6 percent each year (-13 + 19), so that the impact of patents granted in 1999 is -24 percent in the first year, -18 percent in 2001, -12 percent in 2002, -6 percent in 2003 and the citations were 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 percent decline overall in the year following PATENT POST GRANT.

These results also help 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 included 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 estimated a "baseline" effect for each year, from 2000 to 2005. We interpreted 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 percent) – 2*annual acquiescence (12.5 percent) -- about a 24 percent decline in ANNUAL FORWARD CITATIONS. In other words, the analysis in 4-2 identified the overall adaptation effect that took place across the entire community over the period of our analysis, while the annual acquiescence allowed 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 percent reduction in 2000 to more than a 70 percent 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 Community Subpopulations

We now move to a more detailed investigation of the sources of the marginal citations arising from patent grant as examined in Hypothesis 4. 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 allowed us to evaluate these issues more precisely by comparing the impact of patents across different sub-sections of the community. We were particularly interested in whether PATENT POST GRANT has a differential impact on different subpopulations of potential citers in the life sciences community. Consistent with the notion that academic members of the community will be most affected by patent grant and will show rapid acquiescence due to their lack of experience in accessing patent material, we began by examining the difference in the impact of patents for public sector and private sector authors (Table 5).

-- Insert Table 5 about here –

The results (5a and 5b) accorded 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 reflected 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 were significant.

Our results for the HIGH STATUS CITERS and LOW STATUS CITERS also provided us with rich insights into extent of acquiescence to individual patents by members of each subpopulation and of gradual adaptation across the subpopulation community (Table 6).

-- Insert Table 5 about here –

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

CONCLUSIONS

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, 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.

The difference between academic and industry scientists was particularly illuminating: it underscores the importance of historical context when considering the balance of acquiescence and adaptation. While enforcement of patents on academic members of the life sciences community was a new phenomenon in the late 1990s, infringement suits against industrial scientists were more commonplace. Therefore, these sub-groups were not subject to strong legal change during this period (although we would expect that their acquiescence and adaptation would be observable in an earlier period). Less familiar with IP practices than industrial researchers, it is not surprising that the acquiescence effect in our period was much greater for follow-on academic researchers relative to their industrial colleagues. And, that there was also rapid adaptation. Thus, by combining a dynamic process model with historically salient features of the empirical setting we can more precisely understand the changing balance of responses to institutional change.

DISCUSSION

Our dynamic process model explains the complex and historically contingent impact of legal institutional change on knowledge work. By developing a longitudinal empirical analysis, grounded in the historical narrative, to test the hypotheses of the model, we were able to tease out the separate institutional processes at work in the knowledge community – acquiescence and adaptation – and the changing balance between them. Accordingly, we find that two powerful and at times conflicting forces – acquiescence and adaptation -- guide the response to the law by individuals and communities engaged in 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 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.

By demonstrating that legal institutional change in communities is a dynamic and emerging process, our perspective suggests 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 (2005) have argued, organizational theory shifts toward a problem-based approach, making sense of historical occurrences of institutional change (p. 340), then incorporating the historical context into both our theories 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 (Van de Ven & Poole 2005). 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 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 modern institutions of power with critical economic consequences (Davis and Marquis, 2005). 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. However, as O'Mahony and co-authors argue, while open source communities often used to promote exchange and participation, they also engage with the law in their daily work selecting among the bewildering array of licensing conditions that can be appended to their software code. More broadly, 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 2000), 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 IP law and scholarship on knowledge work (Brown & Duguid 1991, 2001; Bechky 2003ab) to encompass legal issues, the organizational agenda will be grounded more strongly in the key challenges of the knowledge economy.

A central tenet of the knowledge economy is growing participation in knowledge production 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 also 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 dynamic process theory focuses on the mechanisms behind this unfolding. While narrow in its empirical focus, our dynamic process theory strengthens the micro- foundations of knowledge work and promises to illuminate other distributed forms of innovation; our theory and methods are widely applicable to quantitative and qualitative analyses of the ways in which different communities learn to live with the law.

By grounding a new agenda in a dynamic process theory, we emphasize the enduring nature of particular responses to legal change (Oliver 1991) -- particularly acquiescence and adaptation -- while recognizing their dynamic interplay, overlapping presence in daily life, and the changing balance between them that unfolds in a rich, historically-contingent setting. With our focus on how law shapes knowledge work, the agenda we propose makes sense of legal institutional change in new settings well beyond formal organizational boundaries. It also raises the question of how individuals and their communities undertake knowledge work in the shadow of many other aspects of the law (and of norms), for example the construction of procedures to adjudicate the quality of knowledge work, to establish governance of knowledge validation, and to manage secrecy. Lastly, by expanding the focus of institutional theory to encompass intellectual property law, we can extend the reach of institutional theory into critical and contested arenas of social life.

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TABLES & FIGURES

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	

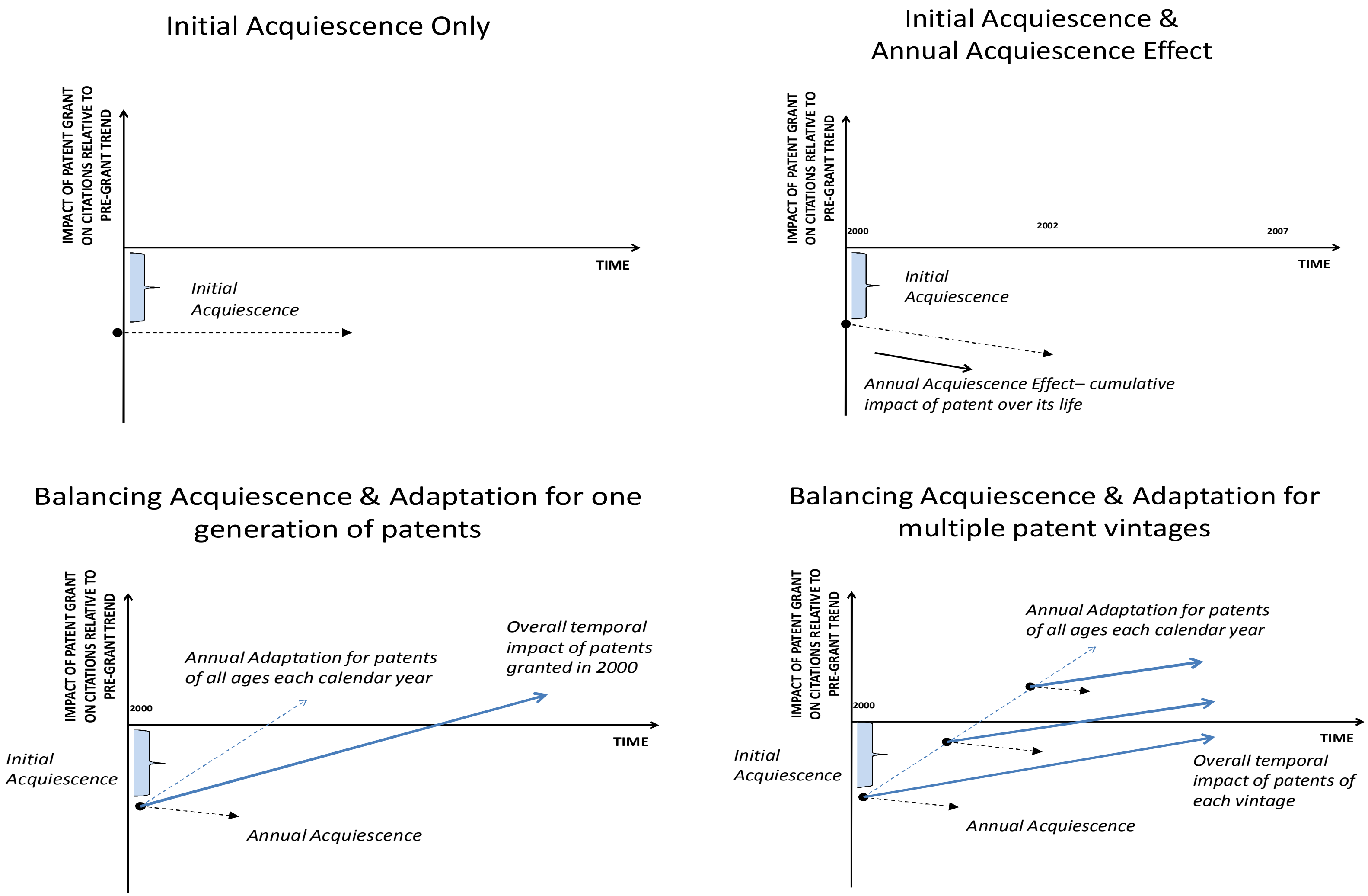
Significance levels: * 10% ** 5% *** 1%

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(a-d)


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