



**Boundary spanning in a for-profit research lab:
An exploration of the interface between commerce and academe**

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Boundary spanning in a for-profit research lab: An exploration of the interface between
commerce and academe^{*}

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Abstract

In innovative industries, private-sector companies increasingly are participants in open communities of science and technology. To participate in the system of exchange in such communities, firms often publicly disclose what would otherwise remain private discoveries. In a quantitative case study of one firm in the biopharmaceutical sector, we explore the consequences of scientific publication—an instance of public disclosure—for a core set of activities within the firm. Specifically, we link publications to human capital management practices, showing that scientists' bonuses and the allocation of managerial attention are tied to individuals' publications. Using a unique electronic mail dataset, we find that researchers within the firm who author publications are much better connected to external (to the company) members of the scientific community. This result directly links publishing to current understandings of absorptive capacity. In an unanticipated finding, however, our analysis raises the possibility that the company's most prolific publishers begin to migrate to the periphery of the intra-firm social network, which may occur because these individuals' strong external relationships induce them to reorient their focus to a community of scientists beyond the firm's boundary.

I. Introduction

A burgeoning literature investigates the porous boundary between universities and companies, especially those in science-based industries. This work has developed along two macroscopic streams. First, a number of studies examine the emergence of the university as an engine of entrepreneurship, singling out its role in spawning startup companies (e.g., Zucker and Darby, 1996; Shane and Stuart, 2001; DiGregorio and Shane, 2003), as well as the significant rise in faculty patenting rates and faculty engagement in other forms of technology transfer (Mowery et al., 2001; Agrawal and Henderson, 2002; Owen-Smith and Powell, 2003; Azoulay, Ding, and Stuart, 2007; Colyvas and Powell, 2007). A second body of work approaches the interface from the reverse direction; it evaluates the potential gains to for-profit firms for contributing to open Science, especially the role of academic publishing in the development of firms' innovative capacity (Liebeskind et al., 1996; Cockburn and Henderson, 1998; Cohen, Nelson and Walsh, 2002; Stern, 2004; Murray, 2004; Lim, 2009).

This literature is large, but distilled, much of it concerns the process of boundary spanning. On one side of the divide, entrepreneurial faculty members have ventured into the world of commerce by building relationships and reputations in industry. On the other side, company researchers and dealmakers have navigated the academic landscape, seeking access to the distributed knowledge base that resides within the community of scholars. The obstacles and incentives to traverse the university-industry “divide”, however, differ on the two sides. For university faculty, the literature has pondered the collision and potential reconciliations of traditional scientific norms and values with the exigencies of commercial science, most notably the need for formal intellectual property rights on research advances (Owen-Smith and Powell, 2001). In negotiating their roles in industry, academic scientists have grappled with the normative challenges of appropriating private returns to a supposedly public good—scientific knowledge—and the construction of role identities that can accommodate juxtapositions between open and commercial Science (Murray, 2010). By contrast, as firms have adopted publication

policies that result in private knowledge crossing into the public sphere, the questions they face surround the balance between the time and disclosure costs that are incurred when research staff publish their scientific findings, versus the potential benefits of open publication policies, including access to the informal networks of science (Powell, Koput, and Smith-Doerr, 1996).

In this paper, we place the spotlight on, or more precisely, inside, a life sciences firm (hereafter, “BTCO”). This particular company owes its existence to entrepreneurial boundary spanners; BTCO’s cofounders hailed from both academic and private sector backgrounds. Along with a group of other biotechnology industry pioneers, BTCO’s founding heralded the emergence of a new type of company with unusually permeable boundaries and the adoption of core organizational design elements that were modeled after universities. As we will show, BTCO possesses an impressive publication record commensurate with its deep-seated ties to the academy. Today, BTCO is a research-intensive organization employing many Ph.D. scientists; it has successfully recruited senior scientists from prominent university appointments; and the internal organization of research at the company mirrors a biology department’s structure. We therefore regard BTCO as a straddler: it is a for-profit company that mimics certain features of a university. Indeed, the integrative activities of this and similar organizations have been a central force in the erosion of the boundary between for-profit and open Science.

The general concern of our paper is the relationship between publishing, the allocation of rewards within the company, and the structure of the communication network inside and beyond the borders of the organization. We ask two primary questions. First, at the researcher level, what are the effects of publishing on discretionary compensation? Or, put differently, does the firm pay scientists to contribute to open Science (cf. Stern, 2004)? Second, how does publishing influence the architecture of communication networks inside and beyond the boundaries of BTCO? To address these questions, we exploit a unique data archive that includes demographic, publication, and compensation information for all researchers in BTCO. In addition, although for a shorter duration of time that will only permit analysis in the cross section, BTCO has provided

daily downloads of all electronic mail for the members of its research division. These electronic correspondences enable us to observe the correlates of publishing on the shape of the within-firm network, as well as basic characteristics of the interaction patterns between members of BTCO's research staff and scientists at universities.

We emphasize three findings. First, BTCO does reward successful publishers. Regressions with person fixed effects show that publication success increases the bonuses that researchers' receive in a given year. Next, we utilize email data to examine the networks of publishers relative to non-publishers. Using these data, we report three results: first, prolific publishers are the recipients of a greater number of the messages sent by their immediate supervisors. Thus, not only do they receive more remuneration, publishers attract greater shares of their managers' attention than do non-publishers. Second, researchers who publish have significantly more correspondents in universities. Using email data, for the first time we are able to provide direct evidence that publishing correlates with a company's access to the informal networks of the broader scientific community.

The third finding, however, intimates a trade-off: there is a negative relationship between researchers' publication counts and their centrality *within* the BTCO email network. This result was unanticipated. Given BTCO's heritage and values, its pro-publication policy, and the apparent priorities for allocating managerial attention, we reasoned that researchers' standing in the academic community would reach inside the company to order its internal status hierarchy. Although these considerations suggest that prolific publishers will be central in the company's communication network, our findings imply an offsetting process: as boundary spanning researchers become increasingly embedded in the academic community, they may migrate to the periphery of the internal BTCO communication network. This result, we believe, raises a challenge for maximizing the benefits of boundary spanning: in a world of widely distributed scientific expertise, the individuals within an organization who are most well networked beyond its boundaries are precisely those people who would ideally occupy central positions within the

firm. Yet, it is these very same individuals who seem to shift the locus of their interaction towards communities beyond the boundaries of the firm.

The paper proceeds as follows. Section II reviews the some of the literature on distributed knowledge production and absorptive capacity, and the implications they have for the motivations and consequences of open publication policies in the private sector. The third section develops three hypotheses. Section IV presents data sources and measures, followed by the findings in Section V. The final section concludes and discusses implications for future research.

II. Publishing, Boundary Spanning, and Social Networks in the Private Sector

Two related insights frame the literature on the publication strategies of private-sector organizations. First, in science- and technology-based industries, the knowledge base that is the foundation for innovation can be very broadly distributed—so much so that Powell, Koput and Smith-Doerr (1996) conceptualize the locus of innovation as residing in networks, rather than within the boundaries of single organizations (or, for that matter, even single organizational forms). In contexts such as biopharmaceuticals, software development, medical devices, and microelectronics, innovation is a process of spotting and borrowing: actors must spot discoveries that are pertinent to them and then borrow these insights to seed their own, internal development efforts. The second idea is absorptive capacity (Cohen and Levinthal, 1990). To identify and assimilate externally developed ideas, organizations first need to create the capacity to absorb. This is accomplished by investing in basic research to cultivate scientific and engineering understandings, and by encouraging researchers within the organization to connect to ideas that are developed beyond it.

These two considerations—the diversity of participants in the innovation ecosystem and the need for absorptive capacity—are major considerations in for-profit firms’ decisions to publish scientific findings. Moreover, their implications extend to the possible adoption of a set

of human resource practices to manage in-house researchers (Cockburn and Henderson, 1998), as well as to optimal structures of communication within and across a company's boundaries.

II.a The Locus of Innovation. In macro-level theories of innovation, scholars see science and technology as collective endeavors. Historical and evolutionary perspectives view innovation as a process in which new discoveries are improvements to, or novel combinations of, antecedent ones (e.g., Schumpeter, 1942; Basalla, 1988; Rosenkopf and Tushman, 1994). Building on this understanding, those who study the sociology of technology employ the metaphor of a “seamless web” to describe the multiplex relationships among participants in the development of any technical field (Hughes, 1987; Pinch and Bijker, 1984). A hallmark of this work, and of historical and sociological characterizations of the innovation process in general, is its emphasis on the relational context in which innovation unfolds (Podolny and Stuart, 1995)—new discoveries are never regarded as *de novo* creations; even path-breaking inventions emerge from antecedents that fall within the continuity of an interconnected set of ideas.

The canvas painted in this broad-brushed work aligns with findings from analyses of the innovation process in contemporary science- and technology-based industries. For example, in a set of empirical papers, Zucker and her colleagues illustrate the dependence of companies in the biotechnology industry on the discoveries of scientists at universities and research institutes (Zucker and Darby, 1996; Liebsekind et al., 1996). In a case study that exploits bibliometric data, Liebsekind et al. (1996) demonstrate two biotechnology firms' use of external social networks to source scientific discoveries through entry into multiple, collaborative research projects with academic scientists. These authors argue that companies in this science-based industry rely on external collaborators to efficiently “prospect” for external developments in an increasingly vast scientific landscape. In the context of a present-day industry, these authors demonstrate that organizational innovation is anything but self-contained; companies heavily rely on external collaborators to develop new technology.

Drawing us back to the macro consequences of actor-level efforts to build connections with other participants in a technical arena, Powell et al. (2005) illustrate the implications of diffuse expertise for the collaborative structure in the overall organizational field in biotechnology. They depict the evolution of the network among firms, universities, research institutes, and financiers, and the changing rules of attachment that appear to drive the structure of the field-wide network over time. These authors observe that in a growing set of technical and scientific fields, a central task for innovators and entrepreneurs is to devise a strategy for developing points of contact with the individuals and organizations that collectively architect a field of ideas (Podolny and Stuart, 1995; Audia and Rider, 2005).

II.b Absorptive Capacity. In what is now one of the most familiar ideas in the literature on organizational learning, Cohen and Levinthal (1989, 1990) argue that the background knowledge required for innovation is cumulative: new ideas are aptly assimilated only if foundational understandings are in place. For multiple reasons, possessing a thorough understanding of the state-of-the-art is necessary for innovation in many fields. First, background knowledge is a prerequisite for opportunity identification. Without detailed knowledge of a particular area, actors may not understand the significance of new opportunities in the area and may even lack the ability to formulate feasible questions to explore. Second, even if new opportunities were recognized, a lack of sufficient expertise effectively excludes the ability to exploit external developments to further internal innovation objectives.

If we accept the premise that the development of knowledge is widely distributed in many current fields of scientific or technical endeavor, then absorptive capacity hinges on a means to reach beyond the boundary of an organization to screen, monitor, and assimilate external developments that are deemed relevant. For example, much like the studies set in the biotechnology industry, Cockburn and Henderson (1998) propose that ties to universities are an essential element of the R&D process in the pharmaceutical industry; they find that R&D productivity is correlated with having staff scientists who coauthor with university faculty. Lim

(2009) pushes the link between absorptive capacity and external relationships one-step further: in a study of the diffusion of copper interconnect technology among semiconductor producers, he describes absorptive capacity specifically in terms of connectedness. Lim argues that external connectedness itself determines absorptive capacity. Of course internal R&D remains important, but its function is largely to enhance a firm's access to external knowledge sources.

Organizations enact multiple, often concurrent and complementary strategies to achieve external connectivity in domains of distributed innovation. First, they enter myriad, formal collaborative agreements to exchange, license, or co-develop technologies (e.g., Ahuja, 2000; Stuart, 2000; Schilling and Steensma, 2001; Katila and Mang, 2003), which may assemble into a dense alliance network within communities of innovators (Powell et al., 2005; Schilling and Phelps, 2007). Second, knowledge traverses organizational boundaries through employee mobility (e.g., Almeida, Dokko, and Rosenkopf, 2003; Rosenkopf and Almeida, 2003) and through organizational members' participation in formal knowledge sharing venues, such as standard setting bodies and industry associations (Rosenkopf, Metiu, and George, 2001). A third avenue of interchange is through myriad, informal associations. These range from participation in open source communities to the cultivation of informal collaborative relationships between members of a focal company and other actors in the broader innovation arena.

Our analysis explores the latter phenomena, which has largely eluded study because of the obvious challenge of systematically observing such interactions. We consider the multifaceted consequences of a private sector firm's participation in open Science. Viewed narrowly, open publication is just a manifestation of a corporate policy to permit the selective disclosure of the firm's research discoveries and, in instances of co-authorship with researchers from other organizations, it provides an incomplete snapshot of the scientific collaborations in which the company is embedded. (The observed network is incomplete because much of the non-contractual collaboration—perhaps even the significant majority—yields outputs other than published articles, such as simple idea exchange or the sharing of research materials.) However,

we believe that the consequences of open publication are considerably broader: echoing the findings of prior work, a company's policy vis-à-vis publication may affect its ability to recruit and retain researchers, its decisions about the allocation of rewards, its capacity to foster a broad network of informal collaborators, and even the status ordering and social structure within the firm. We explore these implications in the following set of hypotheses.

III. Hypotheses

For some time, scholars struggled to understand what seemed a puzzling phenomenon—given the costs, why do companies permit employees to publish and present scientific and technical findings in the venues of open Science? The costs of publication are borne in at least three forms. First, substantial expenses are incurred in the consumption of employee time to craft research results into publications and to shepherd articles through peer review. In fact, given the sizeable time costs of writing and revising research papers, BTCO's current management has recently introduced policies to reduce the number of submissions to second- and third-tier academic journals.¹ Second, publication is disclosure. Although it is possible to time the submission of publications so that they do not interfere with patent filings, firms that publish unavoidably disclose a great deal of information about the focus of their research endeavors. Thus, because science is part of strategy in industries such as biomedicine, open publication is tantamount to a revelation of strategic intent.

Third, publication contributes to the conversion of firm-specific human capital to its general form, which in turn may increase employee mobility and bargaining power. When firms permit researchers to publish, they not only endow specific individuals with the credit for their discoveries; they also divulge this information to the public. It then becomes possible for

¹ BTCO management emphasized that they were not discouraging public disclosure of scientific findings. They continue to authorize conference submissions and to sanction presentations in a variety of venues, but they actively discourage the submission of these results to low quality journals. They simply perceive little value in the production of peripheral papers.

external parties to link a firm's technical developments to the specific individuals who contributed most to its creation. Efforts by competitors to poach talent may be an inevitable result.

What, then, are the compensatory benefits that offset these costs, and what do they imply for how the organization behaves? In our interviews at BTCO (the findings from which closely parallel those reported in Cockburn and Henderson (1998)), interviewees underscored two points. First, a permissive publication policy is an essential component of any strategy to recruit and retain the highest quality researchers, especially individuals who hold doctoral degrees. Second, our interviewees suggested that it is necessary to do more than just permit researchers to publish their work; employees of the firm also should be rewarded based on their standing in the larger scientific community.

This brings us to a larger point, which is that the labor market for top caliber researchers itself contributes to the blurred boundary between academic and commercial science. Because private sector firms must compete with universities and research institutes for new hires, firms attempt to create a university-like milieu to cater to the preferences held by the researchers whom they endeavor to recruit. After years in graduate school and, in many cases, additional training as post-doctoral fellows, candidates for employment will have extensive exposure to the norms and reward system in open Science. This means that potential recruits for whom firms will compete may value publications as a core element of their professional identity. Moreover, they are likely to view publications as the currency of professional achievement, and may prefer employment systems in which internal rewards reflect the professional esteem accorded to publication.

There is an additional benefit of tying compensation levels to publication outcomes. Not only may this be a matter of employee preference, but pegging rewards to publications potentially helps firms to resolve a perennial dilemma: how to evaluate and reward researchers

who work on very long-term and highly uncertain projects, the vast majority of which will fail to deliver revenues for the firm (and none will do so in the proximate future)? Under these circumstances, peer-reviewed publications provide a semi-objective method of evaluating performance to allocate discretionary compensation in a context in which the quality of research is difficult to assess, and effort is challenging to measure. We therefore hypothesize,

H1: Within BTCO, researchers' discretionary compensation will increase in their publication success.

If encouraging publication is necessary to recruit talented scientists, success in this activity is an essential component of building organizational members' external networks. In short, publications are the passkeys to the invisible colleges of the scientific community. When scientists publish important findings, they gain the visibility that leads to invitations to present their research at conferences and colloquia; they attract the interest of potential collaborators; they become nodes in discussion networks about new developments in their fields; and more generally, they establish the types of relationships that provide them access to the exchange of knowledge that constantly circulates in the networks of the profession. In the conventions of exchange in open Science, access to these networks both is contingent on contributing to the corpus of open science, and correlated with the importance of the contributions one makes.² At the *individual* researcher level, this implies that the extent of a scientist's embeddedness in external scientific networks likely will depend on his or her level of publication. We hypothesize,

² In addition to publications, BTCO has an express policy to share reagents with the external scientific community. The exchange of reagents and other research materials is another illustration of conformance to scientific norms that further contributes to the embedding of BTCO researchers in the broader research community. In addition to this indirect benefit, sharing reagents also enables BTCO to directly observe externally performed research that builds upon their proprietary materials, which is another low-cost mechanism to monitor new developments.

H2: Within BTCO, researchers who publish will occupy more central positions in informal scientific networks *beyond* the borders of the company.

Extrapolating from the networks of individual organizational members to their implications for the innovative activities of the overall company, the firm's incentive to adopt a pro-publication policy that furthers researchers' connections in the external scientific community rests in the hope that these ties will contribute to the accumulation of the firm's absorptive capacity. Of course, this is a *quid pro quo* in the decision to permit staff to publish—the organization itself ultimately hopes to benefit from the enhanced networks of its individual members.

The literature on absorptive capacity underscores, though, that an organization's ability to apply the knowledge of its staff toward further innovation depends on the patterns of communication and distribution of knowledge *within* the organization. Thus, there are internal, formal and informal organizational components to absorptive capacity: in science- and technology-based companies, investing in basic research is necessary, but it may be insufficient for persistent innovation. It also is important to develop informal and formal methods of knowledge transfer within the organization.

For example, Sørensen and Stuart (2000) argue that when organizations age, they tend toward an increased rigidity and an ossification of communication patterns among positions and roles within the firm. As the aging process unfolds, divisions within the organization take root and gradually impede the maintenance of the broad networks that facilitate innovation. In part because of these divisions, the rate and quality of innovation tends to decline with organizational age. Mowery and Rosenberg (1991) also underscore the importance of internal communication. They observe that the objective of basic research often is not to produce a good *per se*; it is to create the understandings that lay the groundwork for subsequently developing the good. But because these foundational understandings often are exploited in areas of the organization other

than the one in which they were developed, these authors admonition that the company's R&D may become "sterile and unproductive" when there are silos within basic research or between it and the rest of the firm.

Because publishing embeds the firm's researchers in external scientific networks, publishing scientists are in some sense at the boundary of the firm. Their focus is partly external, and the value they bring to the organization is enhanced when they build relationships in the broader research community. At the same time, the maximization of this value may well depend on the positions that externally networked scientists occupy in the communication flows within the organization (Allen, 1977; Katz, Tushman, and Allen, 1995; Hansen, 1999). The stronger and broader the networks that publishers have within the firm, the more the organization may benefit from their external ties.

In addition to the fact that publishing scientists may possess knowledge and contacts that will be sought by other members of the organization, there is reason to anticipate that researchers' standing in the broader scientific community will contour their social positions inside the firm. In general, the formation of a status hierarchy among any group of employees is likely to depend on demonstrations of competence in the dimensions of job performance that are most valued by coworkers (e.g., Podolny, 2005; Bothner and Godard, 2009). In the specific context of BTCO and companies similar to it, these organizations have been imprinted with the scientific values of their academic founders. Because these firms have cultures that embody many of the values of academic institutions, we anticipate an organic correlation between individuals' positions in firms' internal status hierarchy and their contributions to open Science, much as we would expect to observe in a university context, in which scholarly productivity gives shape to the local status hierarchy. Therefore, we anticipate that in a science-based firm in which staff implicitly values scientific achievement, the standing of organizational members in the broader scientific community partially molds the company's internal status hierarchy. We hypothesize:

H3: Within BTCO, researchers with successful publication records will occupy central positions in the firm's *internal* communication network.

IV. Data and Methods

a. Context. We set our quantitative case study in the biopharmaceutical industry. This industry has served as a fertile testing ground for much of the literature on the relationship between innovation and collaboration among individuals, organizations, and organizational forms. The company that we study, BTCO, is a first-generation biotechnology firm, founded more than 25 years ago. Since its inception, BTCO has continuously dedicated significant resources to in-house research, and today its research division employs hundreds of scientists. The mandate of the firm's research group, which is organizationally separate from its development arm, is to conduct basic and applied research to identify molecules that supply the company's drug development pipeline.

In line with the firm's historical origins and strong ties to the academic community, the internal organization of BTCO's research division resembles a university biology department. Researchers are subdivided into groups that map to scientific specializations, such as immunology, neurobiology, molecular biology, and oncology. These groups are then further divided into the firm's core organizational units, which are laboratories led by (and named after) individual scientists. Though we analyze different subsets of the data, the company provided current and some historical data on all members of the research division.

b. Publications. BTCO scientists have published extensively—in recent years, the firm's staff has produced well over 100 papers per year—and they have succeeded in placing some of their work in the preeminent outlets in life science publication, including *Science*, *Nature*, and *Cell*.

To measure the publication outputs of the individuals in the firm's research department, we collected all articles by BTCO authors that were indexed in the *ISI Web of Science*. We then hand matched the roster of research division employees to the list of authors on papers to correct for spelling discrepancies. Finally, we gathered information on whether or not papers were coauthored with non-BTCO individuals.³

C. Compensation and Rewards Structure. At BTCO, scientists are eligible for three forms of merit compensation. First, all members of the research division receive stock option grants. Second, the firm dispenses end-of-year bonuses that recognize employees' contributions to the company during the prior year. Over the course of the year, the department's total research bonus pool increases as pre-set milestones are met. At year end, managers are given a customized target bonus for each of their reports, which is determined by the size of the total bonus pool, the individual's salary band, and other responsibilities. After receiving a target bonus, managers adjust the target up or down to reflect perceived performance. Importantly, each laboratory is not forced into a normal curve, although BTCO's research division as a whole approaches one. Finally, a distinct bonus pool is distributed to "top contributors", who are the individuals judged to be in the top 5% of the performance distribution.

We combined the latter two numbers to create a "proportion of target bonus-received" for each scientist, which we use to test hypothesis 1, that publication success will influence bonus allocations. For the median individual in the dataset, end-of-year bonus is approximately 20% of their base salary.⁴

³ In the results we will report, we considered all contributors to a paper to be equivalent, regardless of their position within the author list. All of our core findings are robust to limiting publication counts to authors in the two most significant positions, first or last on the author list.

⁴ We can also decompose the two components of the annual bonus and separately analyze, (a) percent of target bonus, and (b) the probability of receiving a top contributor award in a given year. We find a similar effect of publication count on both outcome variables, although the latter cannot be reliably estimated with the inclusion of scientist-specific fixed effects.

d. Network Data. To map the network structure within and beyond the borders of BTCO's research organization, the company provided us with log files containing a record of all emails exchanged on the company's servers. These data were archived each day and then sent to us. We have taken two steps to insure the privacy of company employees. First, before transferring the email logs to us, BTCO's IT staff stripped the subject headings and email content from all files. Second, in constructing the dataset we analyze, after matching publications to individual names but before we merged in compensation or email data, the company assisted us in replacing all names with hashed identification numbers.

In meetings with senior leadership and rank-and-file members of BTCO, we were repeatedly told that BTCO is an "email place" and that a great deal of the research division's business is conducted over email exchanges on the company's servers. This assertion is consistent with the ebb and flow of email traffic in the data, which very much confirm our a priori suppositions about when communications would be most likely to occur in the company, and who in the organization is likely to be most active in the network. For instance, the average daily email volume among the members of our sample is 29-fold less on Saturdays and Sundays than it is on weekdays in a representative month. The average email volume of laboratory heads, who are akin to the leaders of small departments, is 28 percent higher than non-laboratory heads. These and other basic descriptive statistics closely conform to our priors about how the data would be distributed under the assumption that the vast majority of email interactions in the company are related to work, rather than purely personal interaction.

For all cross-sectional analyses, we used the email logs from either January or February 2009. Before aggregating the daily emails into a sociomatrix for the month, we deleted all messages with more than four recipients to cull broadcast mailings (Quintane and Kleinbaum, 2008). While this cut-point is arbitrary, the sensitivity analyses we have performed show that the network variables are highly correlated regardless of the cutoff, and the pattern of results holds across different assumptions.

We use the email data to construct four measures of individuals' network positions. First, using a detailed organizational chart provided by the company, we are able to identify the immediate supervisor of all individuals in the dataset. To analyze the amount of a supervisor's attention devoted to each BTCO scientist, we create a count of the number of emails that a supervisor k sends to a focal employee i , while controlling for supervisor k 's total sent email. We label this variable, "supervisor attention."

The email data we possess are limited to messages that reach BTCO's servers. For internal communications, we have detailed information about senders and recipients, but we have much more limited information about individuals outside the firm who communicate with BTCO researchers. For all incoming messages, however, we were able to retain senders' exact email addresses. This information enables us to construct, at the BTCO-researcher level, a measure of in-degree from scientists in universities. Specifically, we count each individual's unique number of email correspondents in which the partner's email address contains a *.edu suffix.⁵ We assume that these emails are a residue of ties between BTCO scientists and colleagues in academic institutions, and that the greater the *.edu degree score for an individual in BTCO, the better networked he or she is likely to be in academic circles. When we present the results, we will report evidence which suggests that indegree from *.edu email address does indeed appear to capture collaborative interactions with scientists in universities.

Lastly, we use the *internal* BTCO email network to construct two measures of centrality within the firm. First, we create a symmetrized adjacency matrix for all BTCO research employees. Although electronic mail links are directed ties (indeed, we differentiate between sender and receiver to calculate the measures of supervisor attention and *.edu indegree), the

⁵ Restricting the count to *.edu messages effectively means that we undercount the number of interactions between BTCO staff members and scientists in universities. This is because non-US-based universities and research institutes use different email suffixes. To ameliorate the undercounting, for the larger research institutes (e.g., the National Institutes of Health) and for major non-U.S.-universities, we have hand-coded senders' email addresses to incorporate correspondents from these institutions in the *.edu tally.

vast majority of communicating pairs within the company participate in reciprocal interactions. Thus, for the purpose of identifying researchers' centralities in the intra-BTCO network, we treat correspondences as symmetric ties. We use this matrix to calculate betweenness and eigenvector centrality. Our third hypothesis anticipates a positive association between publication outputs and these two measures of centrality within BTCO.

V. Results

We begin our discussion of results with a set of descriptive statistics. Table 1 reports the recent history of publishing and patenting at BTCO. These statistics provide interesting insight into the scientific strategy of the firm. First, the company has published papers and filed patents in a ratio of approximately 2:1 favoring papers. Second, half of the scientific articles BTCO has published during the past seven years have been coauthored with researchers at universities. In turn, many of these articles have been written with collaborators who are affiliated with very prestigious universities in the life sciences.

****Insert Table 1 About Here****

Table 2 lists, in order of frequency, the universities with which BTCO staff have coauthored the greatest number of papers and with which they have exchanged the most electronic messages. There are two points of note in this table. First, the table underscores the fact that BTCO scientists have established relationships with collaborators and colleagues at many elite institutions in the academic life sciences. And second, while there is clearly overlap between the rosters of institutions where the firm has informal interactions and coauthors, there are differences as well. The complete list of communication partners in universities is both broader and different from the roster of coauthors' affiliations. Thus, although the complete

coauthorship graph does inform the true information exchange network in which BTCO is embedded, it both under-represents and misrepresents the network's shape, reach, and density.

Insert Table 2 About Here

To provide a greater sense for these data, in January 2009 a lower bound on the number of unique correspondents who sent electronic mail messages to members of BTCO's research staff from *.edu email addresses was 1,389. As previously noted, this number excludes communications from individuals at many non-U.S. universities and small research institutes, so the actual number of correspondents in the external scientific community was considerably higher than this level. Moreover, when we break down the aggregate number by type of researcher, we find that among BTCO's staff, publishers who hold doctorates are, by a wide margin, the most extensively networked to scientists at American universities. For instance, Ph.D. holders who have no publications in 2008 received emails from an average of 3.1 unique individuals at *.edu addresses in January 2009, while Ph.D.s who have one or more publications received messages from 8.2 distinct university addresses that month. For the 14 individuals who are the most prolific publishers in the firm, this number almost doubles—they engage with an average of 14.4 *.edu contacts. For the 6 most prolific publishers, this number increases again to an average of 21.7 unique *.edu contacts. This correlation between publishing and communication with academic scientists strongly suggests that these correspondences reflect work-related interactions between BTCO researchers and colleagues in universities, rather than personal communications.

Panels A, B, and C of Table 3 present descriptive statistics for all members of BTCO's research staff in the full panel (without email-based covariates) as well as for two subsets of the data in the 2009 cross section (with email). Panel (A) summarizes all staff members in the full panel. Panel B presents descriptive statistics for the 2009 cross section only for the members of the research division whose highest degree is a BA or an MA. Panel C, which is the subset of the

data we analyze most extensively, describes the 2009 cross section for doctoral degree holders only.

Perhaps most notably, consistent with Smith-Doerr's (2004) examination of gender issues in the scientific workforce in the biotechnology industry and with National Science Foundation data on the gender composition of recent Ph.D. cohorts in the life sciences, women actually makeup a slight majority—about 54%—of the scientific staff at BTCO. Panel C shows that even among the doctoral degree holders, women comprise 46 percent of the sample. Turning to publication data, Panel C shows that in 2008, approximately one third of the doctoral degrees holders published one or more papers, and 7.5 percent published three or more articles in that year. For the estimations that follow, we bin publishers into two categories, low (one or two papers published in the previous year) and high (greater than two papers), to allow for a flexible specification of the effect of publication on the outcome variables. In all regressions, the omitted category is zero publications.

Recall that researchers' target bonus payouts are centered on 1.05 to reflect the addition of compensation from the "key contributors" pool. Given the range in Panel A, from 0 to 2.14, it is clear that managers' perceive significant variation in their reports' performance. Figure 1 illustrates the overall distribution of target bonus, which is approximately normal for the research division.

****Insert Figure 1 About Here****

Table 4 presents the first set of regression results, which examine the effect of publication on researchers' bonuses. For these regressions, no email data are required, which enables us to exploit the full 7-year panel that includes compensation, publication, and reporting structure data. In this and subsequent estimations, we analyze two different cuts of the data. In the columns labeled "Non-PhDs", the data are limited to members of the research organization that hold bachelors and masters degrees. In the columns labeled "PhD Only", the data are limited to

Ph.D. holders. If our hypotheses are correct, we expect that the findings will be much stronger for the subsample of doctoral degree holders. Obviously, these individuals are the primary drivers of the firm's publications, and their rewards, internal, and external networks should be much more consequentially influenced by publication activities than would be the technicians and research assistants who support their work.

****Insert Table 4 About Here****

The results strongly support the first hypothesis. First, note that the effect of publications indeed is much stronger in the PhD sample. We report the results for both samples in Table 4; in the subsequent tables, however, we limit the analysis to PhD-level scientists. Across all the regressions, we find associations between publishing activity and the outcomes of interest for those with doctorate degrees, but we find weak or no associations for the BA and MA sample. We take this general pattern of results to be confirming evidence for the predictions; if measurement issues or spurious associations were driving the results, it is likely that we would find significant parameter estimates in the non-PhD sample as well as in the group of doctoral degree holders. Our confidence in the interpretations of the results we present is bolstered by the lack of significant correlations in the non-PhD sample.

Columns (1-3) show the null results for publications in the sample of bachelors and masters degree holders. Columns (4-6) then repeat each of these regressions for the subsample of PhDs. In these regressions, there is evidence of a monotonic increase in the effect of publication on discretionary bonuses across the three levels of publication. Column (5), which includes just a publication/no publication indicator variable, shows that, within person, there is 6.5 point increase in target bonus in the years in which the focal individual has published one or more papers relative to years in which she has not. Column (6) incorporates the three-category specification of publication level, and here the coefficients suggest a monotonic increase in target bonus across levels of article outputs. Individuals in the low publication bin are estimated to earn

a 4.7 increase in target bonus relative to years in which they have no publications, while those in the high publication category garner a 9.4 point increase.⁶

Table 5 columns (1-3) present the relationships between publications and the first measure of individuals' positions in the communication structure within the firm, the extent to which an employee receives a significant amount of the outbound email volume of his or her immediate supervisor. In this table, the dependent variable is the number of emails that supervisor k sends to focal employee i . Note that because we do not have a multi-year panel of email data, all of the regressions in this (and subsequent tables) are estimated in a cross section—we correlate 2008 publication records with January 2009 email network data.

Insert Table 5 About Here

Among the control variables, there is a relatively steep, negative effect of organizational tenure. Presumably, the requirement for frequent interaction between supervisors and reports declines as common understandings and mutual expectations for a working relationship evolve over time. In a finding that we regard as reinforcing results on the effect of publication on target bonus, Columns 2-3 of Table 5 shows that not only do publishers garner greater bonus payments; they also monopolize a higher amount of their supervisor's attention. Among the Ph.D.s in the firm, the parameter estimates suggest that, after adjusting for salary grade, gender, and tenure, publishers attract an additional 55% of a supervisor's email sent volume relative to non-publishers. In contrast to the remuneration results, however, the parameter estimates for the two levels of publication are roughly comparable in Table 5. Although there is no statistical difference between low and high publishers, the fact that publishers receive more attention from their supervisors is another indication of the value the firm places on scientific productivity.

⁶ When we allow both within-researcher and cross-sectional variation to inform the parameter estimates—that is, when we exclude the person-specific fixed effects—the estimated coefficient on “high publication count” increases to 10.9 points.

To test hypothesis 2, that publishers within BTCO have a broader set of informal ties to the external scientific community, columns (4-6) report quasi-maximum likelihood Poisson estimates of the count of university indegree—a count of BTCO researchers' number of distinct correspondents with *.edu email addresses. Among the control variables, we find no effect of gender or tenure, but unsurprisingly individuals who head labs are more likely to correspond with academic scientists. Column (5) in the table shows a positive and significant effect of the publication indicator on the *.edu degree score, and Column (6) reveals that here too, there is a monotonic effect across the three levels of publication counts. BTCO researchers in the high publication category have indegree scores from senders at universities that are estimated to be 1.92 times the rate of non-publishers, and the corresponding estimate is 1.59 for those in the low (one or two article) publication category.

The final table examines the determinants of individual's network centralities in the firm's internal email network in January 2009. The dependent variable in Table 6, columns 1-3 is a scientist's betweenness centrality in the BTCO network, and it is a researcher's eigenvector centrality in columns 4-6. Given the skewed distribution of centrality scores, we again employ a Poisson quasi-likelihood estimator. Because the Poisson model is in the linear exponential family, the coefficient estimates remain consistent as long as the mean of the dependent variable is correctly specified (Gourieroux et al., 1984). Moreover, the PQML estimator can be used for any non-negative dependent variables, whether integer or continuous (Santos Silva and Tenreyro, 2006).

Insert Table 6 About Here

For both outcome variables, the (cross sectional) results indicate that network centrality correlates positively with firm tenure, but at a decreasing slope. Centrality does rise in company tenure for the vast majority of the observed range of company tenure; betweenness centrality is estimated to reach a maximum in the 28th year of tenure, while eigenvector centrality hits a

maximum in the 22nd year of tenure. (In the PhD-only sample in which we estimate these regressions, 22 years is beyond the 98th percentile of the tenure distribution.) Interestingly, *ceteris paribus*, men have statistically *lower* levels of both betweenness and eigenvector centrality than do women. This finding, though, is consistent with one recent study showing that women maintain broader and larger electronic mail networks than do men (Kleinbaum, Stuart, and Tushman, 2008).

Table 6 also contains a surprising finding. Our third hypothesis forecasts a positive association between individuals' publication counts and their centralities within the internal BTCO network. Prolific publishers can be easily singled out for the quantity and quality of their science. We reasoned that in a research organization with deeply ingrained scientific values and a belief in the power of novel science to drive the drug development pipeline, there would be a positive relationship between an individual's standing in the external scientific community and his or her centrality in the internal company network. However, not only do we reject the hypothesis that the most active publishers occupy the most central positions in the firm's network, we in fact observe the opposite effect—frequent publishing is negatively correlated with individuals' network centrality. Relative to non-publishers, prolific publishers are estimated to have a 46% and a 29% decrease in their betweenness and eigenvector centrality, respectively (Columns 3 and 6).

What might account for this unexpected finding? As we reconsider the possibilities, we are reminded of McPherson, Popielarz, and Drobnic (1992) ecological analysis of individuals' voluntary group ties. In their analysis of the dynamics of voluntary group memberships, McPherson et al. find that group attachments are the shifting outcome of a few competing forces: the number and cohesiveness of one's ties within a group, versus the strength of ties to members of different groups. These authors show that turnover in group membership depends on the balance of these relational forces. Viewed in this light, the association between internal BTCO centrality and publication counts becomes understandable. As a direct function of their

contributions to open Science, prolific publishers within the firm appear to strengthen and extend their relationships beyond it. In consequence, they are naturally drawn toward identification with and greater commitments within the external research community. It is possible that this increase in external embeddedness occur at the expense of certain activities and interactions within the company.

If this supposition is correct, then this may be an additional trade-off associated with pro-publication policies. On one hand, the evidence shows that publication activity indeed correlates with BTCO members' external connectivity, as proxied by *.edu indegree. But if a drop in engagement in internal communication is a byproduct of the external ties gained through publication, this raises the specter of a search-transfer-type paradox as identified in Hansen's (1999) work. Either because the act of publication itself results in time constraints that crowd out internal interactions that otherwise may have occurred, because publishing spawns relationships that draw researchers into the collaborative networks in academe and these connections crowd out intra-company communications, or because successful publishers value an identity that is more purely associated with academic science and therefore prune certain internal activities from their routines, prolific publishers may begin to withdraw from some internal interactions. In effect, those who are most able to identify promising external developments because they invest in developing optimal networks to search for information may, in so doing, compromise the within-organization networks that facilitate the internal transfer of knowledge.

VI. Discussion and Conclusion

We began this paper with the observation that innovation increasingly occurs in the context of diverse communities of actors, who are interconnected in a rich, if variegated, set of networks. In scientific fields such as biomedicine, the individuals in these networks are members of heterogeneous organizations, the boundaries of which often can be extremely porous.

Exploiting a combination of data sources including publicly available information on scientific publications and proprietary data on electronic mail communications and human resource records, this paper examines one company that has been a long-time producer of significant scientific advances in the life sciences. We use these data to examine the influence of scientist-level publications on internal performance outcomes, including bonuses and the allocation of managerial attention, and also the effect of publication on the networks of scientists within and beyond the borders of the company.

There are a few findings to highlight. First, collaboration in the form of coauthorship is a common means of interaction between researchers within BTCO and members of other organizations, including universities, research institutes, and companies. However, BTCO's email server logs expose a second fact; researchers in the company maintain a much broader set of informal interactions with other members of its innovation ecosystem. These ties connect internal researcher to actors from a different and broader array of organizations, including domestic and foreign universities, research institutes, and other companies, than do the more limited coauthorship ties. Moreover, the degree centrality of researchers within BTCO in the network of *external* ties is very clearly linked to their level and quality of contributions to open Science via publication. In a set of unreported exploratory analyses, we further unpack this finding. Using data on the quality of the journals in which BTCO scientists publish, we created journal impact factor (JIF)-weighted publication count. We find that a strong, positive correlation between the quality of researchers' publications and their *.edu indegrees.

Although we observe a robust correlation between publishing levels and indegree centrality in the *.edu email network, in the cross section we cannot disentangle causality. In all likelihood, there is a reciprocal relationship between these two variables: connectedness to university-based researchers may facilitate active publishing by exposing members of BTCO's scientific staff to new ideas and potential coauthors. Conversely, publishing draws attention to an individual's work and establishes a researcher's location and credentials in the exchange system

of science, which in turn facilitates the building of a professional network. Given the limits of the data available to us, we must leave the question of the balance of causality to future research.

In addition to sorting out issues of causation, the findings we present raise a few avenues for subsequent research. First, if it is indeed the case that pro-publication policies at companies contribute to the conversion of firm-specific human capital to its general form, there are labor market implications of this practice. For instance, we would expect to observe the heavy use of retention strategies targeted at high publishers (including the adoption of internal norms for the allocation of discretionary compensation, as we have illustrated in this paper). In addition, it is likely that between-firm mobility rates will be highest for active publishers because recruiters outside the firm readily observe these individuals' scientific achievements. BTCO grew rapidly during the period we analyze and turnover rates are too low to precisely estimate the relationship between publication and mobility, but we believe that this relationship is of considerable interest. If in fact active publishers enjoy more external job opportunities, this becomes an important consideration in firms' decisions to encourage publications.

A second avenue that merits further scrutiny is the unanticipated finding that prolific publishers are less central in the internal firm network. Once again, the cross sectional data and the lack of any exogenous sources of variation do not enable us to sort out the causal order between publishing and internal network position. Still, as the allied literatures on absorptive capacity, boundary spanning, and knowledge management all emphasize, the wiring of an organization's internal network is vital to its ability to capitalize on its knowledge base, regardless of the split between internal development and external scouting in the creation of knowledge within the firm. Therefore, we believe that the unanticipated but provocative finding that the most prolific publishers have somewhat more peripheral positions in the internal network than would otherwise be the case warrants closer inspection. If this finding is replicable, it may imply an additional trade-off in the decision to adopt an open publication strategy, as external connectivity comes at the expense of the internal networks that are required to capitalize on it.

Moreover, this result also raises the question of what management strategies and incentive systems might be created to ameliorate any trade-off between the creation and maintenance of networks that are optimal for external search for knowledge versus those that facilitate internal transfer.

Finally, although it is beyond the scope of this analysis, the result on the association between publications and internal centrality raises interesting questions about who communicates with whom inside the firm? Do interactions within the research organization tend to sort within strata of publishing levels (i.e., are prolific publishers prone to interact with one another, forming cliques in the communication structure)? Exactly how does the maintenance of external relations alter the network structure inside the firm? For instance, if productive publishers reconfigure their intra-firm networks, are they more likely to curtail cross-laboratory interactions than those within their units of the organization? As datasets such as the one we have collected for this project become available, it will become possible to answer these and related questions. As well, we will gain further insight into the nature, consequences, and permeability of organizational boundaries in the modern, innovative organization.

Table 1: Descriptive Stats on Yearly Publishing (limited to individuals who appear in this dataset)

| Year | # of Patents | # of Papers | Papers w/ Universities | Papers w/ "Top 5"+ | Papers w/ Industry | Papers in Cell/Nature/Science |
|------|--------------|-------------|------------------------|--------------------|--------------------|-------------------------------|
| 2001 | 83* | 210 | 108 | 45 | 32 | 5 |
| 2002 | 76* | 156 | 69 | 24 | 22 | 4 |
| 2003 | 77 | 150 | 74 | 27 | 27 | 6 |
| 2004 | 63 | 164 | 82 | 26 | 25 | 12 |
| 2005 | 77 | 149 | 78 | 25 | 29 | 5 |
| 2006 | 92 | 136 | 60 | 25 | 27 | 9 |
| 2007 | 26** | 161 | 89 | 36 | 27 | 10 |

*human genome patents were excluded from this count.

**incomplete data collection.

+ "Top 5" are collaborations with Harvard University, MIT, Stanford, UC Berkeley, or UCSF.

Table 2: Prevalent Institutions of Coauthors and Correspondents

| Rank Order | Coauthored Universities | Count | Email Correspondence in January, 2009 | Count |
|------------|-------------------------|-------|---------------------------------------|-------|
| 1 | UCSF | 102 | UCSF | 753 |
| 2 | Stanford | 79 | Stanford | 553 |
| 3 | Harvard | 71 | Salk Institute | 123 |
| 4 | UCLA | 48 | UCDavis | 117 |
| 5 | Duke | 34 | UC Berkeley | 98 |
| 6 | Yale | 32 | Yale | 82 |
| 7 | UColorado-Denver | 31 | U. of Iowa | 74 |
| 8 | UWashington | 30 | Harvard | 64 |
| 9 | UPenn | 24 | U. of Chicago | 58 |
| 10 | NIH | 22 | UCLA | 49 |

Table 3: Descriptive Statistics

Panel A: Pooled Cross-Section Descriptive Statistics (n = scientist-years = 1964)

| | Mean | SD | Min | Max |
|----------------------------|--------|--------|-----|------|
| Age | 39.210 | 8.704 | 22 | 69 |
| Male | 0.462 | 0.499 | 0 | 1 |
| Highest Education-BA | 0.368 | 0.482 | 0 | 1 |
| Highest Education-MA | 0.233 | 0.423 | 0 | 1 |
| Highest Education-PhD | 0.399 | 0.490 | 0 | 1 |
| Firm Tenure | 5.964 | 6.543 | 0 | 30 |
| Lab Head | 0.240 | 0.427 | 0 | 1 |
| No Publications | 0.768 | 0.422 | 0 | 1 |
| Low Publications | 0.136 | 0.343 | 0 | 1 |
| High Publication | 0.096 | 0.295 | 0 | 1 |
| Patents | 4.561 | 69.216 | 0 | 1670 |
| % of Target Bonus Received | 1.058 | 0.254 | 0 | 2.47 |

Panel B: Descriptive Statistics for non-PhDs: Year 2008 (n = 198).

| | Mean | SD | Min | Max |
|------------------------------|--------|--------|-----|-------|
| Age | 39.480 | 9.524 | 24 | 70 |
| Male | 0.394 | 0.490 | 0 | 1 |
| Highest Education-BA | 0.601 | 0.491 | 0 | 1 |
| Highest Education-MA | 0.399 | 0.491 | 0 | 1 |
| Firm Tenure | 7.722 | 7.052 | 1 | 31 |
| Lab Head | 0.045 | 0.209 | 0 | 1 |
| No Publications | 0.763 | 0.427 | 0 | 1 |
| Low Publications | 0.222 | 0.417 | 0 | 1 |
| High Publications | 0.015 | 0.122 | 0 | 1 |
| Supervisor Attention* | 11.497 | 13.409 | 0 | 65 |
| *.EDU Indegree | 2.273 | 2.603 | 0 | 13 |
| Betweenness Centrality | 0.082 | 0.131 | 0 | 1.010 |
| Eigenvector Centrality | 0.814 | 0.762 | 0 | 5.638 |
| % of Target Bonus Received** | 0.997 | 0.203 | 0 | 1.667 |

*N = 197.

**N = 194; for 2008 performance.

Note: Descriptive statistics are for BTCO research employees without PhDs. All publication measures are for 2008 authorships. Low publications is an indicator for 1 or 2 publications. High Publications is an indicator for 3 or more publications. All email network variables are generated using 2009 data. The supervisor attention variable does not apply to the full dataset because some supervisors have departed the dataset. The % of Target Bonus Received dataset is smaller due to the presence of recent hires.

Panel C: Descriptive Statistics for PhDs: Year 2008 (n = 191).

| | Mean | SD | Min | Max |
|------------------------------|-------------|-----------|------------|------------|
| Age | 40.251 | 7.059 | 27 | 64 |
| Male | 0.545 | 0.499 | 0 | 1 |
| Firm Tenure | 5.466 | 5.416 | 1 | 29 |
| Lab Head | 0.346 | 0.477 | 0 | 1 |
| No Publications | 0.675 | 0.469 | 0 | 1 |
| Low Publications | 0.251 | 0.435 | 0 | 1 |
| High Publications | 0.073 | 0.261 | 0 | 1 |
| Supervisor Attention* | 10.972 | 13.855 | 0 | 139 |
| *.EDU Indegree | 4.539 | 6.807 | 0 | 59 |
| Betweenness Centrality | 0.227 | 0.361 | 0 | 3.059 |
| Eigenvector Centrality | 1.921 | 2.129 | 0 | 11.763 |
| % of Target Bonus Received** | 1.139 | 0.282 | 0.6 | 2.143 |

*N = 178.

**N = 150; for 2008 performance.

Note: Descriptive statistics are for BTCO research employees with PhDs. All publication measures are for 2008 authorships. Low publications is an indicator for 1 or 2 publications. High Publications is an indicator for 3 or more publications. All email network variables are generated using 2009 data. The supervisor attention variable does not apply to the full dataset because some supervisors have departed the dataset. The % of Target Bonus Received dataset is smaller due to the presence of recent hires.

Table 4: Fixed Effects (Panel) Linear Model on Share of Discretionary Bonus

| Dataset | (1) Non-PhDs | (2) Non-PhDs | (3) Non-PhDs | (4) PhDs | (5) PhDs | (6) PhDs |
|----------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| Is an author | | -0.0011 (0.0146) | | | 0.0650** (0.0218) | |
| Low Pubcount | | | 0.0073 (0.0157) | | | 0.0467+ (0.0249) |
| High Pubcount | | | -0.0310 (0.0251) | | | 0.0942** (0.0290) |
| Patent Count | 0.0013** (0.0004) | 0.0013** (0.0004) | 0.0013** (0.0004) | 0.0002* (0.0001) | 0.0002* (0.0001) | 0.0002* (0.0001) |
| Tenure | 0.0058 (0.0052) | 0.0058 (0.0052) | 0.0055 (0.0052) | 0.0310** (0.0084) | 0.0291** (0.0084) | 0.0286** (0.0084) |
| Tenure-squared | -0.0003 (0.0002) | -0.0003 (0.0002) | -0.0003 (0.0002) | -0.0003 (0.0004) | -0.0000 (0.0004) | 0.0001 (0.0004) |
| Constant | 1.0479** (0.0755) | 1.0483** (0.0758) | 1.0479** (0.0758) | 0.9073** (0.0764) | 0.8756** (0.0766) | 0.0767** (0.0767) |
| R-squared | 0.04 | 0.04 | 0.04 | 0.09 | 0.11 | 0.11 |
| rho | 1 | 1 | 1 | 1 | 1 | 1 |
| F-test | 3 | 3 | 3 | 6 | 6 | 6 |
| Observations | 1181 | 1181 | 1181 | 782 | 782 | 782 |
| # of employees | 334 | 334 | 334 | 209 | 209 | 209 |

Note: Estimates are displayed as raw coefficients. All publication variables (Is an author, Low Pubcount, and High Pubcount) are binary (i.e., 0/1) indicators. All models include unreported salary-band and year dummies. Robust standard errors in parentheses below; + significant at 10%; * significant at 5%; ** significant at 1%.

Table 5: Impact of Publishing on Supervisor Attention and University Indegree- (QML-Poisson)

| Dataset | (1) | (2) | (3) | (4) | (5) | (6) |
|----------------------|---------------------------|---------------------------|---------------------------|--------------------------------|--------------------------------|--------------------------------|
| Dep. Var. | PhDs Sup. Attention | PhDs Sup. Attention | PhDs Sup. Attention | PhDs University Indegree | PhDs University Indegree | PhDs University Indegree |
| Is an author | | 0.436** (0.119) | | | 0.511 (0.200)* | |
| Low Pubcount | | | 0.432** (0.126) | | | 0.467* (0.220) |
| High Pubcount | | | 0.494* (0.248) | | | 0.656* (0.315) |
| Sup. Outvolume | 0.605** (0.125) | 0.578** (0.122) | 0.576** (0.123) | | | |
| Male | -0.140 (0.176) | -0.098 (0.159) | -0.098 (0.159) | 0.013 (0.166) | 0.055 (0.150) | 0.063 (0.152) |
| Laboratory Head | -0.244 (0.710) | 0.120 (0.652) | 0.124 (0.647) | 0.948** (0.268) | 0.821** (0.289) | 0.839** (0.293) |
| Tenure | -0.086* (0.039) | -0.130** (0.041) | -0.131** (0.044) | 0.081+ (0.047) | 0.029 (0.055) | 0.029 (0.054) |
| Tenure-squared | 0.003+ (0.002) | 0.005** (0.002) | 0.005* (0.002) | -0.003+ (0.002) | -0.001 (0.002) | -0.001 (0.002) |
| Laboratory size | -0.014 (0.044) | -0.027 (0.040) | -0.026 (0.040) | 0.036 (0.024) | 0.026 (0.025) | 0.025 (0.023) |
| Constant | -0.302 (1.108) | -0.133 (1.106) | -0.120 (1.117) | 0.049 (0.556) | 0.052 (0.581) | 0.049 (0.579) |
| Log-pseudolikelihood | -907 | -877 | -877 | -548 | -532 | -530 |
| Observations | 178 | 178 | 178 | 191 | 191 | 191 |
| # of lab clusters | 71 | 71 | 71 | 76 | 76 | 76 |

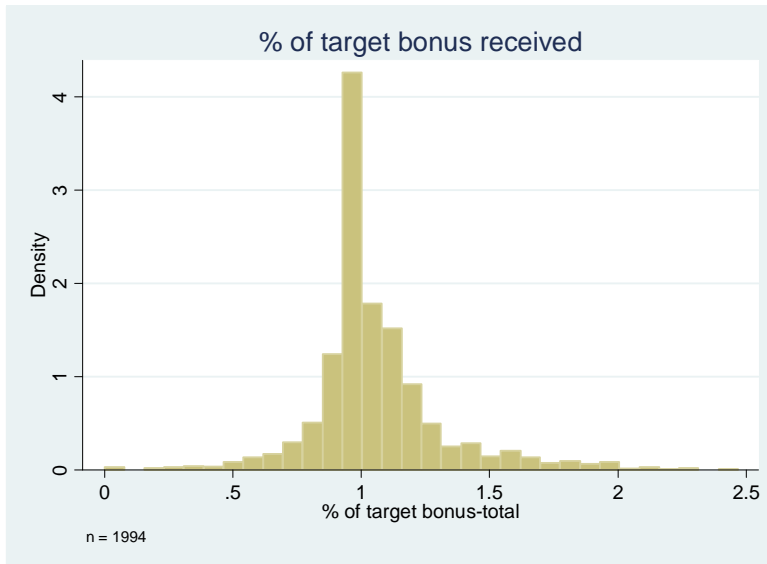
Note: Estimates are displayed as raw coefficients. The supervisor attention dependent variable is the number of messages received from the supervisor. All models include unreported salary-band dummies and division dummies. Robust standard errors, clustered by laboratory, in parentheses below; + significant at 10%; * significant at 5%; ** significant at 1%.

Table 6: Impact of Publishing on Betweenness and Eigenvector Centrality- (QML-Poisson)

| Dataset | (1) | (2) | (3) | (4) | (5) | (6) |
|----------------------|---------------------|---------------------|---------------------|--------------------|--------------------|--------------------|
| Dep. Var. | PhDs | PhDs | PhDs | PhDs | PhDs | PhDs |
| | Betweenness | Betweenness | Betweenness | Eigenvector | Eigenvector | Eigenvector |
| Is an author | | 0.193 (0.164) | | | 0.004 (0.132) | |
| Low Pubcount | | | 0.354* (0.161) | | | 0.091 (0.142) |
| High Pubcount | | | -0.614* (0.258) | | | -0.340+ (0.185) |
| Male | -0.405* (0.178) | -0.382* (0.173) | -0.399** (0.147) | -0.243+ (0.129) | -0.243+ (0.129) | -0.253* (0.117) |
| Laboratory Head | 0.503 (0.314) | 0.436 (0.313) | 0.418 (0.296) | 0.431 (0.272) | 0.430 (0.265) | 0.415 (0.263) |
| Tenure | 0.175** (0.053) | 0.160** (0.052) | 0.168** (0.047) | 0.068+ (0.035) | 0.068+ (0.036) | 0.070* (0.035) |
| Tenure-squared | -0.007** (0.002) | -0.006** (0.002) | -0.006** (0.002) | -0.003* (0.001) | -0.003* (0.001) | -0.003* (0.001) |
| Laboratory size | -0.029 (0.025) | -0.034 (0.025) | -0.031 (0.022) | 0.004 (0.025) | 0.004 (0.026) | 0.005 (0.025) |
| Constant | -0.905+ (0.466) | -0.859+ (0.496) | -0.933* (0.454) | 0.837* (0.423) | 0.838* (0.425) | 0.824* (0.403) |
| Log-pseudolikelihood | -83 | -83 | -82 | -277 | -277 | -274 |
| Observations | 191 | 191 | 191 | 191 | 191 | 191 |
| # of lab clusters | 76 | 76 | 76 | 76 | 76 | 76 |

Note: Estimates are displayed as raw coefficients. All models include unreported salary-band dummies and division dummies. Robust standard errors, clustered by laboratory, in parentheses below; + significant at 10%; * significant at 5%; ** significant at 1%.

Figure 1: Share of Discretionary Bonus



Note: Managers are provided a customized target bonus for each of their direct reports. This target is then adjusted to reflect performance. We present received/target bonus to reflect a weighted measure of performance in each year.

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