



Paper to be presented at the Summer Conference 2009

on

CBS - Copenhagen Business School
Solbjerg Plads 3
DK2000 Frederiksberg
DENMARK, June 17 - 19, 2009

KNOWLEDGE PRODUCTION IN INNOVATIVE FIRMS UNDER UNCERTAIN INTELLECTUAL PROPERTY CONDITIONS

Kenneth G. Huang

School of Business, Singapore Management University
kennethhuang@smu.edu.sg

Abstract:
Knowledge is a valuable and strategic asset that affects how firms and organizations innovate and compete in the global marketplace. This study investigates how innovative firms and organizations produce and accumulate scientific knowledge under uncertain intellectual property right (IPR) conditions, across different levels of intellectual property uncertainty, and when they operate or develop scientific innovations in weak IPR institutions such as China. Developing a novel panel data that covers more than 400 unique life sciences firms and organizations based on the population of 4,270 USPTO issued patents in genomics matched to 1,279 papers from 1988 to 2005, I find a reduction in patent enforcement uncertainty and market value uncertainty, facilitated by the granting of the paired patent over its corresponding scientific knowledge, work in concert to negatively impact (by over 20%) scientific knowledge generation and accumulation within the firm. The decline in annual organization self-citations reflects a reallocation of scientists and scientific resources to alternative knowledge projects, and is most salient for firms operating and developing their scientific innovations in countries with strong IPR institution, for large and established IPO firms and for private firms than public institutes. These findings have significant strategic and management implications for innovative firms and organizations that engage in knowledge-intensive activities and operate across national and geographic boundaries, especially in terms of the dynamic trade-off they have to make between short-term exploitation of firm's existing knowledge base and future exploration into important (but yet unrealized) external areas of research and market for ideas.

JEL - codes: O32, O34, M13

Knowledge Production in Innovative Firms under Uncertain Intellectual Property Conditions

Abstract

When innovating science and technology firms generate knowledge, they often have to first endure a sustained period of uncertain or no intellectual property right (IPR) protection. This paper examines the impact of uncertain IPR conditions on knowledge production and accumulation within different types of innovative firms and organizations, particularly when they operate or develop scientific innovations under weak IPR institutions like China versus strong ones like U.S. I develop and analyze a novel panel data covering 401 unique life sciences firms and organizations based on the population of 4,270 USPTO genomics patents matched to 1,279 papers from 1988 to 2005. I find the reduction in patent enforcement and patent market value uncertainties, due to granting of the associated patent over its corresponding scientific knowledge, negatively impacts (by over 20%) the production and accumulation of follow-on firm knowledge. The decline is most salient for firms that develop their scientific innovations or operate in strong IPR countries, for larger and more established IPO firms, and for for-profit firms than public institutes. These findings highlight the dynamic trade-off innovative firms have to make between short-term exploitation of existing knowledge base and long-term exploration into important external areas of research and market for ideas.

1. Introduction

Knowledge is a valuable and strategic asset that affects how firms and organizations innovate and compete in the global marketplace (Winter 1987, Kogut and Zander 1992, Grant 1996). When innovating science and technology firms generate knowledge, they often have to first endure a sustained period of uncertain or no formal intellectual property rights (IPR) protection. This problem is exacerbated as firms increasingly invest (Farrell et al. 2004, Feinberg and Gupta 2009), operate across national and geographic boundaries in countries with weak or ineffectual IPR protection, or develop their scientific and technological innovations in those countries (Bureau of Economic Analysis 2000).

Recent empirical evidence suggests innovating firms, especially those operating across national boundaries under weak IPR environments cope by making greater use of their internal linkages and complementary assets (Zhao 2006, Branstetter et al. 2004). In other words, to provide immunity against such weak external IPR protections, these firms rely on increased internal mechanisms and intra-firm activities to protect their intellectual assets and appropriate the values of innovations produced.

However, a key puzzle arises: how do uncertain IPR conditions impact knowledge production and accumulation *within* innovative firms and organizations? Specifically, how do different types of firms and organizations produce their scientific knowledge and innovate when such IPR uncertainties have been reduced, particularly when they develop their scientific innovations or operate under weak versus strong external IPR environments?

Using the context of genomics in the life sciences, this paper investigates this puzzle by examining how the reduction of uncertain IPR conditions affects scientific knowledge production and accumulation within different types of innovative firms and organizations, especially when these firms develop their scientific innovations or operate under weak external IPR institutions like China and India versus strong ones such as U.S. and U.K.

This paper focuses on scientific knowledge production and accumulation *within* the firm or organization boundary (versus *outside*). Scientists *outside* the boundary of the focal firm have to navigate

through complex patent arrangements known as “patent thickets” (Heller and Eisenberg 1998, Shapiro 2001) and often pay substantial amount of royalties before they could gain access to valuable patented innovations by other firms. This has been affirmed by recent empirical evidence in the semiconductor industry (Ziedonis 2004) and in the life sciences (Huang and Murray 2009). On the contrary, scientists *within* the firm typically do not need to make patent and royalty arrangements to gain access to their own firm’s scientific innovations, incurring minimal or no transaction cost. Thus, the difference arises between how scientific knowledge is produced and built upon *within* versus *outside* the firm boundary, especially when the intellectual property conditions are highly uncertain in the pre-patent grant period compared to the post-patent grant period when such uncertainties have been significantly narrowed.

Furthermore, the production of scientific knowledge after a reduction in IPR uncertainties should follow different trajectories under weak versus strong external IPR protection environments (as described before); for different types of firms (e.g. more established IPO firms vs. non-IPO firms and start-ups); and in public institutions such as universities and research institutes versus private sector for-profit firms due to their intrinsic differences in operations, functions and capabilities. For the latter, the management of for-profit life sciences firms usually exerts strong mandate over the kind of projects their scientists engage in based on the most efficient scientific resource allocation into strategic research areas perceived to have higher promise for commercialization through in-house development, out-licensing or other external appropriation mechanisms (Teece 1986, Gans and Stern 2003). My own conversations with managers and scientists in biotechnology and pharmaceutical companies also confirmed the importance of efficient resource allocation in assigning scientific projects (including abandonment of project where commercial viability or strategic fit is not established) to mitigate resource constraint to a varying degree in different types of companies.¹ This problem is particularly acute in less established (typically non-IPO) biotechnology firms given tighter budget, availability of scientific resources and access to external resources and networks. On the contrary, academic scientists working in universities, and to a large extent

¹ I had conducted formal and informal interviews with scientists and managers in several large and small biotechnology and pharmaceutical companies in the U.S. from 2004 to 2008. Information was updated through emails and phone calls on confidentiality conditions.

public research institutes and laboratories, enjoy much more freedom in deciding their own lines of scientific research or projects, as long as they are perceived as important, interesting (for the scientists) and potentially yielding high impact.

These observations call for a theoretical framework to understand the impact of uncertain IPR conditions on knowledge production and accumulation in different types of innovative firms and organizations that operate across national and geographic boundaries under various external IPR environments.

For these innovating firms, effective management of knowledge, learning and innovation are critical to gaining and sustaining competitive advantage. A rich literature on the “knowledge-based view” of the firm affirms this position (Kogut and Zander 1992, Grant 1996) and an explicitly knowledge-based view has been adopted in many recent empirical works on the firms and firm strategies (e.g., Martin and Salomon 2003, Zhao 2006). While such conceptualization is important to further our understanding in knowledge-intensive industries such as pharmaceutical and biotechnology, such view appears to be rather incomplete in its conceptualization and in explaining the many complex interactions taking places within firms such as interactions of intellectual property institutions (and strategies) with the knowledge production process, commercialization, investor funding (Hsu and Ziedonis 2008) and the market for ideas (Nelson and Merges 1990, Arora 1995, Arora et al. 2001, Gans et al. 2008). For example, the granting of patent has a positive effect on venture capital investor estimates of start-up firm values (Hsu and Ziedonis 2008) and substantially increases (by 70%–80%) the rate of achieving licensing agreement, with its effect most pronounced in the time period immediately following the patent grant (Gans et al. 2008).

Furthermore, some scholars contend that if the value of the firm is defined as its store of knowledge and expansion of the firm's boundaries is related to the transfer of knowledge, inevitable uncertainties about the value of this knowledge are enough to explain internal transmission and the existence of firms (Kogut and Zander 1992, 1993). This notion does not incorporate the many causal mechanisms and contextual relationships between knowledge processes and organizational factors, particularly with

respect to the organizational mechanisms and causality between knowledge process and organizational process (Foss and Pedersen 2004).

In particular, there have been scant previous empirical works devoted to systematically understanding and theoretically framing the ways in which organization scientific knowledge generation and characteristics may be affected through interactions with varying IP institutions, geographic and organizational factors.

To do this, I develop and analyze a novel panel data set covering 401 unique firms and organizations in the life sciences,^{2,3} based on the entire population of 4,270 genomics patents from the United States Patent and Trademark Office (USPTO) matched to 1,279 genomics papers from 1988 to 2005. I find that a reduction in patent enforcement uncertainty and patent market value uncertainty, due to the granting of the associated patent over its corresponding scientific knowledge, work in concert to reduce the generation and accumulation of scientific knowledge within the firm (by more than 20%). The decline in annual organization self-citations reflects a reallocation of scientists and scientific resources to alternative knowledge projects. This decline is most salient for firms that develop their scientific innovations or operate in countries with strong IPR institutions such as U.S. and Canada than weak ones such as China and India, for larger and more established IPO firms than non-IPO firms and start-ups, and for private sector for-profit firms than public research institutes and universities.

This is the first study, to the author's knowledge, that examines the impact of change in uncertain IP conditions on scientific knowledge production in different types of firms and organizations under various external institutional environments. It contributes to our understanding of the interaction of IP institutions with knowledge processes within innovative firms by combining insights from knowledge-based view of the firms, with its understanding into the value of the firm as defined by its production, generation and

² These firms range from large IPO firms (mostly MNCs) developing scientific innovations and operating across different countries and IP institutions such as Pfizer, Merck and Amgen to non-IPO firms and small biotechnology start-ups like Ceptyr, Inc. and AlphaGene, Inc. based solely in the U.S. or another country.

³ As patent can be assigned to either the parent company or one of its subsidiaries for unobservable reasons, I classify each multiunit firm (i.e. firms with subsidiaries) as one integrated strategic agent. This is consistent with previous literature (e.g. Zhao 2006, Oxley and Wada 2009).

transfer of knowledge (Kogut and Zander 1992, 1993, Buckley and Carter 1999); intellectual property institution and strategy (Gans and Stern 2000, Gans et al. 2008, Zhao 2006, Teece 1986), which focuses on how intellectual property influences strategic outcomes in the firms; and lastly, organization theory examining the emergence of organizations which facilitate knowledge works (Brown and Duguid 2001, Bechky 2003, O'Mahony and Bechky 2008).

In the next section, I develop the theoretical framework and hypotheses. In § 3, I outline the importance of life sciences and biotechnology, specifically the field of genomics, as the context of this empirical research. Section 4 describes the empirical design while § 5 describes the data, measures and models. Section 6 presents the results and robustness checks. Section 7 discusses and concludes.

2. Theoretical Framework and Hypotheses Development

2.1. Probabilistic Patents and Uncertainties over Patent Rights

Patents are “probabilistic” property rights fraught with uncertainty (Lemley and Shapiro 2005). The types of uncertainty include *patent grant uncertainty* – whether patent will be granted at all; *patent pendency uncertainty* – how long after application will patent be granted; *patent scope uncertainty* – scope of patent right eventually allowed by the patent office; *patent enforcement uncertainty* – even after patent has been granted, how effective can it be enforced, and *patent market value uncertainty* – even if legal uncertainty with patents is completely resolved, the economic and strategic value of patents is still subject to some level uncertainty (Gans et al. 2008).

After the granting of a patent closely associated with a piece of knowledge in a paper through an important transition known as a *patent-paper pair* (Ducor 2000, Murray 2002, Murray and Stern 2007, Huang and Murray 2009),⁴ the patent grant uncertainty (u_g), patent pendency uncertainty (u_p), and patent scope uncertainty (u_s) will be eliminated, i.e. $u_g=0$, $u_p=0$, $u_s=0$. However, patent enforcement uncertainty (u_e) and market value uncertainty (u_m) will be reduced but not completely eliminated, i.e. $u_e>0$ and $u_m>0$.

⁴ A *patent-paper pair* refers to instance where the same “piece” of scientific knowledge is manifested and disclosed both in the form of a formal patent and a scientific paper.

For the reduction of patent enforcement uncertainty (u_e) and patent market value uncertainty (u_m), through the granting of a patent, to impact the knowledge generated and used by the firm, three conditions must be fulfilled. First, the patent must be closely associated with a corresponding piece of scientific knowledge generated within the firm (Huang and Murray 2009). Second, the narrowing of patent market value uncertainty must alter the perceived (financial) valuation of the corresponding piece of scientific knowledge generated (Gans et al. 2008). Third, the (financial) cost of using a piece of patented knowledge of the firm by internal scientists within the same firm is zero or close to zero.⁵

Take the simplifying assumption that the scientists in a focal firm can and will work on generating one and only one piece of scientific knowledge a_1 at one time (manifested as a focal scientific publication), either by the firm itself through in-house R&D, or with another organization through joint venture or alliance only if its own capability or resource is not sufficient. Both of these mechanisms are considered to be knowledge production by firm scientists using firm capabilities and resources and should hence be reflected in follow-on organization self-citation counts (to the focal scientific publication). Assume also the focal firm can license out the production of *additional* pieces of scientific knowledge (if identified) to other firms.⁶

If the piece of scientific knowledge a_1 has a perceived value of $V(a_1)$ by the focal firm and external firms alike before any associated patent is granted, and a perceived value of $V(a_2)$ after the patent grant, then $V(a_2)-V(a_1)$ indicates the difference (increase or decrease) in valuation of the same piece of knowledge caused by the narrowing of market value uncertainty as a result of patent grant.

If $V(a_2)-V(a_1) > 0$, i.e. higher valuation for the patented scientific innovation is created by the reduction of market value uncertainty, the firm should take the scientific innovation forward. Even if $V(a_2)-V(a_1) < 0$ but as long as $V(a_1) + [V(a_2) - V(a_1)] = V(a_2) > 0$, the firm which can and will engage in one and only one piece of knowledge production should take it forward. However, if $V(a_2) < 0$ (to the focal

⁵ This condition is verified to be consistently true by scientists and managers in the biotechnology and pharmaceutical firms interviewed from 2004 to 2008.

⁶ From here onwards, “license” (or “out-license”) refers to licensing out or selling the piece of scientific knowledge to external firm(s) and/or organization(s). For the purpose of this paper, both mechanisms serve to externalize firm knowledge production.

firm), the firm should discontinue the development of scientific knowledge a_2 . Before abandoning it completely even in the case of $V(a_2) < 0$, a rational firm typically attempts to license out to other firm(s) the piece of scientific invention after its associated patent grant to extract any perceived value that a_2 may still possess to an external firm.⁷ If out-licensing is successful (albeit with lower probability), this mechanism acts to free up internal capacity and causes a decline in follow-on organization self-citations post patent grant. If licensing is not successful, the firm has to abandon the development of a_2 , which will also cause a decrease in follow-on organization self-citations (to the focal scientific publication).

Now assume the firm identifies a second piece of scientific knowledge b_1 with some perceived value of $V(b_1)$ before its patent grant. If $V(b_1) > V(a_2)$, then the firm should take b_1 forward instead (by itself or jointly) and license out a_2 if the firm could derive more value through internal development of the higher valued piece of knowledge b_1 ,⁸ all else equal. On the contrary, if $V(b_1) < V(a_2)$ (but $V(b_1) > 0$), the firm should take a_2 forward (by itself or jointly) and license out b_1 . Now, if $V(b_1) > 0$ but $V(a_2) < 0$, the firm should discontinue the internal development of scientific knowledge a_2 and switch to b_1 . Here again, the focal firm may attempt to license out a_2 anyways to an external firm before abandoning it completely.

However, if $V(b_1) = V(a_2)$, for the firm that would derive more value through internal development of the higher valued piece of knowledge, is b_1 or a_2 the better candidate for licensing? A rational decision would be to license a_2 , because a_2 has narrowed patent enforcement uncertainty (i.e. recall that an associated patent has been granted to protect a_2) while b_1 still have higher level of patent enforcement uncertainty (along with other types of patent uncertainty).

If we relax the constraint that the focal firm can and will engage in at least one piece of internal knowledge production, yet another possibility is that $V(a_2) \gg 0$ and $V(b_2) \gg 0$ after the narrowing of patent market value uncertainty and patent enforcement uncertainty such that both a_2 and b_2 are licensed out to other firms.

⁷ Again, this condition is shown to be consistently true by scientists and managers in the biotechnology and pharmaceutical firms interviewed from 2004 to 2008.

⁸ Here, “value” could comprise of the added protection afforded by internal development of the piece of scientific knowledge b_1 , in addition to perceived financial value.

The above framework suggests that better market valuation of patented scientific innovation coupled with the increase in IP protection, through granting of the associated patent pair over its corresponding scientific knowledge, work in concert to negatively impact the production and accumulation of scientific knowledge in the firm.

2.2. Hypotheses Development

Based on the proposed framework above, when patent enforcement uncertainty and market value uncertainty have been narrowed post patent grant, two mechanisms: *out-licensing* and *abandonment*, act in concert to reduce the amount of knowledge production and accumulation along specific lines of research within the firm.

First, granting of a patent allows firms to exclude competitors through the legal enforcement of intellectual property assets (by litigation) and facilitates appropriation of the value of scientific innovations through means such as *out-licensing*. Hence after patent grant, patent enforcement uncertainty is reduced and the chance of successful out-licensing increases, all else equal. This is consistent with previous empirical evidence that shows the rate of licensing increases by 70% to 80% post patent grant (Gans et al. 2008). Second, after patent grant, the uncertainty over market value of the patented scientific knowledge has been reduced. If a piece of knowledge cannot show enough commercialization promise at that point (to warrant continued in-house development or to achieve successful out-licensing), the firm has a great tendency to discontinue its development and reallocate scientific resources to other more productive areas. If so, *abandonment* or “switching-out” occurs. In addition, reduction of patent market value uncertainty can also facilitate out-licensing. Out-licensing and abandonment, facilitated by the narrowing of patent enforcement and patent market value uncertainties, allow firms to mitigate self-production risks and free up scientific resources for other more financially promising projects or those with better strategic fit. Although out-licensing and abandonment happen to only a portion of the knowledge projects (while the others could continue to be developed in-house), they reduce follow-on internal knowledge production within the innovative firm and organization. Hence, I hypothesize:

HYPOTHESIS 1. *The grant of a patent over knowledge claimed in a publication will negatively impact the rate of follow-on internal knowledge production (captured by publications).*

Firms use more internal linkages, mechanisms and complementary assets to appropriate the value of their R&D and scientific innovations or to transfer technologies in countries with weak IP institutions such as China, compared to countries with strong IP institutions such as the U.S. (Zhao 2006, Branstetter et al. 2004), where a patent grant implies relatively more certainty over patent enforcement (i.e. more reduction in uncertainty). A scientific innovation is considered to be developed in a country with weak IPR institution such as China if half or more of the inventors for that patented innovation are based in that country (e.g. Zhao 2006). It follows that firms which develop their patented scientific innovations in countries with strong IPR institutions (compared to weak IPR institutions) could make use of more external networks and mechanisms to capture their value. At the same time, under stronger IPR protection, patent enforcement uncertainty is lower and firms are more willing and able to out-license their knowledge projects (and perhaps more successful in doing so), all else equal. As a result, follow-on knowledge production within the firm will be reduced more post patent grant for scientific innovations developed under strong IPR protection where patent enforcement uncertainty is lower, compared to scientific innovations developed under weak IPR protection where patent enforcement uncertainty is higher. Thus:

HYPOTHESIS 2. *Grant of a patent over knowledge claimed in a publication will more negatively impact the rate of follow-on internal knowledge production (captured by publications) when the patented scientific innovation is developed in countries with strong IP institution compared to countries with weak IP institution.*

Similarly, firms that have formal operations or subsidiaries in countries with weak IPR protection tend to use more internal linkages, mechanisms and complementary assets to appropriate the value of their innovations. Hence, compared to firms operating in weak IPR countries where patent enforcement

uncertainty is still relatively higher (post patent grant), follow-on knowledge production within the firms will be reduced more when they operate in strong IPR countries where patent enforcement uncertainty (post patent grant) is lower. Therefore:

HYPOTHESIS 3. Grant of a patent over knowledge claimed in a publication will more negatively impact the rate of follow-on internal knowledge production (captured by publications) when the firm operates in countries with strong IP institution compared to countries with weak IP institution.

To maximize return-on-investment, firms typically attempt to out-license their scientific innovation first before completely abandoning it when its internally perceived value is below the threshold for continuing development (e.g. $V(a_2) < 0$) after better ascertaining its market value post patent grant. Larger and more established IPO firms (e.g. MNCs), have more established external linkages and global networks (Gittelman and Kogut 2003, Singh 2008), more resources and prior experiences dealing with greater number of potential target firms to license out their scientific innovations more efficiently (Arora et al. 2001) compared to less established non-IPO firms or start-ups. It follows that if out-licensing is the predominant mechanism undertaken before abandonment, knowledge production will show a greater decline in these more established IPO firms post patent grant. Thus:

HYPOTHESIS 4A. Grant of a patent over knowledge claimed in a publication will more negatively impact rate of follow-on internal knowledge production (captured by publications) when the patent assignee firm is an IPO firm compared to a non-IPO firm.

However in the (less likely) circumstance, firms could abandon their scientific invention (after reduction of patent market value uncertainty post patent grant) without first attempting to out-license. Here, non-IPO firms and startups, which are typically less established and smaller in size with more severe scientific resource constraints, compared to IPO firms, will have to reallocate their scientists and resources more quickly to other areas if the initial scientific knowledge does not show enough commercial promise to warrant continued investment and development. If the predominant mechanism

IPO and non-IPO firms follow is abandonment before out-licensing, I postulate the following competing hypothesis (to Hypothesis 4A):

HYPOTHESIS 4B. Grant of a patent over knowledge claimed in a publication will more negatively impact rate of follow-on internal knowledge production (captured by publications) when the patent assignee firm is a non-IPO firm (with greater resource constraints) compared to an IPO firm.

For-profit firm scientists typically have to follow strict mandate on when to engage and switch out of a project based on the most efficient scientific resource allocation into strategic research areas with high commercialization potential (as described in § 1). On the contrary, scientists in public institutions such as universities and research institutes are given substantially more freedom to select and pursue their own scientific projects to generate knowledge. These university scientists can more freely conduct follow-on research on their institute's own patented knowledge project, perhaps due to its higher scientific importance and industrial impact (Huang 2006, Huang and Murray 2008). To the extent that firm scientists face more stringent restrictions on knowledge project selection and engagement duration compared to university scientists, I hypothesize:

HYPOTHESIS 5. Grant of a patent over knowledge claimed in a publication will more negatively impact the rate of follow-on internal knowledge production (captured by publications) when the patent is owned by a for-profit firm compared to a public institution.

To summarize, Figure 1 illustrates the causal relationships and framework developed in the above hypotheses 1 to 5.

Insert Figure 1 about here

3. The Field of Genomics in the Life Sciences

Research into scientific knowledge and innovation requires that the scientific innovations be intelligible relative to a context of interest, the setting be well understood and the data be appropriate to

the research questions. Indeed, any firm or organization that gains competitive advantage through IP protection and depends on internally produced knowledge must understand this relationship.

In order to provide empirical insights to illuminate this relationship, several requirements must be met. First, it is important to identify an industry context where knowledge and R&D capabilities are key competitive advantages and patent protection is particularly critical in shaping the firms' and organizations' innovative efforts. Second, it must be able to capture much of the internal scientific knowledge and innovation produced in the form of papers and patents (or a similar measure). Third, it is important to articulate a tight linkage between the patents and the papers, particularly in the identification of patent-paper pairs and in the construction of relevant measures of the organizational and geographic characteristics and institutional environment for each patented innovation. Fourth, it must be possible to distinguish the technological, geographic and organizational characteristics associated with different pieces of scientific knowledge and innovation. The field of genomics in the life sciences and pharmaceutical provides a unique opportunity particularly suited to meet these empirical requirements. Not only because knowledge activities, R&D capabilities and patent protection are particularly critical in this field (Scherer et al. 1959, Mansfield et al. 1981, Mansfield 1986, Levin et al. 1987, Cohen et al. 2000), this context also offers a tremendous wealth of data on individual patented innovations and characteristics. These data can be extracted and combined, using bioinformatics techniques, from the GenBank, USPTO, National Center for Biotechnology Information (NCBI) and ISI Web of Science, and also linked to corresponding organization- and firm-level characteristics using such database as Compustat. Finally, this setting is particularly important because genomic knowledge is used by firms and organizations as the foundation for innovations in biomedical, environmental, industrial and agricultural applications.

It is in this rich, important and knowledge-intensive context that empirical tests are designed to untangle the complex interactions between intellectual property institutions and strategies with knowledge production process and commercialization in organizations.

4. Empirical Design

I analyze the impact of a reduction of patent uncertainties on scientific knowledge production and accumulation in the firms through a number of methodological and econometric advances. First, I use organization self-citations to each paper – defined as citations of peer-reviewed papers written by any author from the same organization as the focal paper – as a proxy for follow-on organization knowledge production and accumulation. This citation-based approach follows a long literature using citations to trace the flow of ideas and their follow-on accumulation in later knowledge production (de Solla Price 1965, Hall et al. 2001). The use of publication citations is subject to several caveats; first, it does not capture the generation of non-disclosed knowledge. To counter this claim, I argue that a shift to secrecy still represents a reduction in follow-on contributions to the (codified) stock of firm knowledge. Given the empirical patent-paper matching setup, this concern is also mitigated by the fact that it is highly unlikely for the same firm to suddenly shift its disclosure strategy to secrecy on the same knowledge project which has just been awarded patent and disclosed to the public. Second, I assume that the published knowledge is the relevant measure rather than forward citations in patents. While citations in patents are also important, the focus is on whether there are changes in follow-on contributions to the stock of firm knowledge after patent uncertainties have been narrowed through a patent grant. Third, I assume the cost of using a piece of patented scientific knowledge of the firm by internal scientists within the same firm is zero or close to zero. This condition has been verified to be consistently true by scientists and managers in the biotechnology and pharmaceutical firms I have interviewed from 2004 to 2008.

I design a well-identified natural experiment to understand the impact of reduction in patent uncertainties on firm scientific knowledge production. First, I focus only on papers that are (eventually) associated with a patent grant. This ensures that the quality of scientific knowledge codified through a scientific paper is consistent as scientific papers not associated with a patent grant may simply be different in quality. Indeed previous studies have shown that scientific knowledge both published in academic journals and disclosed through patents is, on average, more highly cited over its lifetime than

unpatented articles (from the same journal) (Huang 2006, Murray and Stern 2007). Second, through the high specificity of the patent-paper pairs in genomics – by linking the patent and the paper precisely via the disclosed gene sequence – only genes associated with patents are considered in the analyses as genes not associated with any patent may be different which could influence paper citation patterns.

I extend the identification strategy in Murray and Stern (2007) and Huang and Murray (2009) which used patent grant as an exogenous shock, to examine, in this study, the organization self-citation rates to the focal paper in the pre- and post-grant period (with the former serving as a control group for the latter) through a series of econometric analyses. In the period prior to patent grant, there is a high level of uncertainties in patent grant, patent pendency, patent scope, patent enforcement, and patent market value. Scientists have to produce and build on the firm's internal knowledge under these uncertain IPR conditions. After the patent grant event, uncertainties in patent grant, patent pendency and patent scope have been eliminated while patent enforcement uncertainty and market value uncertainty have been significantly reduced. The internal firm environment shifts from one with high level of uncertain IPR conditions to one with low level of uncertainty under which the scientists now produce and accumulate firm knowledge. This *differences-in-differences* identification approach, first developed by labor economists and subsequently introduced into management research (Furman and Stern 2006, Huang and Murray 2009), precisely ascertains the effects of the reduction in IPR uncertainty on scientific knowledge production within innovative organizations by comparing the difference in organization self-citations of papers (as the measure of knowledge production within the organization) in the pre- and post-grant period for those affected by the patent grant to the same difference for unaffected organization self-citations of papers.

To understand the moderating influence of the nature of scientific innovations produced, differential external IPR environments and organizational characteristics, I use four sets of interaction effects between the event of a patent grant and the knowledge produced by scientists in firms and organizations which (1) develop its scientific innovation in weak external IPR institutional environments like China versus strong ones like U.S.; (2) operate in weak versus strong external IPR institutional environment; (3) have

different organizational capabilities and resources specifically for IPO versus non-IPO firms; and (4) have different organizational types specifically for-profit firms versus public research institutes and universities. The operationalization of these moderating variables are described in the following section on *Data, Measures and Models*.

5. Data, Measures and Models

I developed and constructed a novel panel data that cover 401 unique life sciences firms and organizations using the base data set of 1,279 patent-paper pairs (Huang 2006, Huang and Murray 2009) from the population of 4,270 USPTO issued patents claiming uses of human genes as identified by stringent bioinformatics criteria (Jensen and Murray 2005). The typical timeline of the relationship for a patent-paper pair is illustrated in Figure 2.

Insert Figure 2 about here

The definition of a gene patent is specific: the gene sequence must be at least 150 nucleotides in length and match (e-value of zero) a human gene sequence (mRNA transcript) rather than another organism in the National Center for Biotechnology Information (NCBI) RefSeq public database. This results in the 4,270 USPTO patents covering 4,382 or 18.5% of all known human genes (approximately 23,688 genes).

Using a semi-automated search of the Thomson ISI Web of Science database which offers the most comprehensive coverage of peer-reviewed scientific research articles, Huang and Murray (2009) developed the base data set of patent-paper pairs for these gene patents. The following stringent matching criteria were employed: (1) all patent inventors must appear as authors; (2) publication must include the disclosed gene sequence; and (3) patent abstract and application dates must fit the publication abstract and publication dates. This tight matching procedure produced 1,498 matched patents. Finally, in those instances where a gene paper was paired with more than one gene patents, only the first patent was included as the paired patent. The final sample consists of 1,279 unique patent-paper pairs covering

2,637 genes from 1988 to 2005. This paired patent-paper sample is further verified to be statistically similar to the full gene patent population (Huang and Murray 2009).

In addition to the variables on observable characteristics of the gene papers and their citations, and the paired gene patents and citations, I construct the corresponding firm and organization-level characteristics of each assignee firm (and organization) captured by the gene patents. Altogether, the data include 401 unique life science firms (and organizations). These variables are summarized in Table 1.

Insert Table 1 about here

Table 2 provides descriptive statistics for the variables. I draw my data from several different sources. Data for the gene papers and citations are derived from the ISI Web of Science. Data for the gene patents and citations are obtained from the USPTO. Firm and organization characteristics are gathered from Compustat (for IPO companies) and USPTO, supplemented by various industry publications, news articles and firm websites. These variables are then manually double checked and when in doubt, cross-referenced to company annual reports and news articles online. Finally, the classification of strong and weak IPR countries is based on the compiled table of Institutional Environment and Country Classification (Zhao 2006) which summarized eight key indices from general legal and political environment, IPR protection to rule of law and privacy.

Insert Table 2 about here

5.1. Citation-year Characteristics

Annual self-cite, the dependent variable, captures of the annual number of organization self-citations the gene paper receives – defined as citations to the focal paper made by follow-on papers written by any author from the same organization as the focal paper – beginning in the year the paper was published (earliest is 1988), continuing until 2005. The total number of citation-year observations is 11,511. The mean level of *annual self-cite* is 1.54 (with a minimum of zero and a maximum of 48). By the end of the

period, the average article has accumulated about 16 (organization) self-citations over its lifetime as measured by the *total self-cite* for each gene paper. The *citation year* measures the calendar year in which a given citation is made. The *paper age* describes the age of the gene paper when a given citation is made, thus a citation made in 2000 to a paper published in 1998 is two years old. The average *citation year* in the sample is 2001 while the average *paper age* is about 4.4 years old.

5.2. Paper Characteristics

The gene paper is characterized by the following independent variables. *Paper year* is the year the paper is published: the average is 1997 (from 1988 to 2005). I then construct a number of gene paper variables based on a paper's authors and their affiliations. *Number of authors* counts the number of authors on the paper (mean = 7.28). *Number of addresses* is a count of the number of addresses that appear on the paper, measuring the number of different firms and organizations involved in knowledge production (mean = 2.72). *U.S. author address* is a binary variable capturing whether at least one of address is in the United States and reflecting the affiliation of the paper authors. *Public author address* is a binary variable describing the condition under which at least one listed address is from a public institution (defined as universities, government research organizations and laboratories). I then construct the binary variable *for-profit author address* to capture whether there is at least one private sector for-profit address on the paper, coding pharmaceutical, biotechnology and other private sector corporations. *Impact factor* is a proxy for the journal quality in which the gene paper is published (mean = 9.75). Constructed by ISI and published in their annual Journal Citation Reports, it varies between 1 and 33.5. It is defined as the number of current year citations divided by the source items published in that journal during the previous two years. While the journal impact factor is re-calculated annually, the rank ordering of journals exhibits little or no variation over time – I therefore use 2005, the last paper publication year in the sample. The gene papers in the sample come from a small number of high quality journals such that only ten journals account for more than fifty percent of the gene papers. These include

general journals such as Science and Nature as well as more specialist journals like Genomics, Nature Genetics and Cell.

5.3. Patent Characteristics

The following variables capture the temporal impact of a patent grant and characteristics of a patent. *Patent application year* is the year in which the patent application is made (mean = 1997) while *patent grant year* is the year in which the patent is granted (mean = 2000). *Patent grant lag* is the elapsed time between patent application and patent grant (mean = 3.30). I also define the variable *patent in force*, which is a dummy variable equal to one for all years after patent grant and zero prior to patent grant. The mean of *patent in force* is 0.53, suggesting that our citation-year observations are almost equally distributed between years when patents are in operation and those when patents are not. *Patent window* is another dummy variable which is coded one during the year of patent grant and zero otherwise (mean = 0.11).

Several variables are developed to characterize the patentees. *Number of inventors* and *number of assignees* measure the number of inventors (mean = 2.56) and assignees (mean = 1.13) listed on the patent respectively. *Public assignee* is defined in the same way as *public author address* whether at least one of patent assignees is from a public (academic or government) institution (mean = 0.58). In addition, *all public assignee* denotes instances when all patent assignees are from a public institution (mean = 0.54). Similarly, *for-profit assignee* is a binary variable to denote cases when at least one patent assignee is a for-profit firm (mean = 0.46) while *all for-profit assignee* denotes all patent assignees from for-profit firms (mean = 0.42). *U.S. assignee* is denoted as one when at least one patent assignee is based in the U.S. (mean = 0.79).

5.4. Firm and Organization Characteristics

Using the Compustat database, company annual reports and websites, interviews with managers and scientists and secondary data from various sources, I construct a series of variables to capture firm level characteristics for the 401 unique life sciences firms and organizations in the sample. *IPO firm* (mean =

0.30) denotes that the assignee to the patent is an IPO firm. *Non-IPO firm* (mean = 0.10) denotes the assignee to the patent is a non-IPO firm. *Total assets* (mean = US\$14,136 millions) and *total sales* (mean = US\$8,075 millions) denote the total assets and total sales of the (IPO) firm owning the focal patent respectively, in millions of US dollars. They provide a proxy for the size of the IPO firm. *R&D spending* captures the total R&D expenditure of the (IPO) firm in millions of US dollars. *Total number of patents* is the total number of patents of the organization which owns the focal patent over the organization's lifetime (i.e. to the end of 2005 when the sampling period ended). *Number of patents* denotes the cumulative number of patents of the organization which owns the focal patent until the year of the focal patent grant. The high mean values of *R&D spending* (mean = US\$976 million), *total number of patents* (mean = 1,325) and *number of patents* (mean = 841) suggest the firms and organizations in the sample are highly innovative with a relatively high level of research capabilities and resources.

Then I construct a number of variables to denote if the patented scientific innovation (of the focal firm) is developed in countries with strong IPR institutional environments like the U.S. and U.K. or weak IPR environments like China and Israel. I also code for firms and organizations which formally operate or have a subsidiary in strong IPR countries or weak IPR countries. Table 3 lists the strong and weak IPR countries (Zhao 2006) used to inform the selection of these countries into strong or weak external IPR institutions in the data. *Developed domestic (U.S.) IPR strong* (mean = 0.80) is a binary variable to denote if the patented scientific innovation has been developed in the U.S. If half or more of the focal patent's inventors are based in the U.S., it is coded as a 1. *Developed foreign IPR strong* (mean = 0.22) is a binary variable to denote if the patented scientific innovation has been developed in a foreign country (outside the U.S.) with a strong IPR institution. It is coded as 1 if half or more of the focal patent's inventors are based in the foreign country with a strong IPR institution. Similarly, *developed foreign IPR weak* (mean = 0.01) captures patented scientific innovations which have been developed in a foreign country (outside the U.S.) with a weak IPR institution.

 Insert Table 3 about here

Operate domestic (U.S.) IPR strong (mean = 0.86) is a binary variable to denote if the firm or organization which owns the focal patent formally operates domestically in the U.S., defined as having at least a subsidiary, division or formal operational presence in the U.S. Similarly, *operate foreign IPR strong* (mean = 0.36) is a binary variable to denote if the firm or organization which owns the focal patent formally operates in at least one foreign country with a strong IPR environment such as Canada or France. Finally, *operate foreign IPR weak* (mean = 0.19) is a binary variable to denote if the firm or organization which owns the focal patent formally operates in at least one foreign country with a weak IPR environment such as China or India.

5.5. Model Estimation

To precisely ascertain the effects of reduction in IPR uncertainties on scientific knowledge production within innovative firms and organizations, and the interactions with geography of innovation development and firm operation, organizational capabilities and types, I extend the differences-in-differences identification approach first developed in labor Economics and subsequently introduced into management research (Furman and Stern 2006, Huang and Murray 2009). This is achieved by comparing the difference in organization self-citations of papers (as the measure of knowledge production within the organization) in the pre- and post-grant period for those affected by the patent grant to the same difference for unaffected organization self-citations of papers.

I use *annual self-cite* by the organizations and firms in the sample as the dependent variable. As this is a highly right-skewed count variable that takes on non-negative integer values, I use a nonlinear regression approach to avoid heteroskedastic, non-normal residuals (Hausman et al. 1984). There are two ways to deal with the discrete nature of such count data: the Poisson regression model (PRM) or the negative binomial regression model (NBRM), a generalized form of the Poisson regression (Hausman et al. 1984). The Poisson assumes the conditional mean of the outcome is equal to the conditional variance. However, as the dependent variable exhibits over-dispersion with conditional variance significantly greater than the conditional mean (Cameron and Trivedi 1986, 1998), this assumption is violated. Hence,

to overcome the problem of over-dispersion, the negative binomial regression model is used. In particular, the result of the Hausman (1978) test supports the use of fixed effects negative binomial regression model. I also incorporate robust standard errors, using the Huber-White sandwich estimator (Allison and Waterman 2002, Greene 2004) in all regression models to account for possible heteroscedasticity, and lack of normality in the error terms.

In this differences-in-differences regression model given in Equation (1), the dependent variable is *annual self-cite* which denotes the annual organization self-citations. It captures the yearly scientific knowledge production and accumulation by the focal firm's scientists. As I am interested in whether the reduction of IPR uncertainties through the grant of a patent affects organizational knowledge production and built-up, I include the main explanatory variable, *patent in force*, in the marginal effects equation (1). I also include the variable *patent window* to account for the possibility that in the actual grant year of the patent, the impact of IP rights may be noisy. In equation (1), I rely on the observable characteristics of the papers to capture paper-by-paper differences in the underlying annual citation trend:

$$FC_{i,t} = f(\varepsilon_{i,t}; \alpha \text{patent_window}_{i,t} + \beta \text{patent_in_force}_{i,t} + \phi \text{number_of_authors}_i + \xi \text{number_of_addresses}_i + \delta \text{US_address}_i + \eta \text{public_address}_i + \mu \text{impact_factor}_i + \chi \text{paper_age fixed effects}_{t\text{-paper_year}} + \psi \text{citation_year fixed effects}_i) \quad (1)$$

From equation (1), I develop a full regression model to include the sets of firm/organization fixed effects, paper age fixed effects and citation year fixed effects shown in equation (2). As this paper focuses on knowledge production within firms and organizations over time, I use firm/organization fixed effects to account for variation across each firm or organization. Paper age fixed effects and citation year fixed effects control for unobserved heterogeneity in each cohort (or age) of the paired paper and the year in which the forward citation is received respectively.

$$FC_{i,t} = f(\varepsilon_{i,t}; \alpha \text{patent_window}_{i,t} + \beta \text{patent_in_force}_{i,t} + \lambda \text{firm/organization fixed effects}_i + \chi \text{paper_age fixed effects}_{t\text{-paper_year}} + \psi \text{citation_year fixed effects}_i) \quad (2)$$

In both equations, I can test whether the citation rate to a paper changes after the paired patent is granted, accounting for fixed differences in the citation rate across different firms/organizations with

different observable characteristics and over time. Using these two models to evaluate the effect of patent grant, I then examine how geography of innovation development and firm operation, organizational capabilities and types interact with patent grant to impact the production of knowledge in the firm. This is given in equation (3):

$$\begin{aligned}
 FC_{i,t} = & f(\varepsilon_{i,t}; \alpha \text{patent_window}_{i,t} + \beta \text{patent_in_force}_{i,t} + \lambda \text{ firm/organization fixed effects,} \\
 & + \chi \text{paper_age fixed effects}_{t\text{-paper_year}} + \psi \text{citation_year fixed effects}_t \\
 & + \varphi \text{patent_geog_of_development_interactions}_{i,t} + \beta \text{patent_geog_of_operation_interactions}_{i,t} \\
 & + \gamma \text{patent_org_capability_interactions}_{i,t} + \xi \text{patent_org_type_interactions}_{i,t}) \quad (3)
 \end{aligned}$$

6. Empirical Results

Models 4-1 to 4-3 in Table 4 investigate the marginal and main effects of patent grant on the annual organization self-citation rate of the paired papers, employing the negative binomial model specifications as described before. Model 4-1 is the baseline model that controls for the *number of authors, number of addresses, U.S. author address, public author address* as well as the quality of the journal in which the papers are published using journal *impact factor*. Model 4-2 includes *patent window* and *patent in force* in addition to the controls specified in Model 4-1. Model 4-2 provides a first test of hypothesis 1. The result shows the reduction in IPR uncertainties through the grant of a patent significantly reduces the internal knowledge production and accumulation within firms and organizations by more than 13% (at the 1% level).⁹

 Insert Table 4 about here

This finding is supported by the result from the more stringent specifications in Model 4-3 where I include the full set of firm/organization fixed effects, paper age fixed effects and citation year fixed effects. In this model, reduction in IPR uncertainties negatively impacts knowledge production and

⁹ In Tables 4 and 5, I report the coefficients as incidence rate ratios (IRR). IRR can be derived by exponentiating the coefficients, β_k of the independent variable x_k of the negative binomial regression models. In this case, the IRR can be interpreted as the factor change in annual citations received in a given year due to a unit increase in the regressor. For example, an IRR of 0.87 in the coefficient indicates a 13% decrease in the dependent variable for a unit increase in the independent variable, all else equal.

accumulation within firms and organizations, as shown by a decrease in organization self-citations post patent grant by about 21% (at the 1% level) . Hence, hypothesis 1 is supported.

6.1. Development of Scientific Innovations under Different IPR Institutional Environments

Models 4-4 to 4-6 aim to shed light on the effect of a reduction in IPR uncertainties on knowledge production when the patented innovation is developed in countries with different IPR institutional environments, from strong to weak external IPR protection. Across these three models, the main effects, *patent in force* suggests a statistically significant 11% to 22% reduction in follow-on internal knowledge production. In Model 4-4, there is a strong a negative impact of 13% decrease (at the 5% level) post patent grant when the patented scientific innovation is developed domestically in the U.S. where IPR protection is strong. In model 4-5, the interaction effect of patent grant with scientific innovation developed in a foreign strong IPR country shows a 5% increase in knowledge production but is not significant. However, Model 4-6 shows a strong and significant (at the 1% level) increase of 98% internal knowledge accumulation when the scientific innovation is developed in a foreign weak IPR environment. Taken together, the grant of the patent more negatively impacts subsequent knowledge production when the innovation is developed domestically in the U.S. compared to foreign countries and in strong IPR countries compared to weak ones. Hence, Hypothesis 2 is supported.

6.2. Operation across National Boundaries and IPR Environments

When organizations operate across countries especially in those with strong versus weak or ineffectual external IPR environments, the reduction in patent uncertainties may have differential effects on internal knowledge built-up. In Table 5, Models 5-1 to 5-4 seek to ascertain such effects. In Model 5-1, although the main effect of *patent in force* is strong – 25% significant decrease (at the 1% level), the interaction with *operate domestic (U.S.) IPR strong* does not show any significant effect. In Model 5-2, although interaction effect with *operate foreign IPR strong* shows a strong and significant decrease of 40% in subsequent organization knowledge production (at the 5% level), the main effect loses significance. In Model 5-3, the main effect shows a significant 19% decline (at the 1% level) in

knowledge production, while the interaction effect with *operate foreign IPR weak* points to a significant 14% decline (at the 10% level). Nevertheless, relative to this 14% decline (in Model 5-3), the 40% decline (in Model 5-2) represents a significant 26% decrease in follow-on knowledge production and accumulation when the organization operates under foreign strong IPR environment compared to foreign weak IPR environment. Lastly, Model 5-4 includes all three interaction effects. The interaction with *operate foreign IPR strong* shows a 22% significant decrease (at the 1% level) compared to the insignificant 3% increase in the interaction with *operate foreign IPR weak*. Taken together, hypothesis 3 is weakly supported. That is, knowledge production within innovative firm or organization will decline more following patent grant when the firm or organization operates in countries with strong external IPR institutions compared to countries with weak external IPR institutions.

Insert Table 5 about here

6.3. Firm Capabilities and Resources

IPO firms are typically more established and larger in size than non-IPO and start-up firms and have greater pool of resources, access to more established external linkages, networks, and capabilities especially in terms of the experiences in technology licensing and other commercialization activities. Models 5-5 and 5-6 investigate the competing hypotheses 4A and 4B on the effect of patent grant on knowledge production when the focal organization is an IPO firm versus a non-IPO firm. Model 5-5 shows that in addition to the 13% decrease (at the 1% level) in knowledge production caused by the main effect of *patent in force*, if the patented innovation is owned only by IPO firm, there is a further significant decline of 30% (at the 1% level) compared to the marginally significant 16% decline (at the 10% level) if owned only by a non-IPO firm. The difference of more than 14% is statistically significant. Affirming the results of Model 5-5, Model 5-6 shows that if the patented innovation is owned by at least one IPO firm, it reduces the knowledge generation by a further 28% (significant at the 1% level) compared to ownership by at least one non-IPO firm.

Hence, the narrowing of IPR uncertainties through the grant of a patent over knowledge claimed in a publication will more negatively impact follow-on knowledge production when the patent assignee is an IPO firm compared to a non-IPO firm. Hypothesis 4A is supported and the competing hypothesis 4B is rejected. It follows that the plausible explanation is that the mechanisms of out-licensing (or attempts to out-license) usually take precedence over that of abandonment of scientific projects. Thus, the effects of greater external linkages, more established networks and experiences for IPO firms in technology licensing and other commercialization activities dominate the effects of resource constraints in smaller non-IPO or startup firms.

6.4. Organizational Types

The last set of regression models 5-7 and 5-8 seek to address what types of organization would have the most salient moderating effect on the reduction of internal knowledge generation. Model 5-7 suggests a strong and significant decrease of 34% (at the 1% level) if the owner of the patented innovation is only private sector for-profit firms relative to an insignificant decrease for public institutions (i.e. universities, research institutes, or government laboratories). Model 5-8 affirms this notion by showing a significantly higher positive effect of about 51% (at the 1% level) in knowledge production when ownership is by at least one public institution compared to the insignificant effect for for-profit firms.

Hence, the narrowing of IP uncertainties through patent grant reduces follow-on internal knowledge production more when the patent assignee is a private sector for-profit firm versus a public institution. In other word, the decline in knowledge production is much more salient in the case of ownership by for-profit firms than universities and public institutes. Hypothesis 5 is supported.

6.5. Robustness Analyses

To check for robustness and insulate the results against any possibility that the interaction effects in a non-linear model are not the same as their cross-partial derivatives (Ai and Norton 2001), I performed additional regressions similar to Model 4-3 on split samples respectively for Models 4-4 to 4-6, Models 5-

1 to 5-3, and Models 5-5 to 5-8. For example in Model 5-7, I performed the regression in the sub-sample with private sector *for-profit assignee* only (4581 observations) and then another regression on the sub-sample with *public assignee* only (6420 observations). Similar procedure is repeated for the other models. Results from these split sample regressions are robust and consistent with those shown in Tables 4 and 5. Thus, the findings and implications are unchanged across the models.

7. Discussion and Conclusion

Overlapping patent ownerships or “patent thicket” (Heller and Eisenberg 1998, Shapiro 2001) claimed by the focal firm(s) on a particular “piece” of scientific knowledge impedes access and follow-on research and development by scientists *outside* the focal firm(s) (Huang and Murray 2009). This is also known as the anti-commons effect (Heller and Eisenberg 1998). An entirely different mechanism – the reduction in patent uncertainties through the granting of a patent (to the focal firm) over its corresponding scientific knowledge – negatively impacts the production and accumulation of follow-on scientific knowledge by scientists *within* the firm.

In for-profit firms like those in the life sciences, the management often exerts tighter control over scientific resources based on efficient allocation into strategic research areas and potential for commercialization and return-on-investment (assuming firms are rational economic entities to maximize profit). While we cannot completely rule out the possibility of scientists shifting to secrecy (also observed as a decline in organization self-citations) in any particular scientific project by the firm, interviews with scientists and managers in biotechnology firms indicate this is highly unlikely and does not make logical sense because the firm had chosen to pursue the option of patenting their innovation in the first place which forced the disclosure of innovation details in the patents. Hence, immediately after the award of patents, it is unlikely that the same firm decides to shift (its disclosure strategy) to secrecy on the same project which has just been granted patent protection and disclosed to the public.

To the extent that there is a low probability that firms would simultaneously pursue patenting and secrecy on the same project, the interviews, theoretical frameworks and empirical analyses together

suggest that more precise market valuation of the scientific innovations and increased IP protection, facilitated by the granting of the patent over its corresponding scientific knowledge, work together to reduce the production and accumulation of scientific knowledge in the firm. The decline in annual organization self-citations reflects a reallocation of scientists and scientific resources to alternative knowledge projects most likely because the original project had been out-licensed (or sold) or abandoned. This is consistent with previous empirical findings that patent grant substantially increases the rate of achieving licensing agreement, especially in the time period immediately following the patent grant (Gans et al. 2008). In summary, innovative firms produce and accumulate more internal knowledge when IPR conditions are highly uncertain and externalize their knowledge activities under low IPR uncertainties. The decline in internal knowledge production (when IPR uncertainties transition from high to low) is most salient for more established IPO firms than non-IPO and start-up firms, and for private sector for-profit firms than public research institutes and universities, and for firms that operate or develop their scientific innovations in strong IPR countries than weak IPR countries. This last finding is in line with previous empirical evidence that firms rely on increased internal mechanisms and intra-firm activities to protect their intellectual assets and appropriate the values of innovations produced under weak external IPR environment (Zhao 2006).

The findings from this paper have significant implications for public policy. If firms base their decisions only on maximization of return-on-investment and efficient allocation of resources, their follow-on internal knowledge production and accumulation may decline over time. Some knowledge projects will be licensed out (or sold) to other firms or simply be abandoned. To the extent that this negatively impacts the firm's cumulative stock of scientific knowledge due to scientists shifting to alternative knowledge projects, the long-term effect is to gradually reduce the innovative firms' absorptive capacity (Cohen and Levinthal 1990, Cockburn and Henderson 1998). Consequently, this impacts their long-term ability to venture into new (usually not fully realized) areas of research and clinical importance where the costs of pursuing the cure are difficult to justify in the short-term because

of, for example, too a small target population to sustain reasonable profit level. This may be costly for society in the long-term.

Furthermore, this paper sheds light on the underlying mechanisms of how patent grant may reduce the production and accumulation of scientific knowledge in innovative firms, by narrowing IPR uncertainties, specifically patent enforcement and patent market value uncertainties. It highlights the notion that the patent grant event provides an important opportunity for firms to evaluate, manage and reallocate resources to knowledge projects that are more efficient or have greater commercial potential particularly during the time period that immediately follows.

The findings also have significant strategic and management implications for innovative firms that engage in knowledge-intensive activities across national and geographic boundaries. Managers and decision-makers should understand that the consequences of their strategies to maximize return and efficiency on the one hand, may reduce the long-term cumulative stock of scientific knowledge in the firm on the other (assuming that firms cannot expand without limit). Thus, these findings help to better inform managers and decision-makers the consequences of short-term exploitation of scientific knowledge (e.g. out-licensing) and resource reallocation (e.g. abandonment of projects with no immediate commercial potential).

For a firm in the knowledge-intensive industry, its cumulative knowledge is an important strategic asset that provides options for long-term exploration and expansion into new and uncertain external markets (Kogut & Zander, 1992). Here, the decision-makers face a dynamic trade-off between exploiting these knowledge projects for short-term gains post patent grant, and allowing some potentially higher risk scientific projects to continue and build on the firm's cumulative knowledge to position it for future external exploration. If the decision is on short-term maximization of commercial potential of knowledge project each time, it may risk depleting the innovative firm's long-term stock of scientific knowledge and thus limit its ability to explore into important (but perhaps yet unrealized) external areas of research and markets for ideas. This is a tenuous balance that decision-makers need to carefully evaluate and strike.

Table 1 Variable Definitions

Citation-Year Characteristics		
Name	Definition	Source(s)
Annual self-cite	Organization self-citations: citations to the focal paper made by follow-on papers written by any author from the same organization as the focal paper	ISI
Total self-cite	Total number of organization self-citations accruing to a focal paper over its lifetime (1988 to 2005)	ISI
Citation year	The year in which the forward citation is received	ISI
Paper age	Age of paper when a citation is made	ISI
Paper Characteristics		
Paper year	Year when paper is published	ISI
Number of authors	Number of authors appearing on the paper	ISI
Number of author addresses	Number of unique addresses appearing on paper	ISI
U.S. author address	Binary variable (1/0) denoting at least one U.S. author address	ISI
Public author address	Binary variable (1/0) denoting at least one public author address	ISI
For-profit author address	Binary variable (1/0) denoting at least one for-profit private sector author address	ISI
Impact factor	Impact factor for journal in which paper is published	ISI/ Journal Citation Report
Patent Characteristics		
Patent in force	Binary variable (1/0) set to 1 if citation is received in years after patent grant	USPTO
Patent window	Binary variable (1/0) set to 1 if citation is received in year of patent grant	USPTO
Patent application year	The year in which the patent application is made	USPTO
Patent grant year	The year in which the patent is granted	USPTO
Patent grant lag	Number of years between patent application and patent grant	USPTO
Number of inventors	Number of inventors appearing on patent	USPTO
Number of assignees	Number of assignees appearing on patent	USPTO
Public assignee	Binary variable (1/0) denoting at least one public assignee	USPTO
All public assignee	Binary variable (1/0) denoting all public assignee	USPTO
For-profit assignee	Binary variable (1/0) denoting at least one for-profit private sector assignee	USPTO
All for-profit assignee	Binary variable (1/0) denoting all for-profit private sector assignee	USPTO
U.S. assignee	Binary variable (1/0) denoting at least one U.S. based assignee	USPTO

Firm/ Organization Characteristics		
IPO firm	Binary variable (1/0) denoting the assignee to the patent is an IPO firm.	Compustat & various industry publications
Non-IPO firm	Binary variable (1/0) denoting the assignee to the patent is a non-IPO firm.	Compustat & various industry publications
Total assets	Total assets of the (IPO) firm owning the focal patent (in US\$ millions)	Compustat
Total sales	Total sales of the (IPO) firm owning the focal patent (in US\$ millions)	Compustat
R&D spending	Total R&D expenditure of the (IPO) firm owning the focal patent (in US\$ millions)	Compustat
Total number of patents	Total number of patents of the organization which owns the focal patent over the organization's lifetime (to end of 2005)	USPTO
Number of patents	Cumulative number of patents of the organization which owns the focal patent until the end of year of the focal patent grant	USPTO
Developed domestic (U.S.) IPR strong	Binary variable (1/0) denoting 50% or more of the focal patent's inventors are from the U.S.	USPTO
Developed foreign IPR strong	Binary variable (1/0) denoting 50% or more of the focal patent's inventors are from foreign countries with strong IPR	USPTO
Developed foreign IPR weak	Binary variable (1/0) denoting 50% or more of the focal patent's inventors are from foreign countries with weak IPR	USPTO
Operate domestic (U.S.) IPR strong	Binary variable (1/0) denoting if the organization owning the focal patent formally operates <i>at least</i> in the U.S.	Firm/organization websites & various industry publications
Operate foreign IPR strong	Binary variable (1/0) denoting if the organization owning the focal patent formally operates in <i>at least one</i> strong IPR foreign countries like Canada	Firm/organization websites & various industry publications
Operate foreign IPR weak	Binary variable (1/0) denoting if the organization owning the focal patent formally operates in <i>at least one</i> weak IPR foreign countries like China	Firm/organization websites & various industry publications

Table 2 Descriptive Statistics of Citation-Year, Paper, Patent and Firm/Organization Variables

Citation-Year Characteristics					
Variables	n	Mean	Std. Dev.	Min	Max
Annual self-cite	11551	1.54	2.73	0	48
Total self-cite	11551	15.83	21.18	0	152
Citation year	11511	2001	3.24	1988	2005
Paper age	11511	4.44	3.24	0	17
Paper Characteristics					
Paper year	1279	1997	2.78	1988	2005
Number of authors	1279	7.28	4.57	1	63
Number of addresses	1279	2.72	2.00	1	16
U.S. author address	1279	0.80	0.40	0	1
Public author address	1279	0.84	0.36	0	1
For-profit author address	1279	0.35	0.48	0	1
Impact factor	1279	9.75	8.59	1	33.46
Patent Characteristics					
Patent in force	11511	0.53	0.50	0	1
Patent window	11511	0.11	0.31	0	1
Patent application year	1279	1997	2.57	1990	2003
Patent grant year	1279	2000	2.66	1993	2005
Patent grant lag	1279	3.30	1.51	0	11
Number of inventors	1279	2.56	1.40	1	14
Number of assignees	1279	1.13	0.42	1	4
Public assignee	1279	0.58	0.49	0	1
All public assignee	1279	0.54	0.50	0	1
For-profit assignee	1279	0.46	0.50	0	1
All for-profit assignee	1279	0.42	0.49	0	1
U.S. assignee	1279	0.79	0.41	0	1
Firm/ Organization Characteristics					
IPO firm	1279	0.30	0.46	0	1
Non-IPO firm	1279	0.10	0.30	0	1
Total assets (US\$ Million)*	379	14136	51834	10.77	750507
Total sales (US\$ Million)*	379	8075.407	14393.05	0.20	151802
R&D spending (US\$ Million)*	379	976	1218	1.61	5029.71
Total number of patents	1279	1325	15002	1	529955
Number of patents	1279	841	9065	0	321070
Developed domestic (U.S.) IPR strong	1279	0.80	0.40	0	1
Developed foreign IPR strong	1279	0.22	0.42	0	1
Developed foreign IPR weak	1279	0.01	0.11	0	1
Operate domestic (U.S.) IPR strong	1279	0.86	0.35	0	1
Operate foreign IPR strong	1279	0.36	0.48	0	1
Operate foreign IPR weak	1279	0.19	0.39	0	1

* Information available for IPO firms only

**Table 3 List of Strong and Weak IPR Countries
(Adopted from Table 1 from Zhao 2006)**

Strong IPR Countries	Weak IPR Countries
U.S.A. Ireland Italy Singapore Canada France Japan Australia Norway Belgium Sweden New Zealand U.K. Germany Denmark Netherlands Australia	Indonesia Russia Ukraine China Pakistan Peru India Venezuela Brazil Mexico Romania Turkey Thailand Bulgaria Philippines Argentina Egypt Malaysia Slovak Republic Greece Poland South Africa Czech Republic Portugal Hungary Chile Taiwan Spain Hong Kong Israel Korea

Note: This list is compiled using eight indices. Three from the general legal and political environment: The Law and Order index from the ICRG Risk Rating System (ICRG 1997), the O-Factor from the Pricewaterhouse Coopers Opacity Survey (*The Opacity Index* 2000), and the Property Protection index from the *Index of Economic Freedom* (1995). Three indices on IPR protection: the Rapp and Rozek (1990) index, the Ginarte and Park (1997) index, and United States Trade Representative's Special 301 Watch List from 1999. In addition, the Rule of Law index from Kaufmann et al. (1999, 2002) and the Piracy index from the annual BSA Global Software Piracy Study (BSA 2000) prepared by the International Planning and Research Corporation are used. As these indices differ in their coverage of countries and time periods, weights are applied to obtain this reasonably stable list. (Zhao 2006)

Table 4 Negative Binomial Models of the Effects of Patent Grant and External IPR Environment for Scientific Innovation Development

NBRM: DV = Self-Citations							
Coefficients reported as incidence rate ratios, IRR							
	[4-1] Baseline	[4-2] Marginal Effects	[4-3] Full with Fix Effects	[4-4] Patent Developed Domestic (U.S.) IPR Strong Interaction	[4-5] Patent Developed Foreign IPR Strong Interaction	[4-6] Patent Developed Foreign IPR Weak Interaction	[4-7] Full with Interaction Effects
<i>Independent Variables</i>							
Patent window		0.93 (0.05)	0.88*** (0.04)	0.88*** (0.04)	0.88*** (0.04)	0.88*** (0.04)	0.88*** (0.04)
Patent in force		0.87*** (0.04)	0.79*** (0.04)	0.89* (0.06)	0.78*** (0.04)	0.78*** (0.04)	0.96 (0.17)
Patent in force x Developed domestic (U.S.) IPR strong				0.87** (0.06)			0.81 (0.13)
Patent in force x Developed foreign IPR strong					1.05 (0.07)		0.88 (0.14)
Patent in force x Developed foreign IPR weak						1.98*** (0.4)	1.63* (0.43)
<i>Control Variables</i>							
Number of authors	1.04*** (0.00)	1.03*** (0.00)					
Number of addresses	1.03*** (0.01)	1.03*** (0.01)					
U.S. author address	0.89 (0.03)	0.95 (0.04)					
Public author address	0.87*** (0.03)	0.87*** (0.03)					
Impact factor	1.09*** (0.00)	1.09*** (0.00)					
Firm/ Organization fixed effects			Yes	Yes	Yes	Yes	Yes
Paper age fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Citation year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regression Statistics							
Log-likelihood	-17555	-17550	-16604	-16602	-16604	-16598	-16597
Wald chi-square (p)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Number of observations	11551	11551	11551	11551	11551	11551	11551
* Robust standard errors in parentheses. *p<0.10; **p<0.05; ***p<0.01							

Table 5 Negative Binomial Models of the Effects of External IPR Environment in Operating Location, Organizational Capability, Resource and Types

	NBRM: DV = Self-Citations							
	Coefficients reported as incidence rate ratios, IRR							
	[5-1] Operate Domestic (U.S.) IPR Strong	[5-2] Operate Foreign IPR Strong	[5-3] Operate Foreign IPR Weak	[5-4] Full Interaction Effect	[5-5] All IPO Firm vs. All Non- IPO Firm	[5-6] IPO Firm vs. Non-IPO Firm	[5-7] All For- profit Assignee vs. All Public Assignee	[5-8] For-profit Assignee vs. Public Assignee
<i>Independent Variables</i>								
Patent window	0.88*** (0.04)	0.88*** (0.04)	0.88*** (0.04)	0.88*** (0.04)	0.88*** (0.04)	0.88*** (0.04)	0.88*** (0.04)	0.88*** (0.04)
Patent in force	0.75*** (0.06)	1.32 (0.33)	0.81*** (0.04)	0.93 (0.10)	0.87*** (0.04)	0.87*** (0.04)	0.98 (0.10)	0.57*** (0.06)
Patent in force x Operate domestic (U.S.) IPR strong	1.06 (0.08)			0.90 (0.09)				
Patent in force x Operate foreign IPR strong		0.60** (0.15)		0.78*** (0.06)				
Patent in force x Operate foreign IPR weak			0.86* (0.07)	1.03 (0.10)				
Patent in force x All IPO firm					0.70*** (0.05)			
Patent in force x All Non-IPO firm					0.84* (0.08)			
Patent in force x IPO firm						0.72*** (0.04)		
Patent in force x Non-IPO firm						0.88 (0.08)		
Patent in force x All for-profit assignee							0.66*** (0.07)	
Patent in force x All public assignee							0.88 (0.08)	
Patent in force x For-profit assignee								1.14 (0.11)
Patent in force x Public assignee								1.51*** (0.15)
<i>Control Variables</i>								
Firm/ Organization fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Paper age fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Citation year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Regression Statistics</i>								
Log-likelihood	-16604	-16601	-16598	-16594	-16588	-16589	-16590	-16590
Wald chi-square(p)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Number of observations	11551	11551	11551	11551	11551	11551	11551	11551
Robust standard errors in parentheses. *p<0.10; **p<0.05; ***p<0.01								

Figure 1 Summary of Hypotheses

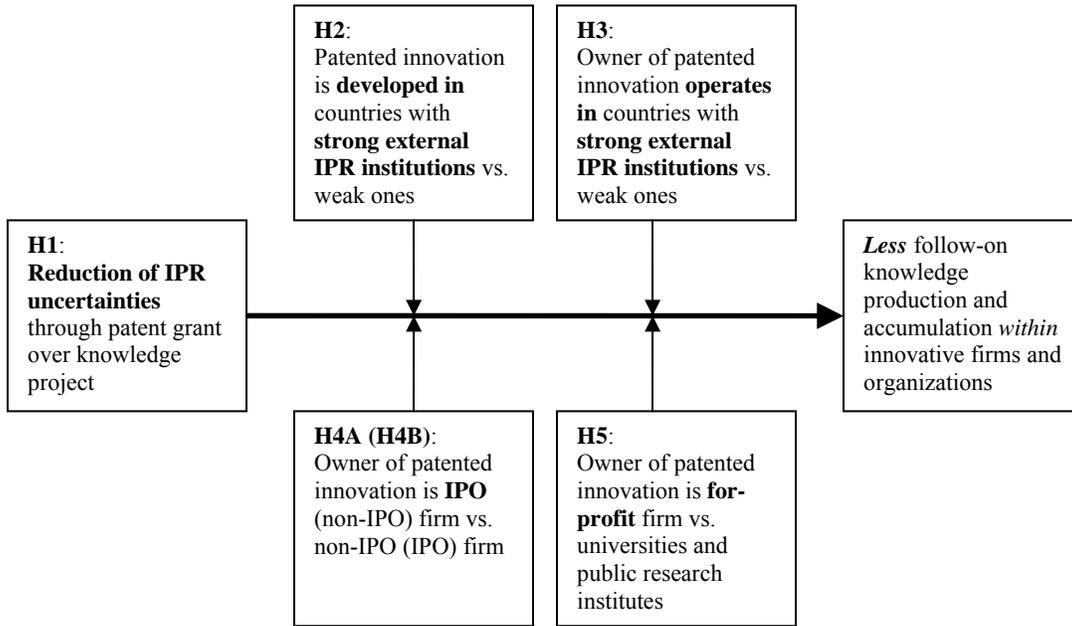
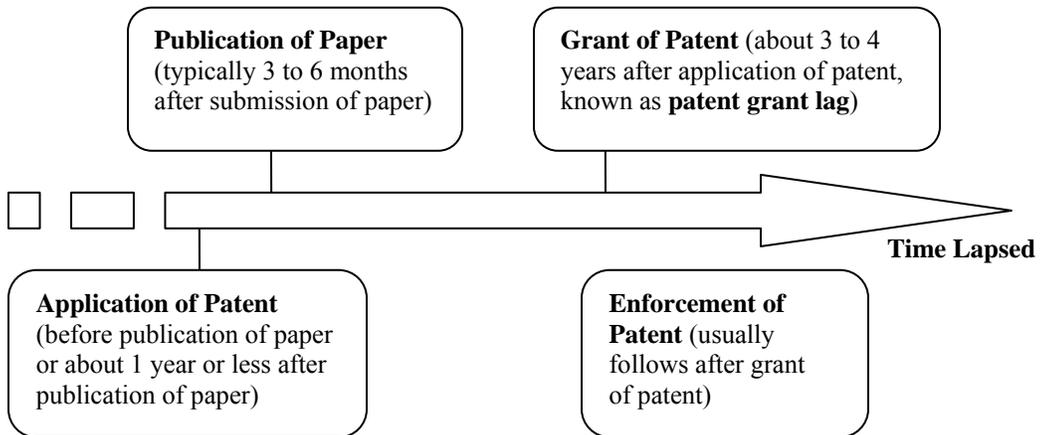


Figure 2 Typical Timeline on the Relationship of a Patent-Paper Pair



References

- Ai, C., E. Norton. 2001. Interaction terms in nonlinear models. Working paper 2, Triangle Health Economics.
- Allison, P. D., R. Waterman. 2002. Fixed effects negative binomial regression models. R. Stolzenberg, ed. *Sociological Methodology*. Basil Blackwell, Boston, MA.
- Arora, A. 1995. Licensing tacit knowledge: Intellectual property rights and the market for know-how. *Econom. Innovation New Tech.* **4** 41–49.
- Arora, A., A. Fosfuri, A. Gambardella. 2001. *Markets for Technology: The Economics of Innovation and Corporate Strategy*. MIT Press, Cambridge, MA.
- Bechky, B. 2003. Sharing meaning across occupational communities: The transformation of knowledge on a production floor. *Organ. Sci.* **14** 312-330.
- Branstetter, L., R. Fisman, C. F. Foley. 2004. Do stronger intellectual property rights increase international technology transfer? Empirical evidence from U.S. firm-level panel data. *Quart. J. Econom.* Forthcoming.
- Buckley, P., M. Carter. 1999. Managing cross-border complementary knowledge: Conceptual Developments in the Business Process Approach to Knowledge Management in Multinational Firms. *Internat. Stud. Management Organ.* **29** 80-104.
- Bureau of Economic Analysis (BEA). 2000. Survey of U.S. direct investment abroad. Annual Series, Washington, D.C.
- Cameron, C. A., P. K. Trivedi. 1986. Econometric models based on count data: Comparisons and applications of some estimators and tests. *J. Appl. Econometric.* **1** 29-54.
- Cameron, C. A., P. K. Trivedi. 1998. *Regression analysis of count data*. New York, NY: Cambridge University Press.
- Cockburn, I., R. Henderson. 1998. Absorptive capacity, coauthoring behavior, and the organization of research in drug discovery. *J. Indust. Econom.* **46**(2) 157-182.
- Cohen, W., D. Levinthal. 1990. Absorptive capacity: A new perspective on learning and innovation. *Admin. Sci. Quart.* **35**(1) 128-152.
- Cohen, W. M., R. R. Nelson, J. P. Walsh. 2000. Protecting their intellectual assets: Appropriability conditions and why U.S. manufacturing firms patent (or not). Working paper 7552, National Bureau of Economic Research, Cambridge, MA.
- Ducor, P. 2000. Intellectual property: Coauthorship and coinventorship. *Science.* **289** 873-875.
- Farrell, D., J. K. Remes, H. Schultz. 2004. The truth about foreign direct investment in emerging countries. *McKinsey Quart.* **1** 25–35.
- Feinberg S., A. K. Gupta. 2009. MNC subsidiaries and country risk: internalization as a safeguard against weak external institutions. *Acad. Management J.* **52**(2) 381-399.

- Foss, N. J., T. Pedersen. 2004. Organizing knowledge processes in the multinational corporation: an introduction, *J. Internat. Bus. Stud.* **35**(5) 340-349.
- Furman, J., S. Stern. 2006. Climbing atop the shoulders of giants: The impact of institutions on cumulative research. Working paper 12523, National Bureau of Economic Research, Cambridge, MA.
- Gans, J., D. Hsu, S. Stern. 2008. The impact of uncertain intellectual property rights on the market for ideas: Evidence from patent grant delays. *Management Sci.* **54**(5) 982-997.
- Gans, J., S. Stern. 2003. The product market and the market for 'ideas': Commercialization strategies for technology entrepreneurs. *Res. Policy* **32**(2) 333-350.
- Gittelman, M., B. Kogut. 2003. Does good science lead to valuable knowledge? Biotechnology firms and the evolutionary logic of citation patterns. *Management Sci.* **49**(4) 366-382.
- Grant, R. M. 1996. Toward a knowledge-based theory of the firm. *Strategic Management J.* **17** 109-122.
- Greene, W. 2004. Fixed effects and the incidental parameters problem in the Tobit Model. *Econometric Rev.* **23** 125-147.
- Hall, B. H., A. B. Jaffe, M. Trajtenberg. 2001. The NBER patent citation data file: Lessons, insights and methodological tools. Working paper 8498, National Bureau of Economic Research, Cambridge, MA.
- Hausman, J. A. 1978. Specification tests in econometrics. *Econometrica.* **46** 1251-1271.
- Hausman, J. A., B. H. Hall, Z. Griliches. 1984. Econometric models for count data with an application to the patents-R&D relationship. *Econometrica* **52** 909-938.
- Heller, M. A., R. S. Eisenberg. 1998. Can patents deter innovation? The anti-commons in biomedical research. *Science.* **280**(5364) 698-701.
- Huang, K. G. 2006. Innovation in the life sciences: The impact of intellectual property rights on scientific knowledge diffusion, accumulation and utilization. Unpublished doctoral dissertation, Massachusetts Institute of Technology, Cambridge, MA.
- Huang, K. G., F. E. Murray. 2008. Do organizational choices shape scientific progress? The Human Genome Project as a policy experiment. Working paper, Lee Kong Chian School of Business, Singapore Management University, Singapore.
- Huang, K. G., F. E. Murray. 2009. Does patent strategy shape the long-run supply of public knowledge? Evidence from human genetics. *Acad. Management J.* Forthcoming.
- Hsu, D., R. Ziedonis. 2008. Patents as quality signals for entrepreneurial ventures. Working Paper, The Wharton School, University of Pennsylvania, PA.
- Jensen, K., F. E. Murray. 2005. The intellectual property landscape of the human genome. *Science.* **310** 239-240.
- Kogut, B., U. Zander. 1992. Knowledge of the firm, combinative capabilities, and the replication of technology. *Organ. Sci.* **3**(3) 383-397.

- Kogut, B., U. Zander. 1993. Knowledge of the firm and the evolutionary theory of the multinational corporation. *J. Internat. Bus. Stud.* **24**(4) 625-645
- Lemley, M. A., C. Shapiro. 2005. Probabilistic patents. *J. Econom. Perspectives* **19**(2) 75-98.
- Long, S. J. 1997. Count outcomes: Regression models for counts. *Regression models for categorical and limited dependent variables*. Sage, Thousand Oaks, CA, 217-250.
- Martin, X. & Salomon, R 2003. Tacitness, Learning, and International Expansion: A Study of Foreign Direct Investment in a Knowledge-Intensive Industry. *Organ. Sci.* **14**(3) 297-311.
- Murray, F. E. 2002. Innovation as co-evolution of scientific and technological networks: Exploring tissue engineering. *Res. Policy* **31** (8-9) 1389-1403
- Murray, F. E., S. Stern. 2007. Do formal intellectual property rights hinder the free flow of scientific knowledge? An empirical test of the anti-commons hypothesis. *J. Econom. Behav. Organ.* **63**(4) 648-687.
- Nelson, R. R., R. Merges. 1990. On the complex economics of patent scope. *Columbia Law Rev.* 90: 839–916.
- O’Mahony, S., B. Bechky. 2008. The role of boundary organizations in managing the problem of incommensurability. Working paper, Graduate School of Management, University of California Davis, Davis, CA.
- Oxley, J., T. Wada. 2009. Alliance structure and the scope of knowledge transfer: Evidence from U.S.-Japan agreements. *Management Sci.* **55**(4) 635-649.
- Shapiro, C. 2001. Navigating the patent thicket: Cross licenses, patent pools, and standard-setting. A. B. Jaffe, J. Lerner, S. Stern, ed. *Innovation Policy and the Economy*. MIT Press, Cambridge, MA, **1** 119-150.
- Singh, J. 2008. Distributed R&D, cross-regional knowledge integration and quality of innovative output. *Res. Policy* **37**(1) 77-96.
- Teece, D. J. 1986. Profiting from technological innovation. *Res. Policy* **15**(6) 285-305
- Winter, S. G. 1987. Knowledge and competence as strategic assets. D.J. Teece ed, *The Competitive Challenge: Strategies for Industrial Innovation and Renewal*. Ballinger, Cambridge, MA, 159-84.
- Zhao, M. 2006. Conducting R&D in Countries with Weak Intellectual Property Rights Protection. *Management Sci.* **52**(8) 1185-1199.
- Ziedonis, R. H. 2004. Don’t fence me in: Fragmented markets for technology and the patent acquisition strategies of firms. *Management Sci.* **50**(6) 804-820.