Intellectual Property Rights and

the Evolution of Scientific Journals as Knowledge Platforms

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Abstract

Scientific journals serve as two-sided knowledge platforms that facilitate the diffusion of scientific knowledge. Journals offer an outlet for scientists to disclose their findings in a way that allow others to evaluate the importance of their discoveries (e.g., through the reviewing process and the reputation of a journal) and, at the same time, are a principal means by which follow-on researchers can gain detailed access to the knowledge underlying scientific discoveries. For scientific discoveries that may also have commercial applications, researchers (or their funders) may also seek to establish formal intellectual property protection (e.g., patents); choosing to establish a "patent-paper pair" allows researchers to influence the use of knowledge that has been disclosed within the scientific literature. This paper evaluates the interrelationship between scientific journal publication and patenting by examining the incidence and impact of patent-paper pairs in two particular journals, *Nature Biotechnology* and *Nature Materials*. We develop a dataset based on all research publication in these journals from their founding through the mid-2000s, and collect detailed information on citations to and from these papers. Patent paper pairs are much more likely to be associated with research discoveries in which at least one author is employed by the private sector, and is also much more likely for articles with at least one author within the United States. Publications associated with patent-paper pairs have a higher overall rate of citation, but this finding masks significant heterogeneity across time and across journals. For example, patent-paper pairs published in the first few years after each journal is founded receive much lower level of citations. Moreover, using a differences-in-differences framework that exploits the long delay between publication and patent grant, the negative impact of patent grant is concentrated in the first few years after journal founding. Finally, after patent grant, there is an increase in citation by follow-on research published in *other* journal but a decline in citations in follow-on research published in the originating journal. Similar to recent evidence about the interrelationship between standard-setting organizations and intellectual property, our findings highlight the role of scientific journals as a particular type of two-sided platforms, and the subtle impact of intellectual property in shaping the use of knowledge disclosed and accessed through that platform.

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I. Introduction

In 2004, researchers from the University of Manchester and the Institute for Microelectronics in Chernogolovka (Russsia) developed the first feasible approach for fabricating and characterizing *graphene* - a complex single-layered carbon crystal structure. This fundamental scientific discovery, confirming a central theoretical prediction at the intersection of physics and materials science, was published promptly in *Science* (Novoselov, et al, 2004) and almost immediately spawned extensive follow-on research. These follow-on studies are wide-ranging, from explorations of the role of graphene in addressing fundamental questions of physics, to consideration of how to exploit these structures across a range of commercial applications such as electronics, chemical engineering and even satellite and aircraft design. Indeed, the fact that the fabrication and characterization of graphene resolves a basic research question while immediately being applicable to important problems is at the heart of the decision to award these researchers the Physics Nobel Prize a mere six years after publication (Swedish Royal Academy, 2010). Importantly, while a small number of the most important contributions to graphene research are published in the two leading general-interest journals - *Science* and *Nature* - the single most important platform for graphene research is the relatively young *Nature* satellite journal, *Nature Materials* (indeed this the most cited specialty journal in the 2010 Nobel Prize announcement) (see for example Geim and Novoselov 2007). Moreover, given the "dual" nature of this research it is perhaps not surprising that many of the graphene discoveries are not simply disclosed through publication in a scientific journal but are also the subject of applications for formal intellectual property (IP) protection.[4] Particularly given the sharp policy debates concerning the proliferation of IP over research in biotechnology during the 1990s (Heller and Eisenberg, 1998; Cohen, et al, 200*; Murray and Stern, 2007), there has been increasing concern, expressed forcefully in editorials and reports in *Nature Materials*, that the proliferation of patents over graphene research (and related research in materials science and nanotechnology) may (or may not!) be enmeshing this research area in a packet thicket undermining scientific research productivity (Tannock, 2012).

[4] However, Novoselov and Geim (and the University of Manchester) chose to simply publish their 2004 *Science* findings and did not additionally seek formal IP over their breakthrough. And in an interview, Geim noted that he had refrained from filing patents in the graphene area because of concerns over potential law suits from "a major electronics company" and over a lack of specific industrial applications and industrial partners for his developments (Brunfield 2010).

The objective of this paper is to evaluate the relationship between and impact of intellectual property on research that is also published within the scientific literature. Building on earlier work (Murray and Stern, 2007), we are particularly interested in how the collision between intellectual property and the norms of the scientific community vary across different research domains and over time as a particular scientific research area evolves and matures.

We organize our analysis by considering the central role of specialist scientific journals as two-sided platforms for knowledge disclosure and diffusion (McCabe and Snyder, 2005, 2007; Jeon and Rochet, 2009). On the one hand, journals serve as mechanism to facilitate certified disclosure of discovery by scientific researchers. By choosing to submit a paper to a particular journal, and having that journal accept the paper for publication, a researcher is able to disclose a discovery to the community of researchers associated with that journal, and also provide an (imperfect but nonetheless closely watched) quality signal about the importance of the discovery (based on the quality and "taste" of the journal). From the perspective of the "demand" side, the process of cumulative discovery in a particular field involves researchers accessing the research published within the field on a timely basis and being able to use those findings as inputs to their own research; as such, a scientific research journal offers (usually) low-cost and independent access to certified knowledge (Mokyr, 2002; McCabe and Snyder, 2007; Mukherjee and Stern, 2008; Furman and Stern, 2010). In addition to the two-sided pricing choice it makes (in terms of selecting a price for both contributors and readers), a journal must select a screening criteria that, over time establishes and reinforces its standard for quality. Particularly when a journal is at an early stage of its publication history, its statement of editorial intent, and then its choice of publishing particular articles (or not) is critical for establishing its early reputation; over time, the level and quality of follow-on research drawing on these articles, as well as the experience of the in dealing with false or misleading findings, is crucial for reinforcing and refining that reputation within a given scientific community (Furman, Jensen, and Murray, 2011).

Within this framework we consider how formal intellectual property rights such as patents will interact with the process of scientific publication across domains and over time. By and large, scientific journals select papers on the basis of their scientific quality and fit with the editorial mission of a journal, and (both explicitly and implicitly) assume that potential follow-on researchers will be able to have straightforward access the knowledge disclosed in the article (e.g., underlying datasets or materials). However, for dual purpose research within Pasteur's Quadrant (Stokes,

1987) researchers (or their funders) face a separate disclosure choice -- whether or not to use the patent system to protect their ideas with intellectual property (IP) rights (Gans, Murray and Stern 2011). This choice subsequently influences the ability (and incentives) to draw upon the discovery disclosed in the publication: When a given discovery is not only published but also protected by intellectual property i.e., forms a patent-paper pair (Murray 2002), follow-on researchers may have to contract separately to draw on that discovery for subsequent research. While many analysts have suggested that establishing formal IP over knowledge within the scientific literature retards the diffusion of scientific knowledge and cumulative progress (Heller and Eisenberg, 1998; Argyres & Liebskind, 1998; David, 2001), it is also possible that formal IP actually facilitates technology transfer across research generations by enabling the market for ideas (Kitch, 1977; Arora, et al, 2001; Hellman, 2005; Gans and Stern, 2000). Given this theoretical ambiguity, we focus on how the relationship between and impact of intellectual property and a scientific journal may vary across different research contexts, and evolve over time. As well, we are particularly interested in what types of researchers may (or may not) be impacted by intellectual property, both in terms of the choice to establish formal IP rights over a discovery and in terms of the choice to draw on that discovery in subsequent scientific research.

Our empirical analysis uses the journal platform as the analytical lens, examining the publications (and associated patents) linked to two relatively new journals, *Nature Biotechnology* and *Nature Materials*. For *Nature Biotechnology*, we observe publications from founding in 1997 through 2005. For *Nature Materials*, we observe publications from its founding in 2002 through 2006. For each of these publications, we then establish whether that publication is associated with a US patent (i.e., form a patent-paper pair). And, finally, we observe detailed bibliometric data about each publication (e.g., author affiliations, etc), as well as detailed bibliometric data about each follow-on paper that cites one of our focal articles (through the end of 2010). The data on both supply and demand for *Nature Biotechnology* and *Nature Materials* allows us to examine a number of supply and demand-side questions and specifically to explore the impact of the decision to patents on both sides of the platform.

We document a range of findings that highlight the nature and evolution of journals as knowledge platforms and the interaction between these disclosure platforms and formal IP rights. First, patent paper pairs are much more likely to be associated with research discoveries in which at least one author is employed by the private sector, and is also much more likely for articles with at least one author within the United States.   Second, while publications associated with patent-paper pairs have a higher overall rate of citation, this masks significant heterogeneity across time and across journals. For example, patent-paper pairs published in the first few years after each journal is founded receive much lower level of citations. Moreover, building on the differences-in-differences framework in Murray and Stern (2007) that exploits the long delay between publication and patent grant, we estimate that the negative impact of patent grant is concentrated in the first few years after journal founding. Finally, after patent grant, there is an increase in citation by follow-on research published in *other* journal but a decline in citations in follow-on research published in the originating journal.

These findings provide important insights into the challenges confronting two publication platforms from their time of inception. Specifically, they suggest that there are significant costs to be borne in the early development of new scientific journals, particularly with regards to using patenting as an additional exchange mechanism. On the other hand, once journals are 2-3 years old, the effects of patenting seem to be ameliorated. Finally, by examining how the use of knowledge disclosed through a platform depends on a separate contract based on intellectual property, our analysis follows an emerging body of research that focuses on the interaction of intellectual property with the disclosure of technical information through standard-setting organizations, as epitomized by, for example, the Rambus case (REF).

The paper is organized as follows. Section 2 motivates the analysis by elaborating on the ways in which journals serve as open access platforms with normative rules of exchange structuring markets for knowledge and the effects of IP rights on both the demand and supply sides of the platform. Section 3 describes the empirical context and approach we use to explore both the supply and demand side characteristics of journal platforms. Section 4 outlines our identification strategy, the data and summary statistics. Section 5 presents the empirical results, and Section 6 concludes.

II. Scientific Journals as Two-Sided Platforms

At the heart of knowledge exchange and accumulation lies the ability of individuals to learn from others who disclose ideas, share knowledge among members and provide sufficient access to enable replication, validation and follow-on innovation (Collins 1974, Mokyr 2002). Scientific journals play a foundational role in the diffusion of scientific knowledge. Scientific research journals are arguably the single most important single mechanism facilitating this process of transferring knowledge across researcher generations and over different research domains. However, despite the importance of journals to the operation of science, the study of scientific journals as economic institutions is still at an early stage (McCabe and Snyder, 2007, REFS).

It is useful to consider the overall evolution of scientific journals as a platform for the disclosure and access to scientific knowledge. Scientific periodicals – such as *Nature Biotechnology* and *Nature Materials* that are the focus of this paper – have a long history as knowledge platforms whose goal is to certify, share and circulate knowledge across the scientific community. This history dates back to the founding of learned scientific societies in Europe in the seventeenth century and their expanding mission to share scientific results among an expanding and geographically diverse community. In 1665 the Academie Francais started the French-language *Journal des sçavans* and the (English) Royal Society started the *Philosophical Transactions of the Royal Society* thus becoming the first journals to systematically publish research results. In the case of the *Transactions*, the publication was the private initiative of Henry Oldenburg who had an agreement with the Royal Society to undertake the journal as a for-profit business thus allowing the Society to become the oldest scientific publisher in the world. Since then, journals have varied widely in their ownership and profit model. Interestingly (for the purposes of our analysis), one of the earliest editions of the Royal Society Transactions contained detailed analysis of both discoveries and more useful patented technologies and methods. In 1887 the *Transactions* was divided to create two separate publications, one for the Physical Sciences (*Philosophical Transactions of the Royal Society A: Physical, Mathematical and Engineering Sciences*) and the other for the life sciences (*Philosophical Transactions of the Royal Society B: Biological Sciences*) thus previewing the much finer grained specialization of these knowledge platforms in the following century.

Nature, from which the subsidiary journals emerged in the late 1990s, was first published in 1869, and claims a worldwide readership of 600,000 [Nature Publishing Group, 2009]. It has been the platform of choice for discoveries ranging from Dart's 1925 discovery of a link between man and ape and the proposal that Africa was the "cradle of humanity" and Watson and Crick's 1953 proposed double helix structure for DNA, to Forman, Gardiner and Shanklin's 1985 research documenting the existence of an ozone hole over Antarctica and Wilmut & colleagues 1997 announcement of the development of Dolly the Sheep from mammalian cells.

However, Nature (and Science in the United States) are unusual because "aside from the proceedings of learned academies, there are only two English-language scientific journals that keep up the old tradition of encompassing all of science" (Weinberg 2003 p. ix). Instead, journals have increasingly served as knowledge platforms for much more narrowly defined knowledge communities. For example within an area such as molecular biology, the leading community journals would include Cell, Nature Biotechnology and Biochemistry. While in chemistry, leading community journals are even more finely divided with Nature Materials, Journal of the American Chemical Society, Journal of Chemical Physics, Tetrahedron (for Organic Chemistry) and Angewandte Chemie among those with the highest impact. Even in more applied fields such as electrical engineering and computer science, journals serve as key platforms, often existing alongside standard setting organizations, the patent system etc. For example much of the knowledge later disclosed in patents and in standard setting bodies by Rambus was also published in electric engineering journals such as the Transactions of the IEEE.

In the context of the current paper, we focus specifically on two journals that were explicitly established to serve as knowledge platforms for research in Pasteur's Quadrant. Specifically, our analysis focuses on the journals *Nature Biotechnology* and *Nature Materials* from their respective founding in 1997 and 2002 through to 2010. While serving as a market for two distinctive scientific communities, both are grounded in chemistry but with a distinctive focus: the biochemical community focusing on tools and applications to biotechnology and the physical chemistry community focusing on materials science. These journals are of particular interest because they were both explicitly founded by the Nature Publishing Group with the intent of providing a market for knowledge that was at once scientifically interesting and of practical relevance. Even though they are only recently established in already crowded arenas with large numbers of journals, they became highly regarded with significant impact in a very short period of time.

Patents as Alternative Exchange Mechanisms

When scientific knowledge is useful as well as making a contribution to fundamental knowledge then it is possible for the authors to select to disclose their findings in the form of a patent. For example, Gans, Murray and Stern (2011) examine the nature of the disclosure choices for a particular research project and argue that these arise on the basis of a negotiation between scientists and those who fund them. Regardless of the identity of the research scientists, the disclosure of scientific knowledge in patents, when it culminates in patent grant (at some later date), challenges publication-based markets for knowledge because they initiate a dynamic process that changes the legal status of knowledge.

With the grant of private property rights, knowledge that was only exchanged on the basis of the norms of the publication platform is now subject to the formal legal rights associated with IP's legal institutional foundations. 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.[5] 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 impact of exchanging knowledge through an alternative mechanism poorly adjudicated by the infrastructure of the journal and its editorial board is widely discussed at the intersection of law and the knowledge economy. In particular scholars are concerned with how the expansion of patents on scientific knowledge and the growing enforcement of these patents influence markets for knowledge traditionally shaped solely by the scientific community (Heller & Eisenberg 1998). More specifically, it is argued that formal IP rights and the concomitant threats of legal enforcement throughout the community challenge established norms (Lessig 2004, David 2003). Some strong qualitative evidence suggests that patenting does rapidly shape to new demand-side practices as IP

[5] 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)

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. More specifically, the effects of IP are argued to be linked to specific legal events i.e. the granting of particular 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 access agreement over research mice as occurred between DuPont and the National Institutes of Health (Murray et al. 2008).

On the other hand, these predictions disregard the power of journals as platforms that *themselves* can establish rules shaping the ways in which IP enforcement intersect with demand-side opportunities for knowledge exchange. Thus journals may be instrumental in muting the effect of IP on markets for knowledge. While journal editorial policies have gone relatively unnoticed in the literature on IP in academia in fact journals such as Nature (whose satellite journals we examine in this paper) have established clear policies on data sharing to pre-empt such effects. For example, Nature notes that "An inherent principle of publication is that others should be able to replicate and build upon the authors' published claims. Therefore, a condition of publication in a Nature journal is that *authors are required to make materials, data and associated protocols promptly available to readers without undue qualifications in material transfer agreements*. Any restrictions on the availability of materials or information must be disclosed to the editors at the time of submission".[6] Also, several important characteristics of formal IP rights raise the possibility of considerable adaptation by knowledge communities to changes in the formal legal status of knowledge – either alone or via their journals. IP rights are facilitative, providing their owners with a variety of legal rights that they may or may not use (Edelman & Suchman 1997). Taken together, these elements suggest that IP may have a limited influence on knowledge shared through journal platforms or even allow for increased participation in knowledge exchange (Kieff 2004).

The clear tension between markets for knowledge established purely through journals as platforms supporting two-sided markets and the "side" markets for ideas enabled by intellectual property rights raises a number of empirical questions:

- *What is the incidence of patent-paper pairs within a given journal, and how does this change over time, or vary by the characteristics of the authors?*

[6] Accessed from http://www.nature.com/authors/policies/availability.html on January 13th 2012.

- *What is the overall relationship between formal intellectual property and subsequent impact on the scientific literature? Are articles that are associated with intellectual property more or less cited in follow-on research? How does this vary over time, by research domain, or by the characteristics of the authors?*
- *What is the impact of formal intellectual property on subsequent scientific reserach? Does the grant of formal intellectual property directly impact the use of a given discovery? How does this vary over time, by research domain, or by the characteristics of the authors and citers?*
- *How does the journal itself evolve as a platform over time? Over time, how does the share of citations within a given article reflect prior work published in that same journal? Is this relationship impacted by formal IPR?*

3. Empirical Framework

This section overviews our empirical context and, in particular, the comparative analysis that allows us to examine how IP rights impact the markets for knowledge exchange enabled by the two-sided platforms provided by scientific journals. However, addressing the critical empirical questions outlined above and more broadly understanding of the ways in which the informal market for knowledge shaped by scientific journals and governed by informal norms interact with formal intellectual property rights raises a number of empirical challenges.

Most of the previous work that examines the role of intellectual property and other aspects of control and exchange of knowledge do not focus centrally on the role of the journal as a critical two-sided platform for exchange. For example, scholars have explored how specific changes in the scope of intellectual property rights have changed the behavior of one scientific community over a long period of time using in-depth qualitative analysis including interviews, documentary analysis etc. (see Murray 2010). Taking a more quantitative approach, others have examined how well defined changes in the *use* of intellectual property rights over specific materials – the licensing terms imposed on a variety of different transgenic mice – have shaped follow-on research (in scientific publications) (Aghion et al. 2010; Murray et al. 2011). Using survey-based approaches, Cohen, Walsh and co-authors have undertaken a series of survey-based analyses that explore to what extent life scientists consider IP rights as they make decisions regarding their follow-on research projects (Cohen et al., 2005).

These approaches suffer from a number of limitations particularly in the extent to which they can inform the literature on two-sided markets and help us shed light on the pivotal role of scientific journals in the market for knowledge. To do so requires that we define our analysis along a number of different dimensions:

1. First, we must shift our focus from research communities defined either by the use of a particular research tool (as for example is the case in Murray et al. 2011) or more broadly construed as crossing in a very large research domain (as the approach pursued by Cohen et al., 2005). Instead we define our analysis in terms of those who supply and demand knowledge from a particular platform – a scientific journal.
2. Second, if we are to explore the role of IP rights in shaping more traditional norms of open exchange around journal platforms, we must focus our attention on journals publishing research that lies in Pasteur's Quadrant – research that makes a contribution to fundamental knowledge while at the same time having the potential for useful application thus necessitating movement across the academic-industry boundary. Without this condition we are unlikely to find research that is both published but also subject to intellectual property rights.
3. Third, while we can obviously examine journals at any period of time, it is particularly instructive to examine these platforms from their inception. This allows us to understand whether and to what extent supply and demand characteristics change as the platform matures, including characteristics of scientists themselves, supply-side choices regarding patenting, and exchange practices with and without patenting.
4. Fourth and finally, it will be important to examine more than one platform in order to determine whether or not we are capturing the idiosyncrasies of a particular new journal, or more robust patterns shaping new markets for knowledge as they emerge. In particular, it is important to explore whether the role of IP rights outlined in prior literature hold beyond the life sciences – the traditional arena for study of these questions (see Heller and Eisenberg 1996).

3.1 Empirical Approach

Our research design focuses on the supply- and demand-side publishing activities for two high quality research journals in the life sciences and in materials science - *Nature Biotechnology* and *Nature Materials.* Both of these journals were established - in 1997 and 2002 respectively - by the same high quality publishing house – Nature Publishing Group (NPG). The NPG also established a variety of other journals in this period however our specific choice of *Nature Biotechnology* and *Nature Materials* is grounded in their similar intellectual origins and similar mission: Research exchanged in both journals is grounded in Chemistry – a discipline that has served as an important foundation spawning powerful new research communities dedicated to particular application arenas. In the life sciences in particular those aspects covered by *Nature Biotechnology*, much of the work on new tools to interrogate (and reshape) the chemical machinery of the human body are grounded in chemistry and bio-chemistry in particular (see Judson 1990). Likewise, in *Nature Materials*, research into new tools and methods to transform the chemical machinery of the material world are grounded in chemistry and in particular in physical chemistry.

In both instances, the journals were initiated in response to a growing awareness of the need for high quality research platforms for the exchange of knowledge in Pasteur's Quadrant in both of these arenas. The editorial mission of Nature Biotechnology emphasizes this need: "*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".* Likewise, the editorial policy of Nature Materials focuses (in part) on issues Pasteur's Quadrant in stating that "*Nature Materials covers all applied and fundamental aspects of the synthesis/processing, structure/composition, properties and performance of materials, where "materials" are identified as substances in the condensed states (liquid, solid, colloidal) designed or manipulated for technological ends*". However its mission is also focused around the journal as a platform for community building:

> "*Nature Materials provides a forum for the development of a common identity among materials scientists while encouraging researchers to cross established subdisciplinary divides. To achieve this, and strengthen the cohesion of the community, the journal takes an interdisciplinary, integrated and balanced approach to all areas of materials research while fostering the exchange of ideas between scientists involved in the different disciplines. Nature Materials is an invaluable resource for all scientists, in both*

academia and industry, who are active in the process of discovering and developing materials and materials-related concepts".

What is particularly striking about both of these journals is the rapidity with which both developed a highly active market for knowledge with average annual citation counts, as captured in the Journal Impact Factor (JIF). In 1998 *Nature Biotechnology* had an impact factor of 8.085 and by 31.04 in 2010. Similarly, *Nature Materials* reached 29.920 in 2010 (in only an 8 year period from 10.778 in 2003) rapidly placing it number one among materials science journals and across all primary research journals in physics and chemistry (see Editorial 2003)[7]. A final note on the specific comparison of choice relates to comparing two journals started by the same publisher and both using a professional editorial board, rather than a board of academics. It allows us to take advantage of the much greater uniformity the policies of the two platforms with regards to editorial policies, screening, and review processes. This is critical to our analysis; such elements are key to the role of the journals as platforms in knowledge exchange. Explicit common policies shared between all NPG journals (including Nature itself) what are relevant to the journal platform in shaping knowledge exchange include statements on author responsibilities, copyright, embargo policies, availability of materials and data, refutations, complaints and corrects, plagiarism and fabrication[8].

We follow supply and demand-side activities centered on these journals since their inception (in 1997 and 2002 respectively) through to 2010. To do so we examine two types of data: First, to measure the supply of scientific knowledge to the platform we capture data on all scientific research articles published by each journal from their year of founding through 2005 (our chosen end date to allow for sufficient time for the market for knowledge to accrue and be captured in follow-on citations). This approach follows a considerable prior literature that aims to use scientific articles to trace out the flow of knowledge and its contribution to the knowledge economy.

To capture the demand-side of the platform we make use of citations to articles published on the journal platform (drawn from the Web of Science - Science Citation Index database). This measure captures exchange and accumulation of the knowledge disclosed on the platform as a

[7] The impact factor measures the average number of citations per paper in a year based on articles published in the previous two years.

[8] See http://www.nature.com/nmat/authors/index.html for a detail list and also for links to the policy specifics in each of these areas.

proxy for participation in the market for knowledge around the journal platform. While it would be ideal to have a direct participation measure i.e. using the knowledge provided and certified by the platform, 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 broadly, 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 analysis, allowing us to trace out how researchers exchanged knowledge, built upon a publication and thus participated in knowledge exchange according to the norms of the particular journal-centered market.

The third aspect of our empirical approach exploits the existence of patent-paper pairs to explore the impact of patenting as an alternative exchange mechanism that can take place alongside the publication-mediated exchange (Murray 2002). Scientists produce "pairs" when they choose to disclose the same novel research results in both scientific publications and patent applications (Murray 2002, Ducor 2000, Gans, Murray and Stern 2011). They thus embody the potential for knowledge disclosed and exchanged on a journal platform to also be additionally embedded within the patent system and available for exchange through an entirely different set of property-based rules and norms. While patent-paper pairs are emblematic of the life sciences community's expanding production of knowledge that is simultaneously of scientific and commercial interest, they are also important in materials science, in areas such as fullerenes, graphene antd the like.

It is useful to consider a particular patent-paper pair to provide a sense of the relationship between publications and patent in practice. Consider the following patent-paper pair from biotechnology:

> "A method has been developed for control of molecular weight … during production of polyhydroxyalkanoates in genetically engineered organisms by control of the level and time of expression of one or more PHA synthases... The method was demonstrated by constructing a synthetic operon for PHA production in E. coli …Modulation of the total level of PHA synthase activity in the host cell by varying the concentration of the inducer …was found to affect the molecular weight of the polymer produced in the cell." (Snell; K. D.; Hogan; S. A.; Sim; SJ; Sinskey; A. J.; Rha; C.. 1998, Patent 5,811,272).

> “A synthetic operon for polyhydroxyalkanoate (PHA) biosynthesis designed to yield high levels of PHA synthase activity in vivo was constructed …. 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)

In addition to using patent-paper pairs to document the extent to which knowledge exchanged in a traditional “IP-based market for ideas” as well as in the market for knowledge provided by the journal, we follow prior scholarship and advantage of the substantial gap between the date of scientific publication and the date of patent grant (see Murray and Sstern 2007). While papers in the *Nature Biotechnology* and *Nature Materials* are typically published rapidly from the time of submission to the journal (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 the nature of knowledge exchange, including the treat of infringement lawsuits.

3.2 Analytical Approach

By taking the population of *Nature Biotech* and *Nature Materials* research articles from the inception of the journals until 2006 – a fraction of which have paired patents (covering the same knowledge) - we are able to evaluate our four questions regarding the role of journals as platforms for knowledge exchange in the presence and absence of patenting and over time from the inception of the platform.

First, we can assess the nature of the supply-side contributions to the journal platform by estimating the characteristics associated with publications associated with patent (paper pairs) and those without patents. Second, we can examine the supply-side nature of the papers with and without patents in terms of the annual citations that they accrue in each year after publication. We then turn to our two demand-side questions. We can assess how demand for papers (as captured in annual citations) change with the impact of patent grant by determining 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 the correlation between of patenting and the underlying quality (or type) of scientific knowledge from the causal impact of patent grant on a particular piece of knowledge shared through the journal platform. Finally, we can ask whether the impact of patent grant differs for different types of suppliers and different demand-side groups.

Our empirical specification predicted the annual count of forward citations in publications in our two journal sample over the period 1997-2010. This dependent variable took the form of count data skewed to the right. We used a negative binomial model of the annual citations for each of the publications in our dataset. For our first set of models, we establish the cross-sectional behavior of both article suppliers and articles users for each journal and how these behaviors relate to patenting. To account for potential correlations between annual forward citations and the effects of particular calendar years, we included journal-specific calendar year fixed effects and journal-age fixed effects in all models discussed in this paper. In our second set of models, we estimate the causal impact of a patent grant on annual forward citations. For these later models, we control for the variation in article quality and impact of individual papers using article fixed effects.

Observations in our data were defined on the citation-year level for each publication. We coded a set of variables to test our hypotheses. We defined an indicator variable, PATENT POST-GRANT, equal to one in years after the patent grant year for each paper that received a patent. When we observe the number of citations a paper receives before and after the grant of a patent, we are able to identify how the average pattern of citations to a paper changes the introduction of a patent. In both the random-effects models, we estimated (RE 1):

$$CITES_{i,j,pubyear(j),t} = \mathrm{f}(\varepsilon_{\mathrm{i,j,t}};\ \gamma + \beta_{\mathrm{t}} + \delta_{\mathrm{t-pubyear}} + \psi\ \mathrm{POST-GRANT_{i,t}})$$

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[9]. The coefficient on POST-

[9] 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.

GRANT (ψ) in this model provides a baseline measure of the association between patenting and annual forward citations.

While model (RE 1) provides an overall estimate of the relationship between patenting and annual forward citations, it does not provide any estimate of how this relationship might change over time. To explore the time dynamics, we estimated the equation (RE 2):

$$CITES_{i,j,pubyear(j),t} = \mathrm{f}(\varepsilon_{\mathrm{i,j,t}};\ \gamma + \beta_{\mathrm{t}} + \delta_{\mathrm{t-pubyear}} + \sum_{\mathrm{pubyear=1997}}^{2006} \psi_{\mathrm{pubyear}}\ \mathrm{POST-GRANT}_{\mathrm{i,t,pubyear}})$$

This equation measures the effect of patenting for publication-year cohorts. The coefficient ψ_{pubyear} provides a potentially time-varying estimate of the relationship between patent grants and annual forward citations.

Specification (RE 2) provides a flexible, non-parametric estimate of the association between patenting and annual forward citations for different publication year cohorts, but it does not identify any differences between the two publications. To examine the potentially different effects of patenting across the two journals, we modified specification (RE 1) to account for journal specific differences. Specifically, we estimated (RE 3):

$$CITES_{i,j,pubyear(j),t} = \mathrm{f}(\varepsilon_{\mathrm{i,j,t}};\ \gamma + \beta_{\mathrm{t}} + \delta_{\mathrm{t-pubyear}} + \psi_{\mathrm{j}}\mathrm{POST-GRANT}_{\mathrm{i,t,j}})$$

In this equation ψ_{j} measures the specific association between patenting and annual forward citations for each journal. ψ_{j} represents an aggregate measure of the relationship between patenting and forward citations across years.

It is only natural, then, to extend the analysis by combining (RE 2) and (RE 3) to identify the time-varying association between patenting and forward citations for each journal. To do so, we created a set of journal-specific publication year cohort dummies that measured when a patent was in force for each article. Specifically, we estimated RE 4:

$$CITES_{i,j,pubyear(j),t} = \mathrm{f}(\varepsilon_{\mathrm{i,j,t}};\ \gamma + \beta_{\mathrm{t}} + \delta_{\mathrm{t-pubyear}} + \sum_{\mathrm{pubyear=1997}}^{2006} \psi_{\mathrm{pubyear}}\ \mathrm{NB\ POST-GRANT}_{\mathrm{i,t,pubyear}} + \sum_{\mathrm{pubyear=2002}}^{2006} \psi_{\mathrm{pubyear}}\ \mathrm{NM\ POST-GRANT}_{\mathrm{i,t,pubyear}})$$

In this equation, NM POST-GRANT is the *Nature Materials* specific POST-GRANT dummy (defined above) and similarly the NB POST-GRANT is the *Nature Biotechnology* specific dummy. This specification allows us to test if there are significant differences between the two journals across years. The final random effects model we estimated in the paper provided a robustness check for equation (RE 4). To test whether journal specific time dynamics measured in (RE 4) masked significant article-level heterogeneity, we included key observable article level regressors from our dataset into the equation. Specifically, we estimated RE 5:

$$CITES_{i,j,pubyear(j),t} = \mathrm{f}(\varepsilon_{\mathrm{i,j,t}};\ \gamma + \beta_{\mathrm{t}} + \delta_{\mathrm{t-pubyear}} + \alpha_{0,\mathrm{i}}\mathrm{INDUSTRY} + \alpha_{1,\mathrm{i}}\ \#\ \mathrm{AUTHORS} + \alpha_{2,\mathrm{i}}\ \mathrm{US\ AUTHOR} + \sum_{\mathrm{pubyear=1997}}^{2006} \psi_{\mathrm{j,pubyear}}\ \mathrm{NB\ POST-GRANT}_{\mathrm{i,t,pubyear}} + \sum_{\mathrm{pubyear=2002}}^{2006} \psi_{\mathrm{j,pubyear}}\ \mathrm{NM\ POST-GRANT}_{\mathrm{i,t,pubyear}})$$

Here, INDUSTRY captures whether at least one of the authors had an industry affiliation, # AUTHORS measures the number of authors for each focal article, and US AUTHOR is an indicator variable set to one if at least one author comes from a U.S. based institution. While the coefficients from these variables might be of interest for other purposes, we were mainly concerned about the potential changes to the ψ_{pubyear} coefficients that could be caused by the introduction of control variables.

In the next section of regressions, we moved from random effects models to fixed effects models as we attempted to make more precise statements about the varying impact of patent grants over time. We began the analysis by adapting (RE 3) into a fixed effects specification. Specifically, we looked at (FE 1):

$$CITES_{i,j,pubyear(j),t} = \mathrm{f}(\varepsilon_{\mathrm{i,j,t}};\ \gamma_{\mathrm{i}} + \beta_{\mathrm{t}} + \delta_{\mathrm{t-pubyear}} + \psi_{\mathrm{j}}\mathrm{POST-GRANT}_{\mathrm{i,t,j}})$$

Note that here that γ_i is a fixed effect for each article. As discussed above, this equation measures the impact of a patent grant on annual forward citations. With the inclusion of fixed effects, we have created a difference-in-difference estimator. Here, 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. Similar to our discussion of the random effects models, we introduced a set of non-parametric cohort effects into (FE 1) in order to identify the time varying marginal impact of patenting. For our fixed effects regressions, we used patent-year cohorts instead of publication year cohorts. Specifically, we estimated (FE 2):

$$CITES_{i,j,pubyear(j),t} = \mathrm{f}(\varepsilon_{i,j,t};\ \gamma + \beta_t + \delta_{t-\mathrm{pubyear}} + \sum_{\mathrm{patyear}=1998}^{2009} \psi_{j,\mathrm{patyear}}\ \mathrm{NB\ POST-GRANT}_{i,t,\mathrm{patyear}} + \sum_{\mathrm{patyear}=2004}^{2009} \psi_{j,\mathrm{patyear}}\ \mathrm{NM\ POST-GRANT}_{i,t,\mathrm{patyear}})$$

In this regression, the set of $\psi_{j,\mathrm{patyear}}$ coefficients identity the separate marginal effects of patenting or each of the journal-specific patent year cohorts in our sample.

Building on Murray and Stern (2011) we next examined whether there were annual Acquiescence effects in our sample. Our acquiescence effect measures the impact of a given patent on publication citations to its paired paper for each year, after accounting for initial acquiescence. Specifically, we estimate a linear trend each year after the initial patent grant. Specifically, we estimated (FE 3):

$$CITES_{i,j,pubyear(j),t} = \mathrm{f}(\varepsilon_{i,j,t};\ \gamma + \beta_t + \delta_{t-\mathrm{pubyear}} + \sum_{\mathrm{patyear}=1998}^{2009} \psi_{j,\mathrm{patyear}}\ \mathrm{NB\ POST-GRANTi,t,patyear} + \mathrm{patyear=20042009}\psi\mathrm{j,patyear}\ \mathrm{NM\ POST{-}GRANTi,t,patyear} + \psi_{\mathrm{Acquiescence}}\ (\mathrm{t} - \mathrm{grantyear}_i) * \mathrm{POST-GRANT}_{i,t})$$

In this specification, $\psi_{\mathrm{Acquiescence}}$ measures the yearly change in the marginal effect of a patent grant on annual forward citations as an article ages beyond the first year of its patent grant.

In our last fixed effects regression, we test whether the acquiescence effect varies across journals. To do so, we created journal specific acquiescence variables. Specifically, we modeled the equation (FE 4):

$CITES_{i,j,pubyear(j),t} = \mathrm{f}\Big(\varepsilon_{i,j,t};\ \gamma + \beta_t + \delta_{t-pubyear} + \sum_{patyear=1998}^{2009} \psi_{j,patyear}$ NB POST − GRANTi,t,patyear + patyear=20042009ψj,patyear NM POST−GRANTi,t,patyear + ψj,Acquiescence t−grantyeari∗ NB POST−GRANTi,t+ ψj,Acquiescence t−grantyeari∗ NM POST−GRANTi,t)

The coefficients $\psi_{j,Acquiescence}$ estimate journal specific acquiescence effects. This last equation provides a rich set of estimates with which we can describe the time and journal varying components of the marginal effect of patenting on annual forward citations.

4. The Data

4.1 Sample Definition

Our sample was composed of 1,450 published scientific research papers disclosing potentially patentable knowledge drawn from two related top-tier journals, *Nature Biotechnology* and *Nature Materials*. Our data set begins with the founding of each journal (1997 for *Nature Biotechnology* and 2002 for *Nature Materials*). Our choice of time period and sample allows us to examine the dynamic effects of IPR in two different research communities, especially in the context of two newly established journals which quickly became focal institutions for these communities. The founding of a journal provides a particularly salient window to explore the use of intellectual property in scientific communities. Prior research has explored the differing motivations for intellectual credit and financial gain and how they influence a scientist's decision making (Dasgupta and David 1994, Stern, 2004). A new journal (even a *Nature* sub-journal) provides particularly sharp tradeoffs for the scientists supplying articles to the journal because they cannot reliably forecast the reach or impact of an article published in a new journal. We therefore expect to see a particularly rich set of time varying effects of patenting on forward citations associated with new journals.

For each of the 1450 articles in our sample, we established whether or not an associated patent had been granted by the USPTO (thus generating a pair). We conducted searches on the USPTO database using a series of decreasingly restrictive combinations of author names and geographical location. We then hand-coded all patents returned from these searches to establish whether or not they represented a part of a pair by comparing abstracts and other patent content. Using this method, we identified 525 patents (36 percent) that were associated with a paper to form a patent-paper pair.

For each of these 1450 articles and 525 patents, we then collected a range of variables describing the observable characteristics of the papers and patents (see Table 1). For each publication, we then created a variable PATENTED equal to one if the article was part of a pair and set to 0 otherwise. Additionally, we coded the date in which the patent application was file (APPLICATION YEAR) and the year in which the patent was granted (GRANT YEAR). We then generated a variable from the difference of GRANT YEAR and APPLICATION YEAR (PATENT LAG) which represented the random latency between filing and USPTO action.

We then collected data on the forward citations to the 1450 articles from Thomson ISI Web of Science for the years 1997 to 2010 (188,126 articles in total). Using the ISI data, we coded a range of variables characterizing the citing team's institutional affiliations and geographical location. In particular, we coded a set of dummy variables to describe whether at least one of the citing institutions was a public entity (CITE PUBLIC) or if at least one of the citing institutions was a for-profit company (CITE PRIVATE). We also created a set of dummy variables to classify each citing article as either having at least one U.S. based author or not (CITE US). These dummy variables were then used to generate marginal citation year counts for each publication that we will use to explore the dynamic interactions effects of intellectual property grants on different sub-populations of our sample.

From the citation-year level data, we constructed one final set of variables. Our main dependent variable was the total number of citations an article received in a calendar year (YEAR) which we defined as ANNUAL FORWARD CITATIONS. For each citation-year observation, we defined PUBLICATION AGE as YEAR – PUBLICATION YEAR. We then defined an indicator variable, PATENT POST GRANT, set to one for each paper's citation-years in which the patent has already been granted (i.e. when YEAR – GRANT YEAR > 1). Using the indicator variables described in the paragraph above (CITE PUBLIC, CITE PRIVATE, and CITE US), we were also able to construct a set of counts of annual citations by different subgroups. ANNUAL FORWARD CITATIONS PUBLIC captures all those forward citations in a given year with at least one public sector author. Similarly, ANNUAL FORWARD CITATIONS PRIVATE measures the number of citations in a year that had at least one private sector author. Taken together, our variables allow us to characterize both the supply and demand side behavior on similar two-sided platforms. In addition, the structure of our data allows us to make comparisons across platforms and across time.

4.2 Summary Statistics

Both *Nature Biotechnology* and *Nature Materials* are highly regarded in their fields with higher than average journal impact factors (31.085 and 29.897, respectively in 2010) making them both the highest ranked journals in their category by this metric. Given their prestige and broad audience, it is unsurprising that they each show high ANNUAL FORWARD CITATIONS: 13.08 (std 20.97) and 18.4 (std 27.33) for *Nature Biotechnology* and *Nature Materials* respectively (see Table 1 and 2).

-- Insert Table 1 about here—

-- Insert Table 2 about here—

Overall, these articles also demonstrated a high degree of collaboration. In *Nature Biotechnology*, we observed an average of 6.86 (std 4.45) authors per paper and 5.77 (std 2.82) authors per paper for *Nature Materials.* While the rates of authorship were high for published papers in both journals, we observed similarly reduced numbers of inventors for patents in our pairs. The average #INVENTORS was 3.3 (std 1.76) for *Nature Biotechnology* and 3.9 (std 1.9) for *Nature Materials*.

We also observed some important differences in article characteristics between the two journals, most notably the rate of patenting between articles in these two journals. Overall, the rate of patenting in *Nature Biotechnology* was 47% in our sample while the rate was 17.4% in *Nature Materials.* The rates of patented articles by publication year for each journal are displayed in figure 1. While patent-paper pairing fluctuates across years in *Nature Biotechnology*, it remains consistently higher than the rate in *Nature Materials.* There are also significant differences between the characteristics of patented and unpatented articles and these differences are heterogeneous across journal (see Table 3).

The compositions of authorship teams varied for patented and unpatented articles (in addition to varying across journal). For *Nature Biotechnology*, 34% of patented articles had at least one private author compared to 26% for unpatented articles; 86% of patented articles had at least one U.S. author compared to 18% for unpatented articles. We also observed significant differences in the rates of private/public collaboration. In *Nature Biotechnology*, roughly 19% of all articles had at least one private and at least one public author. The number of private public collaborations increased slightly for patented articles to 20.2% while the rate decreased slightly from the baseline for unpatented articles to 17.9%. In *Nature Materials*, we observed a lower rate of private/public collaboration overall, but a larger difference between patented and unpatented articles. The rate of collaboration was 10.7% overall, but this rate increased to 16.84% for patented articles and decreased to 9.39% for unpatented articles. Overall, there are noticeable differences across significant margins for articles supplied to the two journals.

Above, we have focused on the characteristics of the articles published in the two journals (the supply side of the platform), but there are also some important differences in the characteristics of the citing articles across journals (the demand side). A similar trend to the differences in patenting explored above is observed when we aggregated yearly citation counts for each journal by the different institutional affiliations of the citing articles (Public versus Private). Overall, the mean ANNUAL FORWARD CITATION PUBLIC was 12.28 (std 19.9) for *Nature Biotechnology* and the mean PRIVATE was 1.77 (std 3.53). For *Nature Materials*, the mean ANNUAL FORWARD CITATION PUBLIC was 18.02 (std 26.74) while PRIVATE was 1.28. When we analyzed the frequency of private forward citations by citation year, we also observed notable time dynamics (see Figure 2).

-- Insert Figure 2 about here --

The frequency of private forward citations has been decreasing sharply for *Nature Biotechnology* throughout our period of observation, moving from a high of 0.195 in 1998 to a low of 0.0975 in 2010.

We noted some differences between patented and unpatented articles in both journals. For articles published in *Nature Biotechnology*, patented articles had a much higher rate of U.S. authored articles (86%) versus unpatented articles (18%). The differences in U.S. authorship were not as large for *Nature Materials* (60% for patented articles versus 52% for unpatented). Similarly, *Nature Materials* had a much larger gap between the percentage of citing articles with at least one private author across patented and unpatented articles (20% for patented versus 10% for unpatented) when compared to *Nature Biotechnology*.

5. Results

Our empirical analysis attempts to disentangle that complicated dynamics of intellectually property grants on subsequent cumulative innovation in the form of FORWARD CITATIONS for different academic communities. While prior work has explored the causal impact of intellectual property grants on the use of a piece of knowledge (Murray and Stern, 2007) and also explored the temporal dynamics for a given community of scholars (Murray and Stern, 2011), it is important to consider the potential differences in the way in which intellectual property is used in different communities across time. As discussed above, our empirical setting provides us with two similar communities (materials scientists and biochemists) and two similar events (the founding of two *Nature* sub-journals) through which we explore these themes. The founding of a journal provides a particularly salient window to explore intellectual property in scientific communities. As discussed in the introduction, the interaction between the probabilistic, flexible nature of patent IP rights and the editorial policies of Nature journals (broad requirements for granting access rights) can theoretically produce varied responses to patenting knowledge on the platform: 1. a "chilling", anti-commons effect on forward cumulative research, 2. a additional channel for increased knowledge exchange (i.e. a marketplace for ideas), or 3. a neutral impact.

Due to the broad range of potential effects, we expect to observe differences in the impact of patenting across the life history of a journal as well as differences across journals. As a journal ages, the institutional norms of exchange for participants on the platform become more formalized and the trade-offs between seeking additional patent protection for a given piece of knowledge become more predicable for the supply-side authors. In addition, more formalized institutional norms of exchange clarify the tradeoffs associated with accessing a piece of patented knowledge for demand-side authors. This theorized reduction in uncertainty produces a set of varied incentives for patented article supply and demand over time. This time varying process might also vary across journal because the institutional norms of exchange that emerge on each platform are highly dependent upon the broader set of exchange norms and institutional context of the scientific community exchanging on the platform.

The empirical core of this paper explores three issues. First, we estimate a random effect negative binomial model to evaluate the cross-sectional impact of patent-paper pairs on the demand side of each journal. Our specification allows us to disentangle calendar effects from the age effects of each journal. These random effects models establish the baseline behavior of both suppliers and users of new knowledge on the two platforms. In the second part of our analysis, we use a series of conditional fixed effects negative binomial regressions to identify not only the causal impact of a patent grant on subsequent use of articles but also how this impact changes over time by journal. In the third portion of our empirical exploration, we examine the response to patenting across two margins of forward citations. First, we use a conditional fixed effects negative binomial specification to examine the differential effect of patenting on articles with public and private authors. Second, we use conditional fixed effects regressions to look at the impact of patenting on forward citations from articles published in the same journal (*Nature Biotech* or *Nature Materials*) versus other journals.

In both the random effects and fixed effects models, our analysis proceeds in two steps. First, we establish the overall impact of patenting across the entire sample using a dummy variable that indicates whether a patent was in force at the time of an articles citation (PATENT POST GRANT) and also journal specific dummy variables measuring whether a patent was in force (NB PATENT and NM PATENT). To establish the time varying effects of patenting in our random effects models, we created a series of interaction terms between Publication Cohort (PUBLICATION YEAR), whether the article has an active patent (PATENT POST GRANT), and (in some models) a third interaction with the journal. These non-parametric Cohort-Patent interaction terms provide test for time-contingent effects of patenting while the Cohort-Patent-Journal interactions allow us to explore whether these time effects vary across journal. For our fixed effects regressions, we focus on patent year cohorts. Similar to the construction above, we established a set of time varying effects by creating a set of indicator variables that were the interaction between the a cohort dummy for a patent's GRANT YEAR, whether the focal article had an active patent (PATENT POST GRANT), and in some cases a dummy for the specific journal. We focused on publication year cohorts for the random effects models because we wanted to establish the cross-sectional associations between patent grants and forward citations over the life cycle of these two journals. In our fixed effects models, we used patent grant year cohorts because these allowed us to identify how the causal impact of patent grants varied over time. Throughout our exposition of the results of our analysis, we will focus on the IRR as the coefficient of interest because of its intuitive interpretation as the multiplicative effect on the expected yearly citations to an article.

5.1 Random Effects models

Our regression results begin in Table 5 with a series of random effects negative binomial models where ANNUAL FORWARD CITATIONS is the dependent variable. For all the models in Table 5, we use a full set of journal-specific age fixed effects as well as full set of journal specific citation year fixed effects so that we fully control for idiosyncratic calendar year effects for each journal. Model (5a-1) provides a baseline measure of the association between patenting and ANNUAL FORWARD CITATIONS. We find a positive and statistically significant coefficient suggesting that a patent is associated with a 9% increase in yearly citations across all years. The next model (5a-2) decomposes the overall patenting association into journal-specific effects of patenting using journal specific patent grant dummies. We find statistically insignificant but positive associations between patenting and annual forward citations for both journals.

In the next table (5b), we move begin to measure the time varying associations between patenting and forward citations with a set of publication year cohort dummy variables (PAT 1997 – PAT 2006). In contrast to the positive effect in the first model, we observe significant variation in the effect of patenting across years in model 3. Most notably, patented articles published in 1997 were associated with a near 40% decline in annual forward citations (significant at the 0.001 level). As we move to later cohorts, patented articles published in 2003-2005 were associated with statistically significant increases in annual forward citations ranging from 54.1% t o 75.9%. These results demonstrate significant variation over time in the relationship between patenting and annual forward citations.

Table 5c continues our examination by combining our journal specific and publication year cohort analyses. Model (5c-4) shows the relationship between patenting and forward citations by publication year but broken out by journal. Again, we observe a statistically significant negative impact of patenting for the publication year of 1997 for *Nature Biotechnology* (IRR of 0.617), but we also observe a parallel, statistically significant negative result for the first year of publication of *Nature Materials* (IRR of 0.534). Both journals seem to have a strongly negative association between patenting and ANNUAL FORWARD CITATIONS in their first year of publication. This negative association shifts into a positive association over time for both journals. By the publication year of 2005, patented articles in *Nature Biotechnology* were associated with a statistically significant 165% increase in annual forward citations. We find similar but not as strong findings in the *Nature Materials* coefficients. Model (5c-5) provides an intermediate robustness check of our results by showing that our results hold after controlling for key observable article-level heterogeneity. When we include focal article level variables to control for institutional affiliation (PRIVATE AUTHOR), co-authorship levels (# AUTHORS), and U.S. authorship (US AUTHOR) of the cited article, Model (5c-5) demonstrates that the basic pattern of the results and the statistical significance of the key results discussed above still hold.

The models presented in Table 5a – 5c establish a clear pattern of time varying effects of patent grants. In addition, they begin to establish similarities and differences between the demand-side behaviors of citers across the two journals. While separated by five years, patented articles published in the initial year of both journals were associated with statistically significant and strongly negative reductions in ANNUAL FORWARD CITATIONS. After this initial year effect, the patented-publication-year cohort effects of both journals seem to trend positive. Our random effects models capture the cross-sectional supply and demand behavior across journals, but they do not provide a clear causal account of the impact of patent grants on demand–side behavior. In the next section, we will use a series of conditional fixed effects models to more carefully characterize the impact of patent grants.

5.2 Fixed Effects Regressions

Tables 6a and 6b show the results of our conditional fixed effects models. Each of these models provide a set of Difference-in-difference estimators that make use of the randomly varying length of patent review to make more precise, causal statements about the effects of patent grants on the level of forward citations for the two journals. Model (6a-1) provides a baseline estimate of the journal-specific effect of patent grant on ANNUAL FORWARD CITATIONS. The coefficient estimate for the effect of a patent grant on *Nature Biotechnology articles* (NB PATENT POST GRANT) shows a positive, statistically significant effect of patenting across time periods (1.068) corresponding to a 6.8% increase in forward citations resulting from a patent grant. For *Nature Materials*, the coefficient estimate (NM PATENT POST GRANT) is also positive, similar in magnitude, but not statistically significant. In Model (6b-2) we explore the time varying effects of patent grants for articles in each journal, and we find results that parallel the findings of the random effects models. Specifically, we observed statistically significant negative effects of patenting for articles whose patents were granted in the earliest cohorts of our sample for each journal (NB PATENT POST GRANT 1998 COHORT = 0.699 and NM PATENT POST GRANT: 2004 COHORT = 0.589). Given the delay between patent application and approval, these coefficients show that patented articles published in the earliest issues of both journals were subject to a significant decline in ANNUAL FORWARD CITATIONS resulting from the patent grant. Also parallel to the random effects models, we observe this negative effect of patenting early in the sample trends to a weakly positive effect for both journals.

Model (6b-3) adds the PATENT ANNUAL ACQIESCENCE variable to the previous model to explore how a patent grant affects the time trend of forward citations and not just the overall level. Our model shows a weakly negative, but not statistically significant time trend for the years following a patent grant. Model (6b-4) explores whether the Acquiescence effect varies across journal. While both journal specific Acquiescence estimates are negative, the coefficient for *Nature Materials* (NM PATENT ACQUIESCENCE) is negative and statistically significant (IRR = 0.948), suggesting that articles in this journal experience a yearly 5.2% decline in annual forward citations after the initial patent year. Taken together, the results of table 6a and 6b show significant differences between the two journals. *Nature Biotechnology* has a positive overall effect of patenting while *Nature Materials* has a significantly negative time trend reducing the annual forward citations to an article each year after its patent grant.

5.3 Margins regressions

In the last empirical portion of the paper, we examine the impact of patent grants on different subpopulations of both the life science and materials science communities. While the results in Table 5 and 6 provide useful evidence showing differences in the impact of patents over time on the aggregate life sciences and materials science communities, our detailed micro-data allowed us to evaluate these issues more precisely by comparing the impact of patents across different sub-sections of these communities. We were particularly interested in whether PATENT POST GRANT has a differential impact on different subpopulations of potential citers in the life sciences community. We focused on two subpopulations of interest: 1. citations from authors with public versus private institutional affiliations and 2. citations from authors publishing in the same journal versus publications in another journal. The first margin helps identify how patent grants impact who chooses to participate on the demand-side of the journal platform. The second margin identifies how patent grants impact the cumulative development of the platform itself.

Our first set of margin regressions is presented in Table 7. As before, all the margins regressions have journal age and citation year fixed effects. Model (1) shows the overall impact of patenting on citations with at least one author with a public institutional affiliation while model (2) shows the impact of patent grant on the number of annual forward citations from articles with at least one author with a private institutional affiliation. In both regressions, we find that patented articles published in *Nature Biotechnology* are associated with statistically significantly higher levels of annual forward citations, but the effect of patenting on private author citations is larger in magnitude (1.22 for articles from private authors compared to 1.066 for articles from public authors). In both regressions, the coefficients estimating the impact of a patent grant on annual forward citations in *Nature Materials* were also positive, but not statistically significant. The positive coefficients for *Nature Biotechnology* across both sub-populations shows that use of IP in the life-sciences community seems to have a facilitating effect for both sub-populations of the community, provides greater facilitation for researchers from private institutions.

The second set of margins we investigated is shown in Table 8. Here, we looked at the impact of patent grants on the level of annual forward citations to an article from its own journal versus from other journals. In model (1), we found that patented articles in *Nature Biotechnology* experienced a large and statistically significant decline in the level of annual forward citations from *Nature Biotechnology* while model (2) shows that these same patented articles experienced an overall increase in the level of annual forward citations from all other journals. For *Nature Materials*, our coefficients were positive but statistically insignificant across both regressions. These results suggest that seeking a patent for an article published in *Nature Biotechnology* significantly hiders the follow-on citations from authors choosing to publish on the same platform while significantly increasing the level of citations from other journals. These regressions add weight to our interpretation of a journal as a platform, because patent grants have a measurably different impact on articles created on the platform as opposed to articles that merely use the platform as a demand-side service for the distribution of new ideas.

6. Conclusions & Discussion

This paper provides an empirical examination the role of two newly established scientific journals in the two-sided market for scientific knowledge. In particular it examines whether scientists using particular journals as a platform for knowledge exchange also take advantage of exchange practices outside the scope of a journal platform that are enabled by the granting of intellectual property rights. By exploring the publishing (and patenting) of particular research articles in two scientific journals since the inception of those journals, we can understand the supply and demand side impacts of patenting on the two-sided market for scientific knowledge.

They are also relevant for scholars of two-sided markets because of course journals are not the only setting in which alternative IP policies and practices arise outside of the context of a standard setting organization (SSO). For example, patents on financial products emerged at roughly the same time as the rapid patenting of academic knowledge stemming from the Bayh-Dole Act. The emergence of patents for the construction of financial indices and the construction of complicated options portfolios provided an important avenue through which financial service firms in the U.S. attempted to capture the rents associated with financial innovation (Lerner 2003). Similar to the decision to patent the knowledge represented by a published article, financial services firms faced trade-offs associated with seeking IP protection for indices, portfolios, or hedging methods that would ultimately appear on a trading platform, some of which were not controlled by the innovating firm. Thus, our findings are informative for the broader debate about the role that intellectual property plays in shaping the structure and impact of knowledge platforms.

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Table 1: Variable Definitions

VARIABLE	DEFINITION	SOURCE
	Publication Characteristics	
PUBLICATION YEARj	Year in which article is published	NB, NM
# AUTHORSj	Count of the number of authors of Article *j*	NB, NM
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
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; NM – Nature Materials; SCI – Science Citation Index

Table 2: Summary Statistics

VARIABLE	N	MEAN	STD	MIN	MAX
Publication Characteristics					
PUBLICATION YEAR	1450	2002.06	2.79	1997.00	2006.00
# AUTHORS	1450	6.46	4.18	1.00	43.00
PRIVATE AUTHOR	1450	0.24	0.42	0.00	1.00
US AUTHOR	1450	0.52	0.50	0.00	1.00
PATENTED	1450	0.36	0.48	0.00	1.00
Patent Characteristics					
GRANT YEAR	525	2004.91	3.96	1996.00	2011.00
PATENT LAG	525	1468.80	642.97	238.00	3714.00
# INVENTORS	525	3.42	1.86	1.00	15.00
Citation-Year Characteristics					
ANNUAL FORWARD CITATIONS	12957	14.52	22.99	0.00	453.00
CITATION YEAR	12957	2005.60	3.25	1997.00	2010.00
ANNUAL FORWARD CITATIONS PUBLIC	12957	13.84	22.11	0.00	446.00
ANNUAL FORWARD CITATIONS PRIVATE	12957	1.64	3.41	0.00	63.00
ANNUAL FORWARD CITATIONS US	12957	5.99	10.25	0.00	166.00
PATENT POST GRANT	12957	0.21	0.41	0.00	1.00

Table 3: By Journal and Patent Status

	Journal		Journal and Patent Status			
Variable	NM, Overall	NB, Overall	NB, Pat.	NM, Pat.	NB, No Pat.	NM, No Pat.
Publication Year Characteristics (N = 1,450 original publications)						
N	534	916	430	95	486	439
Publication Year	2004.4	2000.7	2000.5	2004.6	2000.9	2004.4
# Authors	5.77	6.86	6.76	6.23	6.95	5.67
U.S. Author	0.541	0.503	0.865	0.6	0.183	0.528
Private Author	0.12	0.302	0.347	0.2	0.263	0.103
Patented	0.18	0.47	-	-	-	-
Patent Characteristics						
N	95	430	-	-	-	-
Grant Year	2008.5	2004.1	-	-	-	-
Patent Lag	1441.3	1474.9	-	-	-	-
# Inventors	3.9	3.3	-	-	-	-
Citation Year Characteristics (N = 12,957 original citation-year observations)						
N	3512	9445	4519	610	4926	2902
Annual Citations	18.4	13.08	14.35	23.48	11.91	17.33
Citation Year	2007.1	2005	2004.9	2007.2	2005.1	2007.1
Annual Forward Citations, Public	18.02	12.28	13.41	22.94	11.24	16.99
Annual Forward Citations, Private	1.28	1.77	2.06	1.77	1.5	1.18
Patent Post Grant	0.044	0.27	0.564	0.251	0	0

Table 4: Differences in Citation Patterns Between Journals

By Difference Margins

	NB, Pat.	NM, Pat.	NB, No Pat.	NM, No Pat.	Overall
Private Authorship					
No Private Author	85.7%	92.5%	87.4%	93.2%	88.7%
At Least One Private Author	14.3%	7.5%	12.6%	6.8%	11.3%
U.S. Authorship					
No U.S. Author	53.2%	64.8%	56.2%	67.2%	58.8%
At Least One U.S. Author	46.8%	35.2%	43.8%	32.8%	41.2%
Public and Private Authorship					
No Joint Team	90.9%	94%	91.6%	94.4%	92.3%
Private & Public Authors	9.1%	6%	8.4%	5.6%	7.7%

Table 5: Patenting and Citation

Random Effects Models

Dep Var = FORWARD CITATIONS [Incident rate ratios reported in square brackets] (Robust coefficient standard errors reported in parentheses)	(1) Baseline Regression	(2) Journal Specific Patent Effect
PATENTED	[1.090*] 0.0861* (0.0446)	
NB PAT		[1.083] 0.0801 (0.0493)
NM PAT		[1.115] 0.109 (0.0972)
Observations	11507	11507
Journal-Age Fixed Effects	Y	Y
Journal-Citation Year Fixed Effects	Y	Y
Log Likelihood	-35057.05	-35057.01

* p<0.05, ** p<0.01, *** p<0.001

Table 5B: By Publication Year Cohort Dummies

Random Effects Models

Dep Var = FORWARD CITATIONS [Incident rate ratios reported in square brackets] (Robust coefficient standard errors reported in parentheses)	(3) Publication Year Cohort Effects
PAT 1997	[0.608***] -0.498*** (0.0526)
PAT 1998	[0.999] -0.000619 (0.0987)
PAT 1999	[0.822*] -0.196* (0.0717)
PAT 2000	[1.072] 0.0698 (0.100)
PAT 2001	[1.155] 0.144 (0.116)
PAT 2002	[0.993] -0.00693 (0.108)
PAT 2003	[1.688***] 0.523*** (0.190)
PAT 2004	[1.541***] 0.432*** (0.155)
PAT 2005	[1.759***] 0.565*** (0.183)
PAT 2006	[0.926] -0.0764 (0.142)
Observations	11507
Journal-Age Fixed Effects	Y
Journal-Citation Year Fixed Effects	Y
Log Likelihood	-35002.57

* p<0.05, ** p<0.01, *** p<0.001

Table 5C:
Publication Year Cohort Dummies, By Journal, Random Effects

Dep Var = FORWARD CITATIONS [Incident rate ratios reported in square brackets] (Robust coefficient standard errors reported in parentheses)	(4) Journal Specific Publication Vintage		(5) Journal Specific Publication Vintage with Controls	
Journal-Specific Publication Year Cohorts (In Years Since Publication)	NB (Init. Year = 1997)	NM (Init. Year = 2002)	NB (Init. Year = 1997)	NM (Init. Year = 2002)
0	[0.617***] -0.483*** (0.0536)	[0.534*] -0.628* (0.149)	[0.676***] -0.392*** (0.0606)	[0.507*] -0.680* (0.141)
1	[1.015] 0.0144 (0.101)	[1.729**] 0.548** (0.335)	[1.070] 0.0681 (0.107)	[1.803**] 0.590** (0.350)
2	[0.835*] -0.181* (0.0730)	[1.404] 0.339 (0.248)	[0.894] -0.112 (0.0808)	[1.374] 0.318 (0.240)
3	[1.095] 0.0903 (0.103)	[1.028] 0.0272 (0.160)	[1.167] 0.154 (0.116)	[1.070] 0.0677 (0.168)
4	[1.182] 0.167 (0.119)	[0.893] -0.114 (0.137)	[1.300*] 0.262* (0.139)	[0.868] -0.142 (0.133)
5	[1.113] 0.107 (0.131)		[1.240] 0.215 (0.153)	
6	[1.691***] 0.525*** (0.234)		[1.698***] 0.529*** (0.243)	
7	[1.632***] 0.490*** (0.199)		[1.784***] 0.579*** (0.227)	
8	[2.659***] 0.978*** (0.376)		[2.828***] 1.040*** (0.414)	
Article-Level Covariates				
INDUSTRY ARTICLE			[0.948] -0.0531 (0.0470)	
# AUTHORS			[1.035***] 0.0348*** (0.00534)	
U.S. AUTHORED ARTICLE			[0.903*] -0.102* (0.0425)	
Observations	11507		11507	
Journal-Age Fixed Effects	Y		Y	
Journal-Citation Year Fixed Effects	Y		Y	
Log Likelihood	-34962.95		-34962.95	

* p<0.05, ** p<0.01, *** p<0.001

Table 6A: Journal-Specific Impact of Patenting
Fixed Effects Model

Dep Var = FORWARD CITATIONS [Incident rate ratios reported in square brackets] (Robust coefficient standard errors reported in parentheses)	(1) Journal Specific Patenting Effect
NB PATENT	[1.068***] 0.0654*** (0.0209)
NM PATENT	[1.058] 0.0560 (0.0422)
Observations	11507
Journal-Age Fixed Effects	Y
Journal-Citation Year Fixed Effects	Y
Log Likelihood	-26676.15

Table 6B: Journal-Specific Patenting Impact, By Patent Year Cohort

Dep Var = FORWARD CITATIONS [Incident rate ratios reported in square brackets] (Robust standard errors in parentheses)	(2) Journal-Cohort Effect of Patenting		(3) Journal-Cohort Patenting Effect with Acquiescence		(4) Journal-Cohort Patenting Effect with Journal-Level Acquiescence	
Journal-Specific Patent Year Cohorts	NB	NM	NB	NM	NB	NM
1998	[0.699*] -0.358* (0.111)		[0.722*] -0.326* (0.115)		[0.714*] -0.337* (0.114)	
1999	[0.942] -0.0600 (0.0748)		[0.969] -0.0311 (0.0796)		[0.960] -0.0411 (0.0790)	
2000	[0.969] -0.0319 (0.0575)		[0.994] -0.00647 (0.0618)		[0.985] -0.0154 (0.0614)	
2001	[0.934] -0.0680 (0.0448)		[0.955] -0.0461 (0.0483)		[0.948] -0.0538 (0.0480)	
2002	[1.111*] 0.105* (0.0534)		[1.130*] 0.122* (0.0562)		[1.123*] 0.116* (0.0559)	
2003	[1.199***] 0.182*** (0.0494)		[1.219***] 0.198*** (0.0523)		[1.212***] 0.192*** (0.0521)	
2004	[1.193*] 0.176* (0.0865)	[0.589**] -0.529** (0.118)	[1.211**] 0.192** (0.0889)	[0.607*] -0.499* (0.123)	[1.205*] 0.186* (0.0885)	[0.751] -0.286 (0.166)
2005	[1.199**] 0.181** (0.0755)	[0.952] -0.0489 (0.119)	[1.213**] 0.193** (0.0772)	[0.972] -0.0284 (0.122)	[1.208**] 0.189** (0.0769)	[1.118] 0.112 (0.155)
2006	[0.916] -0.0878 (0.0532)	[1.150] 0.140 (0.136)	[0.925] -0.0776 (0.0542)	[1.169] 0.156 (0.139)	[0.922] -0.0813 (0.0540)	[1.314*] 0.273* (0.170)
2007	[1.169**] 0.156** (0.0637)	[1.065] 0.0629 (0.0777)	[1.180**] 0.165** (0.0647)	[1.078] 0.0750 (0.0792)	[1.176**] 0.162** (0.0645)	[1.177*] 0.163* (0.0977)
2008	[1.080] 0.0770 (0.0761)	[1.074] 0.0712 (0.0792)	[1.085] 0.0820 (0.0765)	[1.083] 0.0799 (0.0802)	[1.084] 0.0802 (0.0764)	[1.155] 0.144 (0.0915)
2009	[1.047] 0.0455 (0.0928)	[1.149] 0.139 (0.0966)	[1.050] 0.0489 (0.0930)	[1.155] 0.144 (0.0973)	[1.049] 0.0476 (0.0929)	[1.205*] 0.186* (0.104)
PATENT Annual Acquiescence			[0.994] -0.00642 (0.00468)			
NB PATENT Annual Acquiescence					[0.996] -0.00413 (0.00480)	
NM PATENT Annual Acquiescence					[0.948*] -0.0537* (0.0207)	
Observations	11507		11507		11507	
Journal-Age Fixed Effects	Y		Y		Y	
Journal-Citation Year Fixed Effects	Y		Y		Y	
Log Likelihood	-26648.93		-26648.009		-26645.57	

Table 7: Public-Private Author Margin Fixed Effects Regressions with Journal Specific Patenting Effects

Dep Var = FORWARD CITATIONS [Incident rate ratios reported in square brackets] (Robust coefficient standard errors reported in parentheses)	(1) Public Author Citations	(2) Private Author Citations
NB PAT	[1.066]** 0.0644 (0.0204)	[1.220]*** 0.199 (0.0326)
NM PAT	[1.042] 0.0408 (0.0437)	[1.092] 0.0878 (0.0987)
Observations	25914	25914
Journal-Age Fixed Effects	Y	Y
Journal-Citation Year Fixed Effects	Y	Y
Log Likelihood	-49713.961	-49713.961

* p<0.05, ** p<0.01, *** p<0.001

Table 8: Same-Journal Margin Regressions

Dep Var = FORWARD CITATIONS [Incident rate ratios reported in square brackets] (Robust coefficient standard errors reported in parentheses)	(1) Same Journal Citations	(2) Other Journal Citations
NB PAT	[0.762]*** -0.272 (0.053)	[1.051]* 0.049 (0.22)
NM PAT	[1.034] 0.033 (0.198)	[1.04] 0.039 (0.048)
Observations	25914	25914
Journal-Age Fixed Effects	Y	Y
Journal-Citation Year Fixed Effects	Y	Y
Log Likelihood	-39162.235	-39162.235

* p<0.05, ** p<0.01, *** p<0.001

Figure 1: Frequency of Patents by Publication Year and Journal

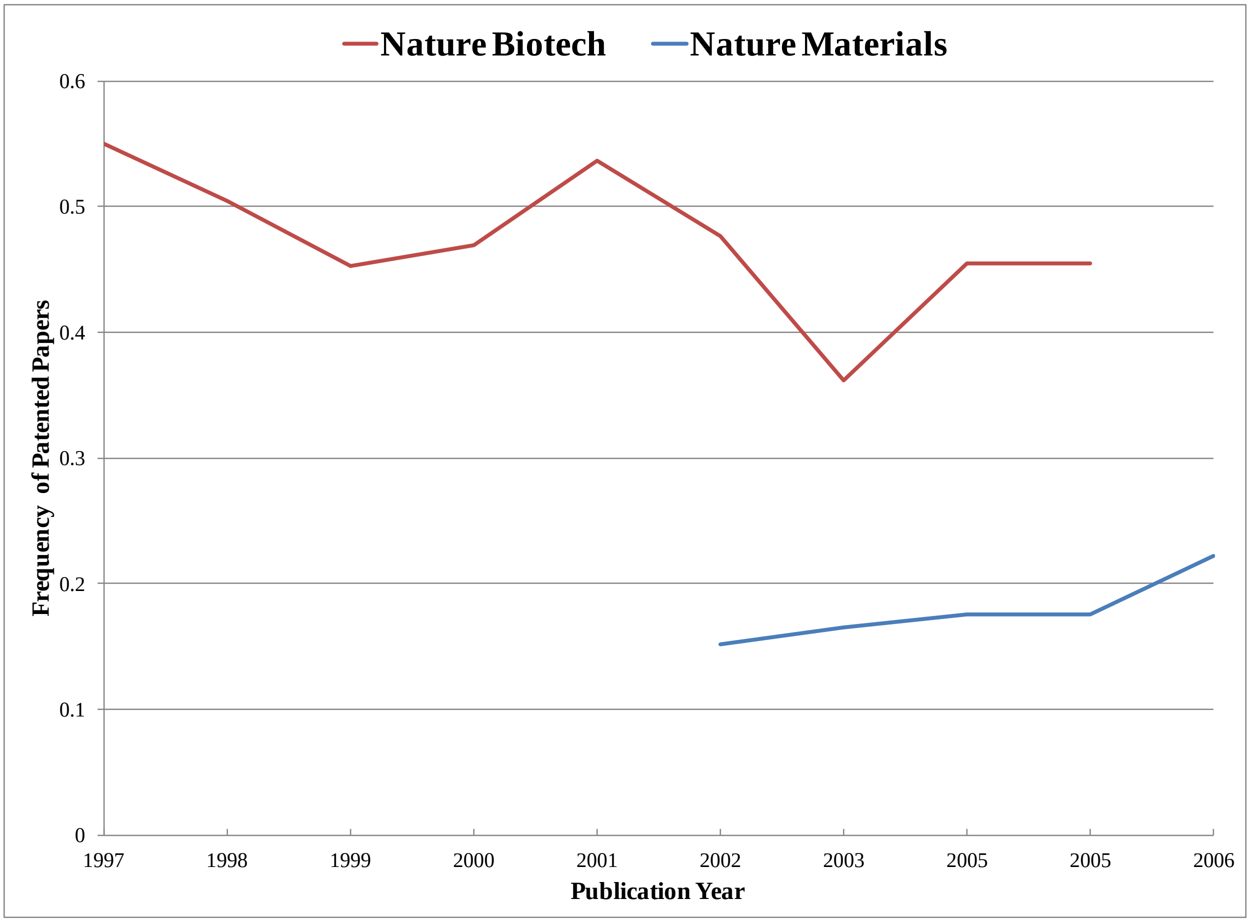

Figure 2: Frequency of Private Authorship in Forward Citations by Citation Year

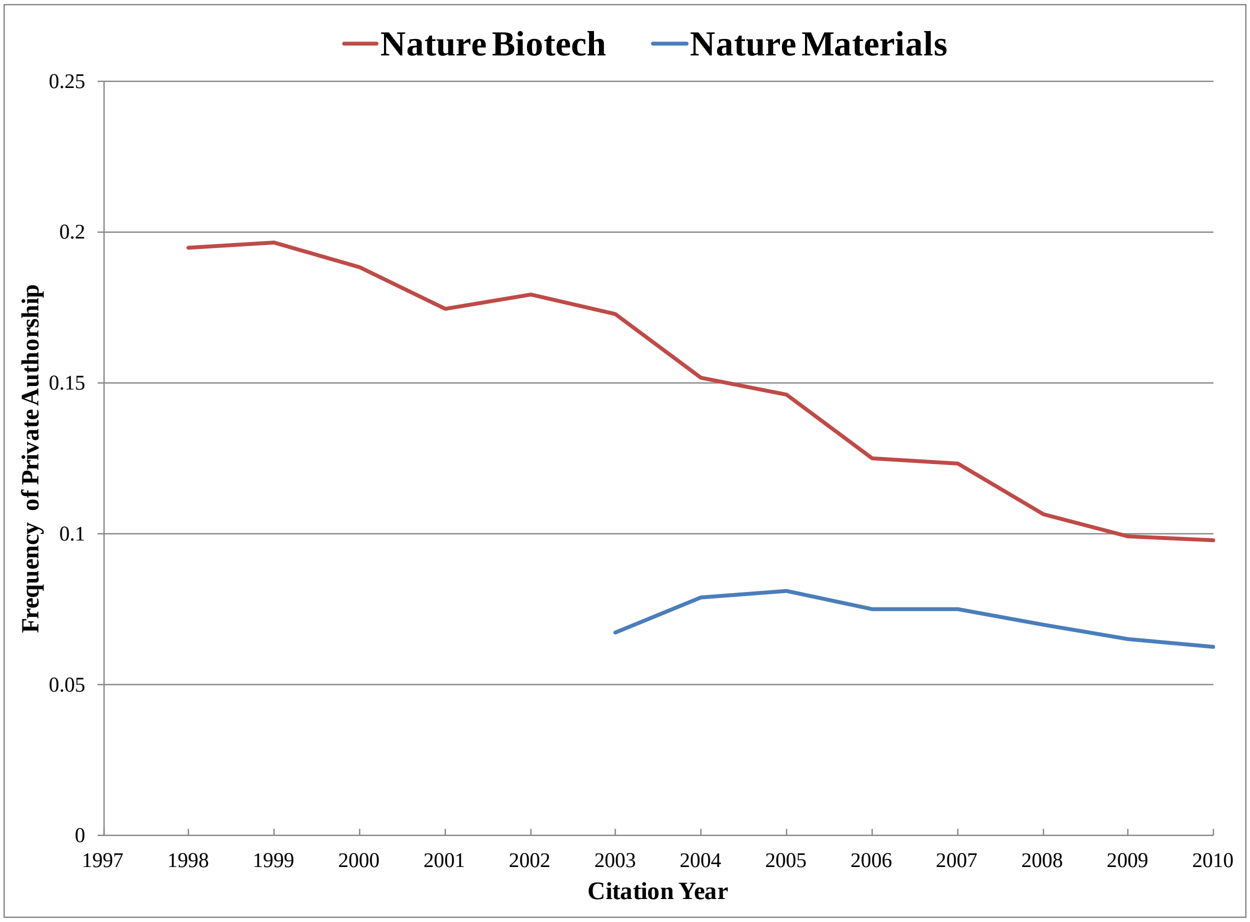

Figure 3: Frequency of Backward References to Same Journal by Publication Year

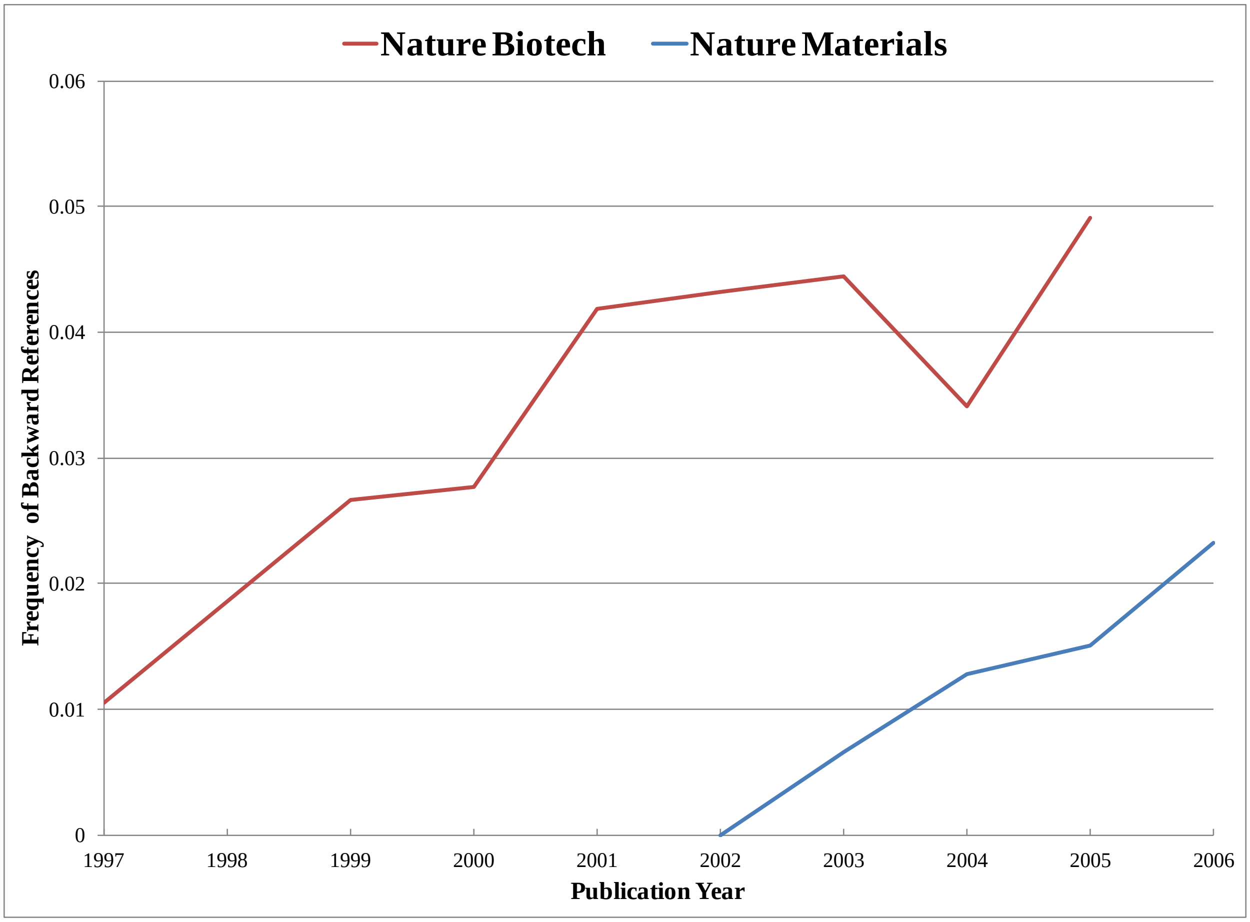

Figure 4: Frequency of Backward References to Nature Journals by Publication Year