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Research Policy 32 (2003) 1695–1711

research policy

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The expanding role of university patenting in the life sciences: assessing the importance of experience and connectivity

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Received 15 July 2002; received in revised form 31 January 2003; accepted 13 February 2003

Abstract

We extend debates about the sources of university capabilities at research commercialization. Drawing upon quantitative data for a panel of 89 research-intensive US universities and interview data from two academic licensing offices, we model the relationship between technology transfer experience, embeddedness in biotechnology industry networks, basic science quality and capacity, and citation impact measures of university life science patents. Technology licensing officers draw upon the expertise of corporate partners to evaluate the potential impact of invention disclosures. The information gleaned through network ties to industry enables well-connected institutions to develop higher impact patent portfolios. Reaping the benefits of such connections, however, requires experience in balancing academic and corporate priorities to avoid the danger of 'capture' by industrial interests as overly tight connections limit patent impact. This pattern of diminishing returns to connectivity is robust across multiple citation measures of patent quality.

Keywords: University patenting; Research commercialization; Technology transfer; Network embeddedness

1. Introduction

The explosion of academic patenting in the last two decades has spawned an accompanying upsurge in scholarly analysis. Investigations of university intellectual property (IP) have ranged from textual exegesis of matched scientific publications and patents (Myers, 1995) to sophisticated econometric analyses of the total factor productivity of university licensing endeavors (Thursby and Thursby, 2002). In between these disciplinary poles lie a number of studies that examine the increase in university patenting, while considering the relationship between increasing patent volume and the impact of new innovations.

Several general trends are apparent in this field of research. Investigators interested in the causes and consequences of increased academic commercialization have focused on the evolution of an institutional regime that merges academic and commercial reward systems (Owen-Smith, 2003; Owen-Smith and Powell, 2001a). Others have emphasized the role of early patenting success in explaining later intellectual property development, suggesting that federal policy changes did not initiate the trend of increasing academic interest in IP (Mowery et al., 2001). Both lines of work suggest that growing commercial engagement

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doi:10.1016/S0048-7333(03)00045-3

has not, thus far, altered the research culture of universities so as to privilege applied orientations at the expense of basic science.[1]

A complementary line of inquiry has examined the relationship between the quality and volume of university patent outputs. Drawing on a patent and citation database developed and maintained at the National Bureau of Economic Research (NBER) (Hall et al., 2001a), economists have generated citation-based measures of patent importance and generality that have proven useful for comparisons of academic and non-academic patents. A key component of every issued patent is the list of prior art upon which the protected innovation depends. The number of citations received by a given patent indicates its impact on later technology and can thus serve as a proxy for its market value (Hall et al., 2001b; Trajtenberg, 1990). Drawing on this data, two research groups have investigated the relationship between the quality and impact of university patents.

Henderson et al. (1998) compare university-assigned patents to a 1% random sample of all US utility patents, finding that the average impact of university patents declined over time with increasing patent volume, and that the impact gap between academic and non-academic patents was smallest for biomedical technologies. This result has two possible implications; one based on inexperience, the other on a shift in goals. We consider each in turn.

In the wake of the 1980 Bayh–Dole act, an increasing number of universities rushed to patent. In their efforts to commercialize the stock of university knowledge, these inexperienced institutions may have filed for IP protection indiscriminately. These efforts would have increased the volume of university-assigned patents while limiting their average impact. Alternatively, increased academic concern with commercial science may have changed the mix of research at universities, heightening the salience of efforts to develop applications and diverting focus from early stage basic research. To the extent that early university patents were highly cited because they broke new ground outside the established paths of commercial innovation, shifting research priorities on campus would result in lower impact patents.

Mowery et al. (2001) find that for a sample of three institutions (Columbia, Stanford, and Berkeley), academic patenting has not changed the orientations of university scientists. Subsequently, Mowery and Zeidonis (2003) examined patents issued to both experienced and inexperienced universities and concluded that aggregate declines in university patent impact are largely the result of entry rather than of transformations in mission, providing support for one of Henderson et al. explanations for declining university patent impact. Drawing on a later time series, Mowery et al. (2002) find that the citation impact of patents assigned to inexperienced (entrant) universities increases in the early 1990s, suggesting that new patentors learn over time to identify and prosecute more valuable intellectual property.

Previous researchers have not, however, been able to specify the mechanisms by which universities learn to commercialize research and develop the capacity to patent effectively. Possible explanations include cumulative patenting know-how, dedicated administrative staff for technology transfer, and early contractual ties to a patent management firm (Research Corporation Technologies); however, none of these factors account for the changing rates of citation to patents issued to entrants (Mowery et al., 2002). Mowery et al. (2002, p. 88) find clear indications of learning by entrant universities, but conclude with a call for further research, speculating that "... a more diffuse learning process may underpin our lack our results."

We enter this discussion with university level data that sheds more direct light on the questions pursued by Henderson, Mowery and colleagues. We focus specifically on life science patenting by "research one"[2] universities in order to integrate NBER patent citation indicators (Hall et al., 2001a) with information on the volume and citation impact of basic and clinical life science publications. We add data that reflect the

[1] There may, however, be important and unanticipated second-order effects of increasing university research commercialization, such as new career trajectories, rivalries based on industrial affiliations, inequalities across research units, and more influence exerted by commercial firms on university research agendas (Powell and Owen-Smith, 1998; McCray and Croissant, 2001; McSherry, 2001; Nelson, 2001; Owen-Smith and Powell, 2001b).

[2] "Research one" is a designation of research intensity that was previously applied to universities by the Carnegie Foundation. In order to qualify as a research one institution, a campus had to receive at least US $40 million per year in federal R&D funding, while granting at least 50 doctorates.

differential positions of universities in contractual networks involving science-based biotechnology firms. These campus-level measures illuminate several possible mechanisms by which universities might learn to patent, while providing direct insight into the relationship between academic and commercial science on research-intensive university campuses. Our focus is on university capabilities; we do not tackle the larger issue of whether university patenting facilitates or hinders scientific and technological progress.

We supplement our quantitative analyses with excerpts from interviews with technology licensing officers, research administrators, and life science faculty on two university campuses.[3] Taken in conjunction with our inferential findings, these narrative data enable us to propose organizational mechanisms that underlie changing university capacities to patent.

We begin by discussing our data sources, emphasizing the points of convergence and divergence with the existing literature while developing some general propositions regarding the processes by which research universities learn to patent in the life sciences field. We then turn to a more formal discussion of our methods and models, and a description of the fieldwork that supports our use of interview data. Next we present findings for a set of regressions relating our organizational variables to counts of issued patents and citation-based measures of patent impact. Interpretation of those models will rely both on the propositions we develop and on insights derived from our interviews.

2. Accounting for life science patenting at universities

Commercial activity in the life sciences has led the recent explosion in patenting and licensing on US university campuses. At most universities, the bulk of both issued patents and revenues result from innovations in the biomedical field (Henderson et al., 1998; Mowery et al., 2001; Powell and Owen-Smith, 1998, 2002). By 1998, nearly half (49.5%) of all patents issued to research-intensive US universities were based on life science innovations. The increase in biomedical patenting on campus, however, may be part of a larger phenomenon. The commercialization of academic life science research is deeply intertwined with the emergence of a new industry, biotechnology, which had its origins in university labs. As the industry evolved, its ties to the academy deepened with 'star' scientists playing central roles in new biotechnology firms (Zucker et al., 1997) and in the transfer of new knowledge from universities to firms (Zucker et al., 2002).

Academic technologies are central to the R&D efforts of these small science-based firms, and universities are central players in the inter-organizational networks that constitute the industry's 'locus of innovation' (Powell et al., 1996; Owen-Smith et al., 2002). Understood in this light, the finding that there is little difference in importance or generality across academic and industrial life science patents (Henderson et al., 1998; Mowery et al., 2002) reflects the development of a common technological community comprised of multiple types of organizations engaged in ongoing collaborations (Powell, 1996). The importance for firms of linkages to universities has been well documented (cf. Owen-Smith and Powell, 2003), but few investigators have considered the reciprocal effects for universities of ties to firms. We contend that universities learn to patent and, in particular, to identify and prosecute high-impact patents through their connections to commercial partners. Thus, in combination with internal scientific and technology transfer capacities, university positions in contractual networks with companies should explain the citation impact of academic life science patents.

We focus our attention on the 6196 life science-based US utility patents issued to research one universities from 1988 to 1998. All patents assigned to R1 universities from 1976 to 1998 ($N = 19{,}815$) were identified through the United States Patent and Trademark Office (USPTO) database. These data were matched to the National Bureau of Economic Research patent citations data file, allowing extraction of all university-assigned patents in the technological category 'Drugs and Medicine.' The citation-based impact measures associated with these patents provide the dependent variables for our analyses.

Our independent variables are drawn from a number of sources. University level measures are taken

[3] Our cases include a private university with an established and successful technology transfer infrastructure and a public university whose licensing office is younger and struggling.

Table 1
Variable summary and descriptive statistics

Variables	Definition	Mean	S.D.	Minimum	Maximum
Dependent					
No. of citations (forward)	Total count of citations received by R1 university patents (application date)	36.09	54.19	0	585.00
Blockbuster patent	Dummy variable, 1 = university issued patent cited >3 S.D. more than the mean for that field and year (issue year)				
Controls					
Medical school	Dummy variable, 1 = university has a medical school				
Private	Dummy variable, 1 = university is privately governed				
Region	Dummy variable, 1 = university located in Boston, SF-Bay, Seattle, San Diego, Bethesda region, or New York City				
Technology transfer experience					
No. of patents	Yearly count of issued life science patents assigned to R1universities	7.84	12.18	0	185.00
TTage	Years since university first dedicated 0.5 FTEs to technology transfer	10.44	12.52	0	73.00
$TTage^2$	Years since university first dedicated 0.5 FTEs to technology transfer, squared	265.66	737.49	0	5329.00
Scientific capacity					
log(life science articles)	log of the count of articles published in basic life science journals where at least one author is affiliated with the university	5.82	0.76	2.48	8.60
log(medical articles)	log of the count of articles published in clinical medical journals where at least on author is affiliated with the university	5.88	1.49	0.69	8.86
Scientific impact					
Life science impact/field	Mean citation impact of university life science articles standardized by the mean citation impact of all life science articles in a given year	1.33	0.58	0.25	11.02
Medical impact/field	Mean citation impact of university medical articles standardized by the mean citation impact of all medical articles in a given year	1.24	0.46	0	2.28
Network					
Isolate	Dummy variable, 1 = university has no connections to the network				
Main component	Dummy variable, 1 = university has at least one tie to the largest weakly connected component in the network				
Degree	Yearly unstandardized degree centrality	4.35	6.43	0	54.00
$Degree^2$	Yearly unstandardized degree centrality, squared	60.29	205.04	0	2916.00

from a database compiled by Owen-Smith,[4] while we draw network measures from a database of contractual ties involving biotechnology firms compiled from *Bioscan* and other sources by Powell, Koput, and their students.[5] Table 1 presents the key variables along with definitions and simple descriptive statis-

[4] This database combines institutional R&D data (from the NSF CASPAR database), and publication impact data (from the Institute for Scientific Information) with data on patent volume and licensing outcomes (from the Association of University Technology Managers) (for details, see Owen-Smith, 2000, pp. 59–66).

[5] For details on the *Bioscan* database (see Powell et al., 1996, pp. 124–129).

tics. For ease of discussion, we group individual variables under the more general concepts we take them to indicate.[6]

2.1. Dependent variables

We first describe our dependent variables, which are aggregated to the level of the university. Our concern here is with flows of citations at the level of the institution. Rather than modeling the impact of each patent individually, we choose to analyze the characteristics of yearly patent portfolios. In effect, we examine the conditions under which universities generate streams of patented innovations and the factors that might account for the eventual impact of those patents.

Our first citation measure is a simple (forward) count of citations received by university life science patents. We sum the citations to patents assigned to a university in a given year to provide an aggregate measure of portfolio impact at the organizational level. A second measure, 'blockbuster,' captures the presence or absence in a given year of an extremely high-impact patent. Such a patent is cited 3 standard deviations above the mean for all patents issued in the same technology category in the same year.[7] Less than 2% (112) of the patents in our sample meet this criterion. Using these two variables we can examine the aggregate impact of innovative flows to universities, and the organizational and network conditions that contribute to the development of blockbuster intellectual properties.

2.2. Independent variables

Our key independent variables include a set of time-invariant controls that indicate the presence or absence of a medical school, whether or not a university is located in one of the United States' six major 'biotechnology clusters' (Owen-Smith et al., 2002), and whether the institution is publicly or privately governed. We expect these three variables to offer broad purchase on variations in the volume and impact of academic patent flows.

The presence of an academic medical center on campus reflects a possible increase in scientific capacity over universities without medical schools. Clinical and translational research, which is closer to commercial application than more upstream basic research, might result in a greater number of patents. More broadly, we have suggested that the integration of the lab and the clinic is a possible source of the dominance of the US public research system in worldwide biomedical innovation (Owen-Smith et al., 2002). Thus, a productive academic medical center may offer greater opportunities for the development of commercially valuable technology, while expanding academic involvement with firms and increasing the resources available for biomedical research on campus.

Similarly, location in an active biotechnology region may confer advantages to universities in terms of the development of intellectual property. Particularly in an industry where firms and universities are more closely equivalent in terms of the type and impact of the patents they develop, the knowledge spillovers generated in a high-tech cluster (Jaffe, 1986; Romer, 1986), along with extensive informal contacts between university scientists and researchers in local firms (Audretsch and Stephan, 1996; Zucker et al., 1997), may benefit universities as they seek to develop higher impact patent portfolios.

Despite their expected effects, time-invariant dummy variables are a blunt instrument. Hence, we include more detailed time-varying indicators of technology transfer and scientific capacity, scientific impact, and network position for these universities. To illustrate, we describe our simple measure of university experience with technology transfer: the time in years since a campus first committed a 0.5 full-time staff equivalent to technology transfer activities. Several recent studies have emphasized the role of the technology licensing office as both a locus for organizational learning about technology transfer (Feldman et al., 2002; Owen-Smith, 2003), and an important factor in licensing success (Siegel et al., 2000; Kaghan, 2001). We use age as a proxy for experience to reflect the possibility that some factors other than direct experience with patent prosecution may be a source of university learning. Similarly, we draw upon a yearly count of successful patent applications to capture the direct effect of experience with patent evaluation and prosecution.

[6] Correlations among these variables are reported in Table A1.

[7] This variant on the 'fixed effects' approach to citation rescaling suggested by Hall et al. (2001a,b), enables us to model a longer time series than is possible with raw citation counts.

2.3. Scientific capacity and impact

We compiled publication-based measures of the volume and impact of basic and clinical life science research on these campuses from the Institute for Scientific Information's University Indicators database. In particular, we include log-transformed counts of articles published in basic life science and clinical medical journals to indicate the volume of life science research on a university campus. We use a publication-based measure of scientific capacity, rather than one based on expenditures, because publication counts reflect the actual amount of research completed on a university campus. Invention disclosures made by academic inventors to university technology transfer offices often take the form of article manuscripts. Research has shown that both organizations and individuals involved with life science commercialization tend to publish more than those that lack such affiliations (Blumenthal et al., 1996; Powell and Owen-Smith, 1998).[8] Thus, we expect a positive relationship between publication volume and patent volume. By the same token, the separation of clinical and basic publications may provide greater insight into the means by which the presence of academic medical centers influences patenting.

As we have noted, the relationship between quality and impact for patents is a tricky one. The difficulties are magnified when we consider possible relationships between the quality and quantity of scientific outputs in different institutional systems. Dasgupta and David (1987, 1994) remind us that public and private science represent different institutional regimes for the creation, dissemination, and use of scientific findings, which are governed by different rhetorical rules (Myers, 1995) and norms (Merton, 1988; Packer and Webster, 1996). Nevertheless, citation measures for both publications and patents are often taken to reflect the 'fertility' or importance of new findings. We turn to standardized measures of citation impact for clinical and basic life science publications to examine the relationship between highly cited articles and the impact of academic patents.

The relationship between important articles and patents has not been fully explained. Owen-Smith (2003) finds that by the mid 1990s, high-volume patenting by universities is positively related to the citation impact of academic publications. In turn, high-impact science leads to larger volume patenting. Nevertheless, few studies have related publication and patent impact in a specific field.[9] Especially in the life sciences, where new findings (for instance, the discovery that a specific gene is associated with a particular heritable disease) can simultaneously yield career-making scientific publications and valuable intellectual properties,[10] both scientists and technology licensing officers often presume that higher impact, more 'fertile' science yields patents that will be more widely used. Nevertheless, very different processes govern citation strategies in manuscripts and patent applications, with the former governed by reputation-driven peer review processes and the latter by legal strategies and patent examiner's prior art searchers. These differences may mitigate a direct relationship between citation measures in the academic and commercial realms.

2.4. Network measures

We include a number of measures of the extent of university embeddedness in contractual networks involving science-based human therapeutic and diagnostic biotechnology firms (DBFs). Developed by coding alliances in such industry publications as *Bioscan* and others for the period 1988–1998, these network measures capture formal contractual relationships of a number of types, including R&D agreements, technology licensing, financial investments, and commercialization efforts such as clinical trials and marketing. Universities play a central role in these networks at the regional, national, and interna-

[8] Interestingly, this relationship may not hold for physical scientists and engineers whose approaches to patenting differ significantly from life scientists (Owen-Smith and Powell, 2001a; Agrawal and Henderson, 2002).

[9] See Agrawal and Henderson (2002) who found that high impact patents are positively related with higher volume publication for individual engineers at MIT, and Sine et al. (2001) who found a positive relationship between a university's scientific reputation (measured by National Research Council rankings) and licensing returns to intellectual property.

[10] Consider, for instance, the recent rapid promotion of James Thomson from assistant to full professor at the University of Wisconsin on the strength of his work with human embryonic stem cells (Associated Press, 2 December 2002).

tional level, while also serving as a source of trained personnel, new technologies, and scientific expertise. Little effort, however, has been expended to establish the relationship between such university–industry interfaces and the characteristics of academic patent portfolios.

The four variables grouped under the 'network' heading in Table 1 reflect varying levels of university engagement in contractual linkages to dedicated human therapeutic and diagnostic biotechnology firms. These variables include: (1) 'isolate,' a dummy variable indicating universities with no connections to DBFs in a given year; (2) 'main component,' an indicator of modest network connection (at least one tie to the largest weakly connected network component in a given year);[11] and (3) 'degree' a simple measure of centrality which, in the unstandardized form we employ here, is a count of each institution's contractual ties to DBFs in a given year.[12]

We draw on these measures to shed light on another possible mechanism by which universities might learn to develop more and higher impact life science patents. Mowery et al. (2002) find no effect of early ties to a key patent management firm (Research Corporation Technologies), the commitment of staff resources to technology transfer, or cumulative patenting experience on the citation impact of university patents. We contend that universities may learn the intricacies of patent prosecution and how to identify and pursue high-impact IP through connections with their commercial partners. Particularly in life science fields, where the science gap between universities and firms is the narrowest and informal ties between academic and commercial organizations are an important condition for firm success, contractual relations between firms and universities may represent 'pipes' through which both information and organizational competencies might flow (Burt, 1992; Podolny, 2001).[13] Our intuition about the importance of such connections is based on numerous conversations with technology transfer staff. Consider the following comment from a senior licensing associate specializing in life science innovations at a private university:

> We know it is hard to get information from companies because they don't want to tip their hand. You definitely value the feedback you can get from your commercial partners, it makes your decision making so much easier. That information gives you something to really substantiate why you are spending money on a patent.

Several informants in technology licensing offices emphasized that the process of technology marketing often occurs prior to a decision to file for patent protection. 'Shopping' a technology to particular licensees amounts to a search for information about the potential impact of a new invention. As the comments above suggest, however, valuable insights are not always forthcoming from corporations and may sometimes require significant parsing by the licensing officer. Under these conditions, established ties to commercial partners may increase both the volume and reliability of the corporate evaluations on which technology licensing officers often base decisions to patent. Seen in this fashion, technology officers develop skills at translation in which they learn to balance the zeal of enthusiastic university inventors with the more sober and strategic assessments of commercial firms, who do not wish to overpay for access to IP.

[11] The main component of a network is the largest group of organizations that are, in graph theoretic terms, reachable through indirect paths of finite length. Thus, a connection to the main component of a network represents the minimum level of connection necessary to enable an organization to search for information through the largest portion of the network.

[12] We employ degree centrality rather than some of the more complex measures developed by social network theorists to avoid potential biases introduced by a network dataset that focuses primarily on the activities of biotechnology firms. These data provide no information on ties between R1 universities and organizations other than DBFs, for instance large pharmaceutical firms, which renders more 'structural' centrality measures problematic.

[13] This diffusion-oriented view of the sources of organizational learning may be even more important as university technology licensing offices converge toward the 'marketing model' (Neuer, 1995; Sampat and Nelson, 2000), pioneered by Neils Reimers at Stanford. Under this organizational model, the primary responsibility of a technology licensing officer is the marketing of technologies and the management of multiple ongoing relationships with firms and inventors. With the marketing model, the role of intellectual property attorneys is minimized or eliminated and patent prosecution duties are often 'outsourced' to external law firms. As the marketing model becomes more common, we anticipate a lesser effect of prior experience with patenting on later patent impact. We expect offices oriented toward technology marketing to learn to manage IP more through ties to firms than from cumulative experience.

3. Models and methods

We model two dependent variables to examine the complex relationship between patent volume and impact on university campuses. Focusing first on explanations for the impact of patent flows to R1 universities, we examine counts of citations to academic life science patents in an 8-year (1988–1995) pooled cross-section using a negative binomial specification (Hausman et al., 1984; Cameron and Trivendi, 1998) to correct for over-dispersion. In the interest of maintaining statistical power and because patents do not tend to receive the bulk of their citations for 4–5 years (Lanjouw and Schankerman, 1999), we consider citation counts by patent application date (Hall et al., 2000). This strategy allows us to maintain a longer time series, while avoiding inclusion of patents that are too 'young' to have yet received the bulk of their citations. We employ fixed university and year effects to control for unobserved heterogeneity across time and campuses, modeling the dependent variable ($y_{i,t}$) as

$$y_{i,t} = \alpha_i + \delta_t + \sum_{j}^{J} \beta_j(x_{i,t,j}) + \varepsilon_{i,t}$$

Where α_i is the effect of university i ($i = 1, \ldots, N$), δ_t is the effect of year t ($t = 1, \ldots, 8$), and β_j is the within university slope for x_j pooled over all universities and years.

Finally we turn to a dependent variable, 'blockbuster,' that captures the presence or absence of a high-impact patent in a university's yearly portfolio. Recall that we define a patent as a blockbuster if it is cited 3 or more standard deviations above the mean for patents issued in the same year and technology category. As our definition of a blockbuster patent represents a variant of the 'fixed effects' approach to rescaling citation measures suggested by Hall et al. (2001a,b) and given the relative sparseness of 'blockbuster cases,' we opt to model the full 12-year time series (1988–1998), acknowledging that in the later years (approximately 1996–1998) the blockbuster designation may capture patents that were 'merely' cited more quickly than their cohorts.

Because the dependent variable is dichotomous, we use a conditional logistic regression specification to enable the inclusion of fixed university effects (Allison, 2002).[14] In essence, this special case of the standard logit model eliminates the cases (42) where there is no change in the dependent variables across time periods (e.g. where a university is never assigned a blockbuster patent or receives one in every year), thus providing a fixed effects model of the year to year likelihood of a university receiving a high-impact patent, conditional on the institution's ever having received such a patent. An unavoidable side effect of this model specification is its inability to include time-invariant independent variables. Hence, we include multiplicative interactions between year and the dummy variables capturing the presence or absence of a medical school, location in a high-tech region, and private governance, to analyze their changing effect over time.

4. Findings

4.1. Portfolio impact

Table 2 presents results from a series of regressions on the overall citation impact of yearly academic patent flows in the life sciences. We begin with the most effective regression, model 5, which finds a positive and significant effect of portfolio size on number of citations. This finding provides further support for Mowery et al. (2002) conclusion that the impact of university portfolios, at least in years well after Bayh–Dole, does not decline with increased patenting. Note the positive and significant effect of network degree upon this measure of university patent impact. This variable provides some insight into the mechanisms by which universities might learn to obtain high-impact patents.

We think spillovers and access to evaluations provided by commercial contacts are key elements in successful technology transfer. Centrality in a system of contractual network 'pipes' provides sources of information that enable universities to more effectively evaluate invention disclosures. Of course, there are limits to connectivity; too much reliance on a handful of local partners might create cognitive

[14] Because our definition of a blockbuster patent implicitly controls for unobserved year-to-year differences in citation rates, we do not include fixed year effects in this model.

Table 2
Negative binomial models of patent citation counts, 1988–1995

	Model 1	Model 2	Model 3	Model 4	Model 5
Controls					
No. of patents (S.E.)	0.014** (0.003)	0.010** (0.003)	0.005* (0.003)	0.005* (0.002)	0.020** (0.004)
No. of blockbusters	0.098 (0.084)	0.115 (0.080)	0.112 (0.073)	0.119+ (0.072)	0.051 (0.069)
Medical school	0.376* (0.159)	0.562** (0.163)	−0.094 (0.233)	−.094 (0.234)	−0.130 (0.235)
Private	0.498** (0.147)	0.317* (0.151)	0.302* (0.153)	0.361* (0.159)	0.364* (0.162)
Region	0.059 (0.193)	0.050 (0.193)	−0.191 (0.197)	−0.165 (0.199)	−0.062 (0.204)
Technology transfer experience					
TTage		0.091** (0.015)	0.069** (0.016)	0.069** (0.016)	0.068** (0.016)
TTage^2		−0.001** (0.000)	−0.001** (0.000)	−0.001** (0.000)	−0.001** (0.000)
Scientific capacity					
log(life science articles)			0.486** (0.173)	0.503** (0.172)	0.499** (0.172)
log(medical articles)			0.155 (0.097)	0.212* (0.106)	0.215* (0.107)
Scientific impact					
Life science impact				0.001* (0.000)	0.001* (0.000)
Medical impact				−0.285 (0.199)	−0.270 (0.199)
Network					
Isolate					−0.035 (0.250)
Main component					−0.220 (0.249)
Degree					0.063* (0.026)
Degree^2					−0.003** (0.001)
Constant	−1.003** (0.173)	−1.267** (0.174)	−4.236** (0.708)	−4.359** (0.704)	−4.325** (0.772)
LR χ^2	80.21	132.82	162.46	169.64	204.84
log-likelihood	−2099.72	−2075.97	−2063.14	−2060.55	−2050.57
Pseudo R^2	0.213	0.222	0.227	0.228	0.232
N	624	624	624	624	624

All models include fixed university and year effects.
* $P < 0.05$.
** $P < 0.01$.
+ $P < 0.10$.

'lock-in' or limit licensing staff's ability to appropriately weight those evaluations that are strongly colored by corporate priorities. Accordingly, note the negative quadratic term for network degree, implying decreasing returns to centrality for universities. As with other types of learning (note the pattern of significance for our TTage and $TTage^2$ variables), there appear to be diminishing returns to network embeddedness.[15]

The implication is that universities learn to patent through 'diffuse' channels in addition to simple experience. Seen in this respect, connections to a range of science-based firms provide academic institutions with the relevant tools to evaluate invention disclosures through the eyes of potential partners. Access to such information may allow universities to more effectively evaluate the possible impact of new faculty innovations. The negative quadratic effect, however, indicates that it may be possible to be too connected to a few industrial interests. This flipside of the network effect may represent a form of 'capture' of university research endeavors by corporate partners. A university that relies too heavily on input from a small sample of corporate partners or on a narrowly commercial standard of judgment will see a decline in the impact of its patent portfolio. To the extent that this variety of network capture generates change in the research priorities of universities, our finding fits with the results offered by Henderson et al. (1998).

The apparent challenge for universities is to mine network position for information without becoming overconnected. In this case, successfully navigating network connections means avoiding capture and competency traps, while overcoming isolation in the ivory tower. Similar returns to an intermediate level of embeddedness have been found to be propitious in research on industries as disparate as women's fashion (Uzzi, 1996, 1997) and banking (Uzzi, 1999; Mizruchi and Stearns, 2001).

Beyond the network effects, we see a steady relationship between high-volume publication in both basic and clinical life science and the number of patent citations. Increased research productivity in terms of published life science articles creates a larger and more diverse 'pool' of findings that might potentially be patented.[16] Consider the comments of a senior licensing associate who emphasizes the extent to which learning is a function of the volume of evaluations performed.

> There is no curriculum for training someone. We try to send people to the AUTM seminars but they are really going to learn more by being here on the job, by going out and meeting with inventors and by sitting in on negotiations. This business is very much learn as you go and the more deals you are involved with, the more quickly you learn.

In addition to increasing the volume of potential deals, high-volume publication may reflect greater scientific diversity on campus, yielding more broad ranging invention disclosures. Assessing diverse innovations on a regular basis may mitigate against 'competency traps' (Levitt and March, 1988), which are a common source of diminishing returns to organizational learning.

The importance of academic patent portfolios is at least partially a function of the amount of basic science research that is conducted on campus. Net of publication impact measures, the effect of publication volume on patent portfolio impact suggests that successful IP development may depend jointly on having access to high-volume flows of scientific findings and the network connections and experience that

[15] While these models do not explicitly incorporate time lags, we recognize that learning may be attenuated. Hence we conducted several validity tests. We divided our sample of universities into isolate (no ties), moderately embedded (at or below the mean number of ties) and highly embedded (greater than the mean number of ties) groups at two time periods (1988, 1990) and compared 5-year citation rates from issue date (Lanjouw and Schankerman, 1999) for patents whose applications were filed in the following years. In both instances, the descriptive data were consistent with the findings reported above. Isolate patents were cited less often than both moderately and highly embedded patents, but the most highly embedded universities subsequently applied for patents that had less impact.

[16] In unreported sensitivity analyses, we included the yearly number of new invention disclosures reported in the Association of University Technology Managers (AUTM) survey as an independent variable. These data are available for a reduced sample of universities across a shorter (1991–1995) time series. When run on this limited sample, however, our model five remained unchanged and, while it was positive and significant, the inclusion of the disclosure count variable did not qualitatively alter our results. These analyses suggest that disclosure rates have an independent effect on patent quality, perhaps by offering licensing associates greater opportunities to evaluate new technologies. That effect, however, does not alter the positive impact of a deeper pool (e.g. more publications) of potential innovations on a campus.

enable their evaluation. These models also indicate that highly significant academic publications are directly related to high-impact patents. Nevertheless, the small magnitude of the significant basic science impact variable suggests a relatively small substantive effect.

Table 2 implies that having high-impact patent flows is largely a function of basic knowledge flows, access to information from commercial partners, and experience. Multiple linkages appear to be more valuable than a tight reliance on a few commercial partners. High-impact basic science serves as an entry ticket to the patenting arena for universities (Owen-Smith and Powell, 2003), but exploiting the potential value of patents is more a function of having access to information that assists in evaluating the potential economic impact of faculty innovations than of having a small number of industrial partners who tell universities how to commercialize research. These findings are nicely summed up in the remarks of a technology transfer officer who comments on the value of fast access to corporate assessments:

> We have very good pipelines into the biotech world, we know who is doing what in cancer, who is working in auto-immune, etc. and we go to these companies and get a quick response. There is nothing equivalent on the physical science side. The product life cycles are so short that little companies can't spend time on building relationships with universities.

In addition to highlighting the importance of networks to academic patenting, these comments further emphasize the distinction between biomedical and engineering approaches to intellectual property and university–industry interactions.

4.2. Accounting for blockbusters

On some university campuses, licensing strategies are, out of necessity, oriented more towards garnering spectacular 'home run' successes than generating stable flows of higher impact patents. This strategy may be particularly salient for late entrants who find that a blockbuster is the fastest means to overcome the constraints that accompany limited budgets and underdeveloped network connections.

As an illustration of this process, consider recent data on licensing from AUTM. Among the 20 universities that earned in excess of US$ 5 million in 1998 licensing income, 10 had 50 or more issued patents. These institutions have routinely appeared at the top of the AUTM revenue list. Their deep patent portfolios stand in sharp contrast to three new entrant universities (Florida State, Canegie Mellon, and Tulane) with 15 or fewer patents. Each of these universities 'swung for the fences' and landed a single highly lucrative blockbuster in an otherwise small IP portfolio.

Technology transfer capacity develops through experience in evaluating a broad range of invention disclosures. Ample connections to firms, as well as translational research in medical schools, aid this process by increasing the amount and quality of feedback universities receive from commercial partners. Technology transfer experience itself may represent not only increased competency in evaluation, but also expanded flexibility in the choice to pursue IP. The director of a young technology transfer office at a large public university sums up the challenges of being a new entrant, whose limited budget constrains their ability to patent:

> Generally speaking, unless we have companies interested in a technology, we simply can't afford to go forward. If that company doesn't agree to reimburse us for patenting costs, then that's the decision right there.

The limitations implied above suggest that new academic entrants to the commercial arena face a particularly difficult double bind. Universities may depend on the interest of firms to justify pursuing IP, however, that very dependence may limit a university's ability to capitalize on the few technologies they succeed in protecting. Under these circumstances, network connections to firms may be both necessary and dangerous for universities whose technology transfer infrastructures are not economically self-sufficient. Clearly, linkages to companies are important to evaluating the impact of academic life science patents. But the importance of firm input to assessments at well-off incumbent institutions and the necessity of corporate buy-in for any patent prosecution at more cash-strapped entrant schools suggests that the relationship between embeddedness and the impact of academic IP portfolios may be contingent on experience.

Most university licensing revenues derive from a very small number of patents. On many campuses, a single patent has accounted for the lion's share of royalty income (Powell and Owen-Smith, 2002). These inventions are often based in life science research and represent broadly licensed biological processes (for instance, the Stanford/UCSF gene splicing patent and Columbia's protein synthesis patent were extremely consequential for those campuses' early technology transfer success), or on therapeutically valuable compounds or uses thereof (such as Florida State's more recent and highly lucrative Taxol patent) (Mowery et al., 2001).

The challenge facing academic technology transfer is whether to "swing for the fences" for a blockbuster that could produce windfall revenues, which would seed broader commercialization efforts, or to bet on a wider range of inventions, generating a steady stream of small successes with the hope that a blockbuster might emerge from this wide portfolio (Owen-Smith, 2000). Adding to the challenge is the fact that identifying such a blockbuster ex ante is very difficult. Interviews and archival materials suggest that where blockbusters have been realized, few appreciated their potential at an early stage.

Nevertheless, the pressure to develop such blockbusters is particularly pressing on entrant campuses where technology transfer offices most often function in the red. Consider the comments of the vice president for research at a large public institution whose licensing efforts have yet to generate significant returns. His comments suggest both the necessity of scoring a blockbuster and the benefits of such success.

> What you want is one really big winner, and then you can reinvest and build some other winners off that. Then you are out of the gate. Eventually, we are going to hit one. We've got a bunch of technologies that I think have $1 billion a year projected markets. Everybody needs to get their first hit. We just haven't yet. We do have some nice stuff in the pipeline, though.

This passage implies that landing an initial big hit is viewed as the pathway to viability on some entrant campuses. Technology licensing officers at numerous universities have cautioned us, however, that evaluating the market potential of an early stage proof of concept technology is risky.[17] A senior licensing associate at a commercially successful private university sums up these difficulties:

> In most cases you don't even have a prototype, let alone an established market. So going out and saying 'what's the potential market for this technology,' doesn't work for most of the technologies we deal with. We're often hard put even to figure out what the product is going to be, let alone determine market size. Using that kind of criteria just doesn't work.

We turn to conditional logit models to discern which organizational features are associated with the presence or absence of an extremely highly cited (>3 standard deviations above the mean) patent in a university's portfolio.[18] As the comments above suggest, the search for a blockbuster patent requires the ability to evaluate uncertain and early stage technologies. Table 3 presents findings from our conditional logit regressions.

The results suggest that obtaining "home run" patents has little to do with the impact or volume of science conducted on campus. Instead, this form of success is largely a game of numbers, experience, and embeddedness. As with Table 2, we find a consistently significant pattern relating high-volume patenting to a measure of patent impact. All other things being equal, universities that patent more are more likely to generate a very successful patent in any given year. We also note the strongly negative effect of the medical school × year interaction,[19] which suggests that the importance of having a medical school on campus has declined over time.

[17] Jensen and Thursby (2001) find that that such 'proof' patents are much more difficult to license lucratively than are technologies which have reached the prototype stage.

[18] Recall that a conditional logit model enables a fixed effects specification for universities at the expense of information about institutions that are never issued blockbuster patents. Thus, these coefficients are best understood in terms of the factors that contribute to the yearly presence or absence of very high impact patents in the portfolios of institutions that received at least one such patent in any year in our data.

[19] Conditional logit models prevent the use of time invariant coefficients, but a common strategy is to include interactions between such variables and a year marker. Coefficients for such interactions are best understood to indicate the changing effect of the variables over time.

Table 3
Conditional (fixed effects) logistic regression of blockbuster, 1988–1998

	Model 1	Model 2	Model 3	Model 4	Model 5
Controls					
No. of patents	0.067** (0.025)	0.063* (0.027)	0.060* (0.027)	0.058* (0.028)	0.069* (0.029)
Medical school × year	0.025 (0.088)	−0.142 (0.115)	−0.234+ (0.129)	−0.258* (0.132)	−0.312* (0.139)
Private × year	−0.149 (0.120)	−0.220+ (0.127)	−0.233+ (0.139)	−0.219 (0.141)	−0.252+ (0.144)
Region × year	0.077 (0.140)	0.100 (0.145)	0.130 (0.152)	0.138 (0.154)	0.134 (0.169)
Technology transfer experience					
TTage		0.305* (0.135)	0.342* (0.147)	0.368* (0.149)	0.374* (0.158)
TTage^2		−0.001 (0.002)	−0.001 (0.002)	−0.001 (0.002)	−0.000 (0.002)
Scientific capacity					
log(life science articles)			3.355+ (1.934)	3.334+ (1.929)	3.622+ (1.944)
log(medical articles)			−1.828 (1.415)	−1.430 (1.442)	−1.759 (1.506)
Scientific impact					
Life science impact				0.604 (0.645)	0.478 (0.646)
Medical impact				−0.870 (0.828)	−1.058 (0.857)
Network					
Isolate					0.547 (1.604)
Main component					−0.883 (0.739)
Degree					0.268* (0.119)
Degree^2					−0.006* (0.002)
LR χ^2	15.40	21.26	24.78	26.96	32.38
log-likelihood	−109.05	−106.12	−104.36	−103.27	−100.56
Pseudo R^2	0.066	0.091	0.106	0.115	0.139
N	333	333	333	333	333

All models include fixed university effects.
* $P < 0.05$.
** $P < 0.01$.
+ $P < 0.10$.

The role of technology licensing offices and network embeddedness in this form of patenting accomplishment is apparent in Table 3. The strong positive effect of formal technology transfer experience, combined with positive but declining returns to network degree, again suggests the importance of access to information that enables evaluation of invention disclosures, and the capacity to take advantage of such information. The negative quadratic term for degree further implies the possibility that university patenting efforts may be harmed by a very high volume of firm connections. Particularly for the sort of 'big hit' patents we model here, the ability of a technology transfer officer to identify findings that may be very useful to industry, while remaining outside established commercial R&D trajectories is important. Such evaluative skills may require that universities remain connected, but not subservient, to commercial R&D programs.

5. Conclusion and implications

Our qualitative and quantitative findings combine to present a story of the opportunities and potential pitfalls of university engagement in contractual networks with biotechnology firms. We focus here on two patenting outcomes for R1 universities, emphasizing the extent to which research-intensive campuses produce higher impact life science patents for their involvement in university–firm networks. Both the regressions and the comments of technology licensing officers emphasize the central role that firms play as a source of information that enables effective evaluation of the potential of often ambiguous faculty innovations.

While connections to a commercial network are of great value, too many linkages can preclude the development of a stable flow of higher impact patents. Moreover, in terms of overall portfolio impact, a

"Goldilocks" approach of partial embeddedness (neither too isolated, nor captured) may generate positive benefits for academic technology transfer efforts. To the extent that such benefits are present, they seem to depend upon an institution's level of technology transfer experience. The advantages of embeddedness and experience depend upon having both available stocks of basic life science and a higher volume flow of patents.

The findings presented in Table 2 suggest that in the late 1980s and through the 1990s, an increased volume of patenting led to higher impact patent portfolios at US universities. These schools developed increased ability to evaluate the possible value of patents and to discern potentially valuable intellectual properties from the broad range of new findings developed on campus. The findings presented in Table 3 reiterate this pattern, as high-volume patenting exhibits a positive effect on the development of blockbuster intellectual properties. The relationship between network connections and both types of patent impact is curvilinear. We contend that the pattern of decreasing returns to connectivity highlights both the importance and potential dangers of turning to corporate partners for help in assessing the value of innovations. These findings reflect the extent to which university learning about technology transfer proceeds through diffuse channels, embedded in contractual relations with firms.

We also find several mediating factors. The role that medical schools and clinical publications play in explaining the impact of university life science innovations is interesting. Life science research conducted in medical centers is closer to commercial needs and thus contributes to both the volume of patents developed by a university and to the overall value of patent portfolios. Nevertheless, that very intersection makes medical school research less likely to contribute to the development of a blockbuster technology, as increasing integration between academic and commercial biomedicine may limit the possibility for developing highly novel findings outside the established trajectories of corporate research.

The complex relationship between published and patented life science research extends beyond academic medical centers. The impact of a university's patent portfolio depends on the stock of basic life science findings (articles) developed on campus. The impact of those articles, though, affects aggregate flows of prior art citations but does not significantly alter the likelihood of developing a blockbuster. In other words, highly fertile publications may serve as an entry ticket to commercialization networks that enable universities to develop higher impact intellectual property.

The academic reputation of university scientists may matter indirectly as researchers who are both highly visible and commercially engaged attract the attention of corporate partners and, in so doing, increase the flow of valuable information into university technology transfer offices. While we do not find direct evidence of this phenomenon in our regressions, the comments of a very experienced licensing associate suggest the importance of academic accomplishment for access to firms: "We have faculty who are well known to companies, who may have done consulting for them, referrals from such professors get us attention." If high-impact publications provide an entry ticket to information rich networks in the life sciences, and if access contributes to increasing commercial accomplishment, then scientific reputation might start universities on a path of increasing returns.

Such feedback loops, however, can be dampened by the negative effect of over-embeddeness on patent impact. If highly cited intellectual property helps make universities more attractive to commercial partners, and universities build strong links to a small number of affiliates, then connectivity can reduce overall patent impact. In such cases, commercial accomplishment may carry the danger of too much integration across academic and commercial interests.

Under these circumstances, the dynamics of entry and movement in complex networks governed by multiple, overlapping institutional regimes may force universities into an uncomfortable position where one outcome of achievement is the diminution of the very characteristics that make university research potentially valuable to industry. In addition to the more straightforward dangers of capture by corporate partners, university involvement in such commercial networks may carry unforeseen consequences for both academic and commercial activities on campus.

Table A.1
Correlation matrix

No.	Variable name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	No. of citations	1.000																
2	Blockbuster	0.533	1.000															
3	No. of patents	0.582	0.339	1.000														
4	No. of blockbusters	0.612	0.918	0.397	1.000													
5	Medical school	0.083	0.048	0.157	0.028	1.000												
6	Private	0.121	0.083	0.081	0.073	0.202	1.000											
7	Region	0.244	0.124	0.287	0.144	0.133	0.368	1.000										
8	TTage	0.256	0.081	0.268	0.132	−0.113	0.023	0.089	1.000									
9	$TTage^2$	0.218	0.096	0.200	0.145	−0.119	−0.037	0.047	0.926	1.000								
10	log(life science articles)	0.456	0.190	0.599	0.218	0.432	0.146	0.308	0.244	0.143	1.000							
11	log(medical articles)	0.289	0.150	0.390	0.147	0.729	0.231	0.240	0.021	−0.041	0.759	1.000						
12	Life science impact/field	0.277	0.102	0.172	0.104	0.164	0.431	0.373	0.116	0.064	0.323	0.224	1.000					
13	Medical impact/field	0.273	0.143	0.272	0.138	0.530	0.418	0.366	0.082	0.011	0.614	0.782	0.402	1.000				
14	Isolate	−0.059	−0.045	−0.030	−0.047	−0.023	0.019	−0.088	0.090	0.117	0.041	0.022	0.031	−0.017	1.000			
15	Main component	0.185	0.111	0.257	0.110	0.205	0.420	0.342	0.076	−0.007	0.401	0.417	0.290	0.482	−0.282	1.000		
16	Degree	0.453	0.237	0.576	0.260	0.136	0.348	0.502	0.235	0.112	0.578	0.424	0.340	0.463	−0.159	0.538	1.000	
17	$Degree^2$	0.438	0.213	0.609	0.251	0.057	0.201	0.448	0.241	0.134	0.495	0.305	0.254	0.311	−0.077	0.273	0.907	1.000
18	*N*	624																

Acknowledgements

This research is supported by a grant from the National Science Foundation (NSF Grant #0097970) and the Merck Foundation (EPRIS Project). We are grateful to the staff of the two university technology licensing offices that granted us access and gave freely of their time. We appreciate the helpful comments of participants at the Roundtable on Engineering Entrepreneurship Research held at Georgia Tech., comments from Bronwyn Hall, David Mowery and their students at a Berkeley workshop, Richard Nelson, and from two anonymous reviewers for *Research Policy*. Any remaining errors are our own.

Appendix A

See Table A1.

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