

**Intellectual Property Rights and
The Evolution of Scientific Journals as Knowledge Platforms**

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Intellectual Property Rights and
The Evolution of Scientific Journals as Knowledge Platforms

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Abstract

The objective of this paper is to evaluate the role that formal intellectual property rights (IPR) play in shaping the downstream demand for knowledge that is initially disclosed through scientific publication in fields where research is generated and utilized across different institutional settings (i.e. academia versus industry). For scientific discoveries with potential commercial applicability, 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 follow-on access to knowledge disclosed in a given scientific journal. This paper evaluates the relationship between scientific journal publication and patenting in research communities with significant public and private authorship by examining the incidence and impact of patent-paper pairs in two journals founded in the late 1990s/early 2000s; Nature Biotechnology and Nature Materials. Using a differences-in-differences framework that exploits the delay between publication and patent grant, we document a range of findings about the impact of patent grant across time and across research populations. First, we find that the negative impact of patent grant is concentrated in the first few years after a journal’s founding and eventually becomes positive. Second, patent grant positively impacts follow-on citations from private authors more than from public authors. Finally, we observe an assortative matching pattern where intellectual property grant increases forward citations from authors sharing the same institutional affiliation (e.g. public authors citing public papers) more than research across institutional lines (e.g. public authors citing private papers).

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1. INTRODUCTION

In 2004, researchers from the University of Manchester and the Institute for Microelectronics in Chernogolovka (Russia) 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 aircraft design. The simultaneous impact of graphene research on both basic scientific research and commercial applications typifies the dual purpose of research which Stokes and subsequent scholars have classified as residing in “Pasteur’s Quadrant”⁴ (Stokes 1997; Murray 2002). Indeed, the fact that the fabrication and characterization of graphene resolves a basic research question while immediately being applicable to important practical problems was 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 outlet for graphene research publication is the relatively young *Nature* satellite journal, *Nature Materials* (see for example Geim and Novoselov 2007).

Given the “dual” nature of this research, it is perhaps not surprising that many graphene researchers chose not only to disclose their findings through publication in elite scientific journals but also to seek formal intellectual property rights (IPR) (see Stokes 1997; Murray 2002).⁵ Indeed, IPR has become so prevalent a form of disclosure in graphene research that recent editorials in *Nature Materials* considered whether the complicated web of patents from a

⁴ Pasteur’s Quadrant refers to the quadrant in Stokes’s taxonomy of science where a piece of research has both basic theoretical impact and direct and immediate practical application. It takes Pasteur’s name because the germ theory of disease is a seminal example of this type of science.

⁵ Interestingly, 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).

broad range of both public and private research labs might eventually become a “patent thicket” (Tannock 2011; Shapiro 2001). This discussion is reminiscent of policy discussions in the 1990s about the proliferation of IP in biotechnology and its potential anti-commons effect (Heller and Eisenberg 1998; Cohen, Nelson, and Walsh 2000). Like contributors to any institution designed for knowledge sharing and exchange, scientists and the editorial staff of the newly formed journal *Nature Materials* were concerned that IP might restrict access and undermine the nature and functioning of their scientific journal. This worry was particularly salient for *Nature Materials* since its mission was to create “an invaluable resource for scientists, in both academia and industry, who are active in the process of discovering and developing materials.”⁶

The objective of this paper is to evaluate the role that formal intellectual property rights (IPR) play in shaping the downstream demand for dual use knowledge that is initially disclosed through scientific publication in fields where research is generated in different institutional settings (i.e. academia versus industry). Research on standard setting organizations (SSOs) has shown that the interactions of actors with differing incentives and preferences shape an institution’s success in fostering knowledge disclosure and cumulative innovation (Simcoe, Graham, and Feldman 2007). Analogously, we examine how the scientific journal acts as a key point of interaction binding potentially diverse constituencies into a research field. Specifically, we examine how a researcher’s decision to pursue intellectual property rights impacts the demand for the article from follow-on researchers and how this impact varies across time and between public and private researchers.

Our empirical analysis uses the publications (and associated patents) linked to two new journals, *Nature Biotechnology* and *Nature Materials*, which share common “platform rules” including editorial policies, access policies, etc. For *Nature Biotechnology*, we observe publications from its founding in 1997 through 2005. For *Nature Materials*, we observe publications from its founding in 2002 through 2006. For each of these publications, we establish whether that publication is associated with a US patent (i.e. form a patent-paper pair). Finally, we observe detailed bibliometric data about each publication (e.g. author affiliations, citations etc.), as well as detailed bibliometric data about each follow-on paper that cites one of our focal articles (through the end of 2010).

⁶ <http://www.nature.com/nmat/authors/index.html>

Building on the empirical approach of past research, we first document a range of findings that highlight the interaction between a journal article's follow-on citations and formal IP rights. In the cross section, patented articles are associated with higher forward citations. Building on the differences-in-differences framework in Murray and Stern (2007), we find that the average impact of IPR grant on follow-on citations was positive. Using non-parametric patent grant year cohorts to explore the time dynamics, we find that the impact of patent grant is negative in a journal's early years then subsequently becomes positive. Thus, formal IPR seems to facilitate a "market for ideas" once a journal's reputation is established.

We then turn to the heart of our analysis and focus on whether the public versus private institutional affiliations of both the cited and the citing researcher drive the magnitude of IPR grant's impact on forward citations. First, we find that IPR grant increased forward citations from both populations but has a larger positive impact on forward citations from private authors than from public authors. Next, when we account for the institutional affiliation of both the cited and citing author, we observe an assortative matching pattern where intellectual property grant increases forward citations from authors sharing the same institutional affiliation as the cited author (e.g. public authors citing public papers) more than research across institutional lines (e.g. public authors citing private papers). For example, IPR grant increases annual private citations to private articles by 50% while it decreases annual public citations to private articles by nearly 10%. In addition, when we account for citations coming from *Nature* publications versus other journals, we find suggestive evidence that the identity of the journal publishing the forward citations mediated this institution-based assortative matching process. Thus, IPR grant seems to increase the potential for incremental research projects where the cited and citing authors have matching institutional affiliations.

If IPR not only changes demand for a paper but also induces an assortative matching process shifting the institutional locus of subsequent research, IPR grant impacts not only the amount of downstream cumulative research but also the organization of downstream projects through their institutional location (public versus private). As a bundle of control rights and disclosed knowledge, a patent grant can change both a follow-on researcher's access to the prior work and their beliefs about the value of building upon it, but these two factors can have very different implications for welfare. While disclosure might change the *ex ante* tradeoffs between different potential projects, contracting frictions between researchers across an institutional

divide might inhibit projects with high potential value from going forward. If, for instance, public researchers face differentially easier access to patented research from other public researchers (perhaps because of institutional norms promoting open science) than from private researchers (because the technology licensing offices of universities license IP only in one direction), then patented scientific discoveries made in private research labs may not receive the optimal mix of “exploratory” versus “exploitative” follow-on projects (Aghion, Dewatripont, and Stein 2008; Bikard 2012).

The paper is organized as follows: Section 2 motivates the analysis by a review of the relevant literature. 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.

2. The Role of IP on the Diffusion of Knowledge in Scientific Communities with Heterogeneous Actors: Theory and Evidence

Central to knowledge exchange and accumulation is the ability of individuals to learn from others who disclose ideas, share knowledge and provide sufficient access to enable replication, validation and follow-on innovation (Collins 1974; Mokyr 2004). Scientific journals play a foundational role in such cumulative exchange and learning. Indeed, scholarly journals are arguably the single most important mechanism facilitating the process of knowledge transfer across researchers and different research domains, especially in fields where researchers are drawn from significantly different institutional settings.

When scientific knowledge is useful, it is possible for the authors to disclose their findings in the form of a patent as well as via publication through a journal. With the grant of private property rights, knowledge that was otherwise exchanged only on the basis of the norms of the publication platform is now subject to the control rights associated with the IPR. The impact of institutions that offer authors an additional set of control rights beyond those specified by the infrastructure of the journal and its editorial board is a contentious area of debate among legal scholars, economists, policymakers, and the scientific community.

One set of scholars consider how the increased use of intellectual property rights might undermine the established institutions of academic science. 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 and 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 2004). Some strong qualitative evidence suggests that patenting does rapidly shape demand-side practices as IP owners send “cease and desist” letters to potentially infringing individuals and their organizations: unwilling or unable to respond to these requirements, knowledge workers rapidly reduce their participation in the community (Murray 2010).

Other work has grounded the impact of intellectual property in its specific functioning in a particular institutional context. Overall, it is important to consider that IP rights are facilitative, providing their owners with a variety of legal rights that they may or may not use (Edelman and Suchman 1997). Thus, the effects of IP is often linked to specific legal events which clarify the particular rights and agreements for a specific community: examples include incorporating patents into technical standards (Rysman and Simcoe 2008), the signature of an access agreement over research mice as occurred between DuPont and the National Institutes of Health (Murray et al. 2009), or the formulation of national and institution specific standards for material transfer agreements (Walsh, Cohen, and Cho 2007; Mowery and Ziedonis 2007). Taken together, these studies highlight that the impact of IPR on knowledge exchange can vary significantly across different institutional locations.

Another set of research more formally conceptualizes the impact of patenting on the potential negotiation between upstream and downstream researchers in specific settings. Williams (2010) interprets the lower downstream use of Celera genes as a result of increased transaction costs in a setting with private information (Williams 2010). On the other hand, researchers have stressed that it is also possible that formal IP actually facilitates technology transfer across research generations by enabling the market for ideas (Kitch 1977; Gans and Stern 2000; Arora, Fosfuri, and Gambardella 2004; Hellmann 2007). Theoretical work has explored the complementarities between publication and patents in the context of contracting between scientists and commercial firms (Gans, Murray, and Stern 2008). Taken together, these empirical and theoretical elements suggest that IP may have a limited influence on knowledge

shared through journals or even allow for increased participation in knowledge exchange (Kieff 2005).

Recent work has linked these debates to the design of institutions promoting cumulative innovation from a two-sided platform perspective. In the context of SSOs, researchers have found that the use of formal intellectual property varies significantly across different types of contributors, and across different platforms (Rysman and Simcoe 2008; Simcoe, Graham, and Feldman 2007). Analogously, a number of papers have suggested that scientific journals can usefully be placed into the theoretical framework of two-sided platforms and have explored how editorial policies and selection criteria influence the characteristics of researchers both supplying and utilizing research on the platform (McCabe and Snyder 2005; McCabe and Snyder 2007; Lerner and Tirole 2006). Unlike the platform-informed approach to SSOs, empirical researchers have yet to examine journals as a critical site of exchange between heterogeneous types of researchers (e.g. public versus private) and the consequences of these exchanges for the functioning of academic journals. By focusing on the differential impact of IPR on the downstream use of scientific knowledge, our analysis follows an emerging body of research that clarifies the causal channels through which intellectual property impacts the disclosure and cumulative use of technical information through specific institutions (Murray and Stern 2007; Williams 2010; Furman and Stern 2011).

3. EMPIRICAL FRAMEWORK

We now focus on the role of scientific journals in the market for knowledge and their influence over the policies and practices of scientists (arising both as a result of the professional editorial staff and the editorial practices of prominent scientists). This section overviews our empirical context and analytical strategy which allow us to explore how IPR impacts the cumulative use of scientific knowledge in scientific journals and how this varies by the institutional affiliation of the cited and citing researchers.

3.1 Empirical Approach

Our research design focuses on the demand-side publishing activities for two high quality research journals which share significant scientific and institutional similarities, *Nature Biotechnology* and *Nature Materials*. Both of these journals were established by the same high

quality publishing house – Nature Publishing Group (NPG). While the NPG also established a variety of other journals in this period, 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 for spawning powerful new research communities dedicated to particular application arenas. In the life sciences, especially 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 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*”.

What is particularly striking about both of these journals is the rapidity with which both developed a highly active market for knowledge with high average annual citation counts, as captured in the Journal Impact Factor (JIF). In 1998, *Nature Biotechnology* had an impact factor of 8.09 which rose to 31.04 in 2010. Similarly, *Nature Materials* reached 29.92 in 2010 (up from only 10.78 in 2003) rapidly placing it in first place among materials science journals and across all primary research journals in physics and chemistry (see Editorial 2003).⁷ We use

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

publication citations in our study to trace the flow of ideas over time and across institutional settings (de Solla Price 1965; Garfield and Merton 1979; Hall, Jaffe, and Trajtenberg 2001; Jaffe, Trajtenberg, and Henderson 1993).⁸

In addition to their success as impactful journals serving research communities at the intersection of academic and commercial research, both *Nature Biotechnology* and *Nature Materials*, as NPG journals, also use professional editorial boards rather than academic editors to administer the journal and select articles for publication. Professional editorial boards remove the risk that “political gatekeepers” govern the selection of published articles and ensure consistent application of editorial policies. They also allow NPG to promulgate uniform policies across their holdings with regards to editorial policies, screening, and review processes. As described above, these editorial design choices influence how a journal functions in its research community.⁹

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; Ducor 2000; Gans, Murray, and Stern 2008).¹⁰ A patent-paper pair embodies a decision to additionally embed a piece of knowledge within the patent system which makes it available for exchange through an entirely different set of property-based rules and norms. In addition, the substantial gap between the date of scientific publication and the date of patent grant provides a natural experiment to measure the impact of IPR grant (see Murray and Stern 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 four years. It is important to emphasize that patent grant delay is more than simply a pro forma administrative glitch. The formal process of patent application produces successive reductions in uncertainty about the extent of an application’s

⁸ 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 1975; Schubert and Braun 1993).

⁹ Explicit common policies shared between all NPG journals (including *Nature* itself) that are relevant to a journal’s ability to shape knowledge exchange include statements on author responsibilities, copyright, embargo policies, availability of materials and data, refutations, complaints and corrects, plagiarism and fabrication. 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.

¹⁰ Scientists produce “pairs” when they choose to disclose the same novel research results in both scientific publications and patent applications

formal IP rights. Each of these reductions shifts the uses the potential patent in knowledge exchange culminating with the threat of infringement lawsuits after a patent grant.

3.2 Analytical Approach

By following the supply and demand-side activities of the population of *Nature Biotech* and *Nature Materials* research articles – a fraction of which have paired patents (covering the same knowledge) – we are able to evaluate two main questions regarding how IPR impacts the downstream use of scientific knowledge disclosed in academic journals. First, we can build upon prior research by assessing how patent grants change the average demand for papers (as captured in annual citations) in our sample by determining how the rate of forward citations changes after patent grant. Second, we can see how the impact of IPR grant on forward citations varies not only by the institutional affiliation of the citing author but also the match between citing and cited author (e.g. public authors citing public papers). Additionally, we can examine whether this institution-based matching process varies for downstream citations within the *Nature* family versus all other publications.

Our empirical specification examines the annual count of forward citations in publications. 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 regressions, we use random effects models to establish the cross-sectional behavior of both article suppliers and articles users for each journal and how these behaviors relate to patenting. In our second set of models, we estimate the causal impact of a patent grant on annual forward citations using a difference-in-difference framework where we control for the variation in article quality and impact of individual papers using article fixed effects. In all models, we use additional controls. To account for potential correlations between annual forward citations and the effects of particular calendar years, we include journal-specific calendar year fixed effects in all models in this paper (called Journal-Citation Year fixed effects in our empirical tables). To account for the age-related patterns in the citation year data, we include journal-specific article age fixed effects in all models discussed in this paper (called Journal-Age Effects in our empirical tables). 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 after the introduction of a patent.

By identifying whether each follow-on citation has either entirely public authors or at least one private author, we can examine how the impact of IPR varies by the institutional affiliation of the follow-on researchers. Our key regression results used a difference-in-difference framework to estimate the causal impact of patent grant on annual forward citations. The specific form of each regression presented in our results is discussed in detail in Appendix B, but our key regression results build upon the results from Murray and Stern (2007) by exploring the different marginal responses to patent grant in two critical populations in Pasteur’s quadrant: private and public authors. We simultaneously estimate the impact of a patent grant on follow-on citations by public and private authors. Specifically, we jointly estimated:

$$CITES_{i,pubyear(j),t,public} = f(\varepsilon_{i,j,t,p}; \gamma_i + \beta_{tp} + \delta_{t-pubyear,p} + \psi_{public} \text{POST-GRANT}_{i,t})$$

$$CITES_{i,pubyear(j),t,private} = f(\varepsilon_{i,j,t,p}; \gamma_i + \beta_{tp} + \delta_{t-pubyear,p} + \psi_{private} \text{POST-GRANT}_{i,t})$$

β_{tp} is a separate year effect for public and private citations, $\delta_{t-pubyear,p}$ captures the separate effect for the age of the article by citation type, and POST-GRANT is a dummy variable equal to one only for articles which have received a patent.¹¹ Conditional on the vector of fixed effects and the treatment variable, the number of forward citations for each article’s citation year is modeled as being drawn independently from a common negative binomial distribution (i.e. $\varepsilon_{i,j,t,p}$ is assumed to be i.i.d.). In this specification, ψ_{public} measures the impact of patent grant on the downstream demand behavior of researchers with public affiliations, while $\psi_{private}$ measures the impact of a patent grant on the downstream behavior of researchers with private affiliations. Thus, ψ measures 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. The difference-in difference framework implicitly compares treated and untreated articles from the same journal publication year across the same citation years ensuring that our causal estimates are not affected by potential truncation problems. Overall, we are interested in assessing whether $\psi_{public} = \psi_{private}$ or whether there are heterogeneous

¹¹ Similar to Murray and Stern (2007), 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.

treatment effects across the two subpopulations. Also, we want to examine whether ψ_{public} and ψ_{private} each varied for citations to public versus private articles.

In our results, we extend our analysis of the two institutional populations in a number of additional ways. We provide a brief summary here, but provide a detailed account of our estimation techniques in Appendix B. First, we examine whether the marginal impact of patenting for each population varies by journal. Next, we introduce a set of non-parametric cohort effects into the above regression to identify the time varying marginal impact of patenting by journal across the different citing populations. We used patent grant year cohorts because these allowed us to identify how the causal impact of patent grants varied over time. Lastly, we examined how the impact of IPR grant varied for authors in Nature publications across the two different institutional populations.

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 journals allows us to examine the impact of IPR in two different research 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). By choosing two journals which quickly became focal institutions in research communities squarely in Pasteur's quadrant, we expect to see a rich set of interactions between researchers with different institutional affiliations.

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 filed (`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 all of the citing institutions were public entities (`CITE PUBLIC`) or if at least one of the citing institutions was a for-profit company (`CITE PRIVATE`). 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` and `CITE PRIVATE`), 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 all sector authors. 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 subpopulations, across journals 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: 14.11 (std 20.97) and 21.25 (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 18% 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*, 35% of patented articles had at least one private author compared to 26% for unpatented articles. Figure 2 shows how the rate of private authorship has varied across publication years for both *Nature Biotechnology* and *Nature Materials*. While there is variation across time for both journals, neither shows a clear trend. Overall, there are noticeable differences across significant margins for articles supplied to the two journals.

-- Insert Figure 2 about here --

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). The mean ANNUAL FORWARD CITATION PUBLIC was 12.21 (std 19.18) for *Nature Biotechnology* and the mean ANNUAL FORWARD CITATION PRIVATE was 1.9 (std 3.67). For *Nature Materials*, the mean ANNUAL FORWARD CITATION PUBLIC was 19.76 (std 26.59) while ANNUAL FORWARD CITATION PRIVATE was 1.48 (std 3.24). When we analyzed the frequency of private forward citations by citation year, we also observed notable time dynamics (see Figure 3).

-- Insert Figure 3 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.

Table 3 explores how annual forward citations vary by patent status for both journals. For both journals, patented articles receive had a higher mean annual forward citations as well as higher mean public and private annual forward citations than non-patented articles. Table 4 shows the impact of patenting on annual forward citations broken down by the institutional affiliation of the cited article's authors. Interestingly, ANNUAL FORWARD CITATION PRIVATE is highest when citing patented private authored papers and higher for articles citing unpatented private papers than patented public papers for both *Nature Biotech* and *Nature Materials*. Similarly, the highest level of ANNUAL FORWARD CITATION PUBLIC is observed when citing public patented articles. Thus, we observe an assortative pattern between the institutional affiliation of cited and citing author that we will return to below.

5. Results

The empirical core of this paper explores two issues. First, we build upon the prior literature by establishing the overall relationship in our sample between IPR grant and forward

citations. We use random effects negative binomial models to evaluate the cross-sectional relationship and then follow with two difference-in-difference regressions to establish baseline results similar to prior work such as Murray and Stern (2007). Second, we move on to the heart of our analysis and examine how the institutional affiliation of both citing and cited authors drives the impact of IPR grant on follow-on citations. Throughout our exposition of the results of our analysis, we report exponentiated coefficients, commonly referred to as incidence-rate ratio (IRR) coefficients. 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 Overall Relationship between IPR and Follow-on Citations

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, article-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 and thus addressing potential truncation bias. For the first two models in the table, the random effects specifications depart from the conditional independence of the fixed effects models described in section 3.2 and developed throughout the rest of the paper. By introducing the correlated error term of the random effects models, these models allow us to characterize the full relationship between patenting and forward citations (both sorting and treatment effect) before we measure the causal impact of patenting. For more details, see appendix B. Model (5-1) provides a baseline measure of the association between patenting and ANNUAL FORWARD CITATIONS similar to baseline regressions in prior work on the impact of IPR (Williams 2010). 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 last random effects model (5-2) 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. Our random effects models capture the cross-sectional demand behavior across journals, but they do not provide a clear causal account of the impact of patent grants on demand-side behavior.

The rest of the models in Tables 5 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 allow us to estimate the effects of patent grants on the level of forward citations for the two journals. Model (5-3) 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. While this baseline regression accords substantially to the structure of key regressions in prior research on the impact of IPR (Murray and Stern 2007; Williams 2010), our results show evidence for an overall positive impact of patent grant compared to prior results which established a negative effect.

The source of these differences can be seen in Figure 4 where we explore the time varying effects of patent grants for articles in each journal. We observe statistically significant negative effects of patenting (less than one in the graph) for articles whose patents were granted in the earliest cohorts of our sample for each journal. 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. This negative effect of patenting early in the sample trends to a positive (greater than one) but statistically insignificant effect for both journals. Thus, the negative impact of IPR grant on forward citations is largest for an article published in the early years of both journals, before they established a reputation for selecting high quality science (and, in the case of *Nature Biotech*, corresponding to the Murray and Stern (2007) sample).

5.2 Impact of Institutional Affiliation and IPR on Follow-on Citations

We now examine the differing impact of patent grants on researchers with private and public institutional affiliations for both the life science and materials science communities. While the results in Table 5 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 for the demand behavior of follow-on researchers disaggregated across these key subsets of research communities in Pasteur's Quadrant. Specifically, we were interested in whether PATENT POST

GRANT has a different impact on the different the subpopulations of potential citers in our sample (i.e. whether $\psi_{\text{public}} = \psi_{\text{private}}$).

The results of this analysis are presented in Table 6. All the regressions have journal-specific article-age and citation-year fixed effects for each subpopulation which addresses potential forward citation truncation bias. Model 6-1 examines how impact of patenting varies across our two populations. While both public and private downstream research demand show a statistically significant positively increase after the grant of a patent, the magnitude of the increase is larger for private forward citations than public (a 21% increase versus a 5.8% increase). The difference between these coefficients is statistically significant ($p < 0.001$). This result suggests that IPR grant facilitates greater follow-on research from private researchers than public.

Model 6-2 explores whether these effects vary by journal. Similar to the previous regression, 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). The difference between these coefficients is statistically significant ($p < 0.001$). 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 but provides greater facilitation for researchers from private institutions. Figure 5 provides time varying estimates of the impact of patent grant across both journals and across the public/private margin. It shows a negative and statistically significant impact of patenting on public citations in the early years of both journals, but a smaller and statistically insignificant effect on private citations.

Table 7 builds upon model 6-1 to ask whether the impact of patent grant on public and private forward citations depends upon the institutional affiliation of the cited author (i.e. whether ψ_{public} and ψ_{private} each vary by type of cited author). Model 7-1 estimates the impact of patent grant for each possible combination of institutional affiliation of cited and citing authors (e.g. private authors citing private papers, private authors citing public papers, etc).

Overall, we observe a strongly assortative pattern where intellectual property grant increases forward citations from authors sharing the same institutional affiliation as the cited author (e.g. public authors citing public papers) than follow-on research across institutional lines (e.g. public authors citing private papers). IPR grant increases the count of private authors citing private papers by 50% while decreasing citations from public researchers by nearly 10% (both coefficients and their difference were significant at the 0.001 level). Similarly, IPR grant increases the annual count of public authors citing public papers by a statistically significant 15% compared to a statistically insignificant 4.7%. The difference between these coefficients is statistically significant ($p < 0.001$). These results show that the positive coefficient estimates in 6-1 mask a great deal of heterogeneity. Patent grant seems to induce a matching process where follow-on research from a patented article seems to draw more heavily from researchers with the same institutional affiliation as the authors of the cited paper.

Next, we asked whether the matching process observed in Table 7 is different for cumulative knowledge exchange within *Nature* publications versus other publications. To do so, we classify each of the forward citations measured in the baseline regressions described in Table 5 as either published in a *Nature* journal or published in any other journal. We then measure the differences in forward citation rates from articles published in *Nature* journals versus forward citations from all other journals. Overall, we found the same assortative matching pattern as observed in Table 7: IPR increased forward citations from citing authors who shared their institutional affiliation with the cited paper. Interestingly, the magnitude of this effect seems larger for *Nature* citations. For example, IPR grant increases the count of private authors citing private papers by 70% within *Nature* publications compared to a 50% increase for all other journals. Due to the small size of the sample of *Nature* articles, the Wald Test comparing the size of these coefficients is statistically insignificant. Similarly, IPR grant increases the count of public authors citing public papers by 22% for *Nature* articles compared to 12% for all other journals.

Our results suggest that IPR grant not only changes the demand for a piece of knowledge (as measured by follow-on citations) but creates greater incentives for research that is an “institutional match” (i.e. both citing and cited research have the same institutional affiliation). Furthermore, the resulting matching process seems particularly acute for follow-on contributions in *Nature* publications. By shaping a community of researchers across institutional settings

through their editorial policies and reputation for quality, journals mediate the impact of IPR on downstream use across the public/private institutional divide.

6. Conclusions & Discussion

This paper provides an empirical examination the relationship between IPR and the exchange of scientific knowledge across a critical institutional divide (public versus private researchers) for fields in Pasteur's Quadrant. In particular, we examine the differing impact of IPR grant on the follow-on citations from public and private researchers. We document how the differing impact of IPR grant on the rate of follow-on citations from these different subgroups is driven by the institutional affiliation of the cited authors of the original paper: IPR grant leads to an assortative matching process whereby the patent grant increases forward citations from authors sharing the same institutional affiliation more than research across institutional lines.

These results suggest IPR grant impacts not only the amount of downstream cumulative research but also the organization of downstream projects through their institutional location (public versus private). The welfare implications of this matching process hinge largely on the specific channels through which it shifts project choices of researchers in private and public settings. A patent grant provides newly disclosed information to follow-on researchers and new control rights to the original author. New information changes the *ex ante* tradeoffs between potential new projects whereas new control rights could introduce new contracting frictions in a marketplace for ideas which might inhibit a high value project from being undertaken. If, for example, public scientists more easily access patented research from a university (because of the norms of open science) than from a private firm (because university legal resources are specialized in licensing IP out of rather than into the University), then a patented discovery made in a private lab might experience a very different mix of follow-on research than it would have if it were discovered in a public lab (Aghion, Dewatripont, and Stein 2008; Bikard 2012). We remain cautious in the interpretation of our results since we are not able to identify which of these mechanisms are at play in our setting.

Our results are relevant for scholars in a growing literature on the interaction of intellectual property and institutions with platform characteristics in contexts ranging from SSOs, to the growth of exchange traded financial products, to the impact of biological resource centers (Rysman and Simcoe 2008; Lerner and Tufano 2011; Furman and Stern 2011). While these

studies draw from wide-ranging phenomena, they attempt to measure the impact of innovation institutions on the formation of cumulative knowledge while addressing the importance of complementary institutions (like the patent system) for shaping the long-run success of these institutions. 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.

We also view this article as the first thrust in a larger effort to characterize the time-varying dynamics of journals in important scientific fields located squarely in Pasteur's Quadrant. While our choice of two related NPG journals allowed us to control for a good deal of unobserved heterogeneity in order to observe some of the basic dynamics of journals as two-sided platforms for knowledge diffusion, our study design limited us to a focus on the demand side of the platform for our key regressions. We intend follow-on studies to remedy this gap by broadening our perspective away from just NPG journals to the key journals serving as conveyors of knowledge, simultaneously basic and applied, in the fields of materials science and biotechnology. In so doing, we hope to make more precise statements about the ways in which the mechanisms outlined in the two-sided platform literature shape the growth of cumulative knowledge in Pasteur's Quadrant.

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Table 1: Variable Definitions

VARIABLE	DEFINITION	SOURCE
Publication Characteristics		
PUBLICATION YEAR _j	Year in which article is published	NB, NM
# AUTHORS _j	Count of the number of authors of Article <i>j</i>	NB, NM
PATENTED _j	Dummy variable = 1 if Article is associated with a patent issued by the USPTO prior to October, 2003	USPTO
TOTAL CITATIONS _j	# of FORWARD CITATIONS from publication date to 12- 2005	SCI
Patent Characteristics		
APPLICATION YEAR _j	YEAR in which PATENT was applied for	USPTO
GRANT YEAR _j	YEAR in which PATENT has been granted	USPTO
# INVENTORS _j	Count of the number of inventors listed in the granted patent associated with Article <i>j</i>	USPTO
Citation Year Characteristics		
ANNUAL FORWARD CITATIONS _{jt}	# of Forward Citations to Article <i>j</i> in Year <i>t</i>	SCI
ANNUAL FORWARD CITATIONS PUBLIC _{jt}	# of Public Forward Citations to Article <i>j</i> in Year <i>t</i>	SCI
ANNUAL FORWARD CITATIONS PRIVATE _{jt}	# of Private Forward Citations to Article <i>j</i> in Year <i>t</i>	SCI
PATENT POST-GRANT _{jt}	Dummy variable = 1 if PATENTED = 1 & CITATION YEAR > GRANT YEAR	USPTO
YEAR _{jt}	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

	MEAN	STD. DEV	MIN	MAX
Panel A: Publication Characteristics				
PUBLICATION YEAR	2002.06	2.79	1997	2006
# AUTHORS	6.46	4.18	1	43
PRIVATE AUTHOR	0.24	0.42	0	1
PATENTED	0.36	0.48	0	1
Observations	1,450			
Panel B: Patent Characteristics				
GRANT YEAR	2004.91	3.96	1996	2011
PATENT LAG	1468.80	642.97	238	3714
# INVENTORS	3.42	1.86	1	15
Observations	525			
Panel C: Citation-Year Characteristics				
ANNUAL FORWARD CITATIONS	15.96	23.95	0	453
CITATION YEAR	2006.04	3.02	1998	2010
ANNUAL FORWARD CITATIONS PUBLIC	14.16	21.60	0	425
ANNUAL FORWARD CITATIONS PRIVATE	1.79	3.57	0	63
ANNUAL FORWARD CITATIONS US	6.55	10.70	0	166
PATENT POST GRANT	0.23	0.42	0	1
Observations	11,507			

Table 3: Summary Statistics by Journal and Patent Status

	Nature Biotech			Nature Material Science		
	Overall	Patented	Not Patented	Overall	Patented	Not Patented
Panel A: Publication Characteristics (N = 1,450 original publications)						
N	916	430	486	534	95	439
PUBLICATION YEAR	2000.69	2000.49	2000.86	2004.42	2004.58	2004.39
# AUTHORS	6.86	6.76	6.95	5.77	6.23	5.67
PRIVATE AUTHOR	0.30	0.35	0.26	0.12	0.20	0.10
PATENTED	0.47	-	-	0.18	-	-
Panel B: Patent Characteristics						
N	430	-	-	95	-	-
GRANT YEAR	2004.1	-	-	2008.5	-	-
PATENT LAG	1474.9	-	-	1441.3	-	-
# INVENTORS	3.3	-	-	3.9	-	-
Panel C: Citation Year Characteristics (N = 11,507 original citation-year observations)						
N	9445	4519	4926	3512	610	2902
CITATIONS	14.11	15.50	12.83	21.25	27.30	19.98
CITATION YEAR	2005.51	2005.42	2005.59	2007.58	2007.65	2007.56
ANNUAL FORWARD CITATIONS PUBLIC	12.21	13.27	11.22	19.76	25.26	18.62
ANNUAL FORWARD CITATIONS PRIVATE	1.90	2.23	1.61	1.48	2.04	1.36
PATENT POST GRANT	0.27	0.564	-	0.044	0.251	-

Table 4: Citation-Year Demand by Author Demographics and Patent Status

	Private, Patented	Private, No Patent	Public, Patented	Public, No Patent
Panel A: Nature Biotech				
CITATIONS	14.65	14.16	15.95	12.37
ANNUAL FORWARD CITATIONS PUBLIC	11.71	11.66	14.10	11.08
ANNUAL FORWARD CITATIONS PRIVATE	2.94	2.51	1.85	1.30
Panel B: Nature Materials				
CITATIONS	29.93	26.32	26.61	19.22
ANNUAL FORWARD CITATIONS PUBLIC	25.79	23.05	25.12	18.09
ANNUAL FORWARD CITATIONS PRIVATE	4.14	3.27	1.49	1.14

Table 5: Baseline Random Effects and Fixed Effects Models¹

Dep Var = FORWARD CITATIONS			
	(1) Patenting Effect (RE)	(2) Journal Specific Patenting Association (RE)	(3) Journal Specific Patenting Effect (FE)
PATENTED	[1.090*] 0.086* (0.045)		
NB PATENT		[1.083] 0.08 (0.049)	
NM PATENT		[1.115] 0.109 (0.097)	
NB PATENT POST GRANT			[1.068***] 0.065*** (0.021)
NM PATENT POST GRANT			[1.058] 0.056 (0.042)
Observations	11,507	11,507	11,507
Individual Article Fixed Effects	N	N	Y
Journal-Age Fixed Effects	Y	Y	Y
Journal-Citation Year Fixed Effects	Y	Y	Y
Log Likelihood	-35,057.05	-35,057.01	-26,676.15

* p<0.05, ** p<0.01, *** p<0.001, ¹ [Incident rate ratios in square brackets] (Robust coefficient standard errors in parentheses)

Table 6: Public/Private Author Margin Fixed Effects Models¹

Dep Var = FORWARD CITATIONS	(1) Margin Specific Patenting Effect		(2) Margin Specific Patenting Effect by Journal	
	Public Citations	Private Citations	Public Citations	Private Citations
PATENT POST GRANT	[1.058**] 0.056** (0.019)	[1.210***] 0.190*** (0.036)		
NB PATENT POST GRANT			[1.061**] 0.059** (0.021)	[1.221***] 0.199*** (0.038)
NM PATENT POST GRANT			[1.044] 0.043 (0.043)	[1.116] 0.11 (0.107)
Observations	23,014		23,014	
Journal-Age Fixed Effects	Y		Y	
Journal-Citation Year Fixed Effects	Y		Y	
Log Likelihood	-49,253.06		-34,581.50	

* p<0.05, ** p<0.01, *** p<0.001, ¹[Incident rate ratios in square brackets] (Robust coefficient standard errors in parentheses)