University patenting activities and their link to the quantity and quality of scientific publications

Poh Kam Wong · Annette Singh

Abstract Integrating data from three independent data sources—USPTO patenting data, Shanghai Jiao Tong University's Academic Ranking of World Universities (ARWU) and the Times Higher Education Supplement's World University Ranking (WUR), we examine the possible link between patenting output and the quantity and quality of scientific publications among 281 leading universities world-wide. We found that patenting by these universities, as measured by patents granted by the USPTO, has grown consistently faster than overall US patenting over 1977–2000, although it has grown more slowly over the last 5 years (2000–2005). Moreover, since the mid-1990s, patenting growth has been faster among universities outside North America than among those within North America. We also found that the patenting output of the universities over 2003–2005 is significantly correlated with the quantity and quality of their scientific publications. However, significant regional variations are found: for universities in North America, both the quantity and quality of scientific publications matter, but for European and Australian/NZ universities, only the quantity of publications matter, while for other universities outside North America and Europe/Australia/NZ, only quality of publications matter. We found similar findings when using EPO patenting data instead of USPTO data. Additionally, for USPTO data only, the degree of internationalization of faculty members is found to reduce patenting performance among North American universities, but to increase that of universities outside North America. Plausible explanations for these empirical observations and implications for future research are discussed.

Keywords University patenting · Publication quantity & quality ·
Technology commercialization

P. K. Wong · A. Singh (✉)
NUS Entrepreneurship Centre, National University of Singapore, Singapore, Singapore
e-mail: necaas@nus.edu.sg

Introduction

The growing importance of universities as sources of commercializable technological invention has been much highlighted in recent literature on the role of universities in economic development in general, and especially among proponents of the "Triple Helix" concept (Etzkowitz et al. 2000; Etzkowitz 2003). In particular, patenting by universities has been used as an indicator of the involvement of universities in "third stream" technology commercialization activities, beyond the traditional role of research and teaching. While royalties derived from licensing of university patents or the frequency of spin-off company formation are more proximate measures of the extent of university involvement in technology commercialization (Siegel et al. 2003; Friedman and Silberman 2003), they are not as widely available as patenting data.

Earlier literature has noted a significant increase in university patenting in the United States from the 1980s, particularly since the passage of the Bayh-Dole Act (Henderson et al. 1998; Mowery et al. 2001; Shane 2004). University patenting in Canada has likewise been found to be increasing since the 1990s according to the regular Association of University Technology Managers (AUTM) surveys (AUTM 2005). The evidence on patenting trends among European universities is more fragmentary, although a recent review by Guena and Nesta (2006) suggests that there may be an overall trend of increase as well. They noted however that the phenomenon is highly heterogeneous across countries. Moreover, unlike in the United States, there are large discrepancies between data on patents invented and patents owned by universities in many European countries. While there has also been a growing literature on patenting trends among universities outside North America and Europe, they tend to focus on individual universities or universities in a single country (see e.g. the special issue of *World Development*). One exception is Wong et al. (2002), which provides a comparative analysis of 22 universities in the Pacific Rim (including 10 in Asia and one in South America).

To address this gap in the literature, this paper seeks to examine the trend and determinants of patenting among the leading universities in the world by integrating data from three independent data sources—USPTO patenting data, Shanghai Jiao Tong University's Academic Ranking of World Universities (ARWU) and the Times Higher Education Supplement's World University Ranking (WUR). The focus on the leading universities in the world as ranked by both the ARWU and the WUR has two advantages. Firstly, being among the most research intensive universities across the world, these leading universities are likely to account for a disproportionately large share of all university patenting. As partial evidence for this, according to data available for US universities covered by the AUTM 2005 survey, while the total of 152 responding universities reported 2840 patents granted, the subset of 85 universities that are included in both the ARWU and WUR rankings (56% of all responding universities) contributed 2339 patents, or 82.4% of the total number of patents generated. Secondly, ARWU and WUR represent the two most comprehensive attempts at ranking universities on a world-wide basis, with each capturing a different set of sub-indicators of university performance. By looking at only universities that are ranked by both, we are thus more likely to capture the most research intensive universities in the world.

As neither ARWU nor WUR capture information on patenting activities, we have complemented these databases by extracting data on patents assigned to the individual universities from the patenting database of the US Patents and Trademarks Office (US-PTO). As highlighted in prior literature (see e.g. Jaffe and Trajtenberg 2002), despite obvious limitations, the choice of patents granted by the USPTO has the advantage of

providing the highest degree of international comparability as well as a reasonable measure of commercialization potential.

The integration of data from the three independent data sources enables us to explore the relationship between research output and technology commercialization among universities on a worldwide basis. In particular, we are able to examine the extent to which patenting output by universities worldwide may be linked to the quantity and quality of their research output as measured by scientific publications and citations intensity respectively. While several prior empirical studies have examined such possible relationships, they were primarily focused on a small set of universities or universities within a single country, and typically at the level of individual disciplines (see, e.g., Owen-Smith and Powell 2003; Owen-Smith 2003; Landry et al. 2005). By extending the analysis to cover leading universities across all regions of the world, we believe that the findings of this paper contribute to the scientometric literature in two ways: Firstly, we provide new evidence on the global trend of university patenting. Secondly, we show that the relationships between patenting and the quantity and quality of scientific outputs appear to vary systematically between North America, Europe and other parts of the world.

Relationship between research performance and technology commercialization performance

Different approaches to measuring the relationship between patenting and research output

As highlighted in prior scientometric literature, the most common methods for evaluating research output utilize bibliometric indicators (see, e.g., Noyons et al. 1994; Owen-Smith and Powell 2003; Owen-Smith 2003; Landry et al. 2005; Meyer 2006), although peer reviews and measures of esteem (e.g., invited papers at international conferences, attraction of outside funding, honors and professional status indicators) are also used. Bibliometric indicators of university research output can be classified along two dimensions: the *quantity* of publication output (usually measured by publication counts), and the *quality* of publication output (usually measured by citations to publications).

Research on the relationship between research output and patenting in universities is commonly conducted using one of two levels of data. The first is the institutional level, through patents assigned to universities. These are often referred to as "university patents" (Meyer 2003) or "university-owned patents" (Geuna and Nesta 2006). The second level is that of the individual. Studies at this level have traced patents with university researchers as inventors, regardless of whether the patents are owned by the university. These may be known as "academic patents" (Meyer 2003) or "university-invented" patents (Geuna and Nesta 2006).

Relationship between patenting and research output at the institutional level

There is some reason to believe that university technology commercialization and academic publications are positively related at the institutional level. Previous studies in the life sciences, where much of this research has been done, have found that organizations involved in technological commercialization tend to have higher publication rates than those who are not (Owen-Smith and Powell 2003). Powell and Owen-Smith (1998) noted a substantial overlap between the universities which are "centers of excellence" in research,

and those with the highest number of formal contracts with biotechnology firms. Another study (Foltz et al. 2007) similarly found significant economies of scope between quality-adjusted life science patent and publication output, suggesting that there are synergies between these two activities at the university level. Generalizing from the life sciences, Lach and Schankerman (2003) found that licensing revenues at the university level are positively influenced by publication citations per faculty, while Baldini (2006) found journal publication and citation rates to be highly correlated with patent productivity at the university level as well as at the individual level.

Instead of examining the correlation between publications and patenting directly, a number of studies have investigated the indirect relationships between the two by looking at how certain common determinant factors affect university patenting and publications separately. Payne and Siow (2003) looked at the effects of federal research funding on patent output and publication counts and citations for US universities, finding that funding has a positive influence on publication and patenting output, but not on publication citations. Azagra-Caro et al. (2007) tested for common determinants of patenting and publishing in Spanish universities at a regional level, finding that patents are more responsive to R&D expenditure while publications are more responsive to the number of researchers. In these studies, publication data are typically obtained from ISI (now Thomson Reuters), while patent data is obtained from a variety of sources, including the USPTO (Foltz et al. 2000), Chi Research (Payne and Siow 2003) and the national patent office for countries outside the US (Azagra-Caro et al. 2007).

Relationship between patenting and research output at the individual level

At the level of the individual researcher or inventor, some studies have used survey data to examine the relationship between publications and patenting. The results from these studies regarding the effect of the volume of research output on patenting are mixed. Landry et al. (2006) used a survey questionnaire for academic researchers to investigate the effect of publication counts on patents granted and spin-off creation for Canadian engineering and life sciences university researchers. Their results showed that the number of publications have no impact on patenting in engineering, and a negative impact for life sciences. In contrast, Stephan et al. (2005), also using survey data, found that publishing has a positive relationship on patenting (as measured by patent applications) for the life sciences, with similar but weaker results for the physical and engineering sciences.

Another method for studying the relationship between publishing and patenting at the level of individuals involves using archival data to match inventor names with scientific author names. For example, Noyons et al. (1994) extracted 30 patents from the EPO database in the field of laser medicine and used the SCI to identify inventors who were also authors of scientific articles. By studying various characteristics of the publications of these inventor-authors, they explored the relationship between technology (patents) and science (publications). They found that patent co-inventorship increased co-publications of scientific papers around the date of the patent application, thus suggesting that patents and publications are complementary forms of R&D output. Meyer (2006) used a variant of this by matching inventors in the USPTO and authors in the SCI in the field of nano-science and -technology, to explore the relationship between their publication and patenting performance. He found that inventor-authors tend to out-perform non-inventing researchers in terms of both publication volume and citations.

Agrawal and Henderson (2002) also used publicly available databases (SCI publications data from ISI Thomson and patent application data from the USPTO) to investigate the

relationship between the volume of publishing and patenting for faculty in the Department of Mechanical Engineering and the Department of Electrical Engineering and Computer Science at MIT. Restricting their sample to faculty members who have either patented or published or done both, they found neither a complementary nor substitutionary relationship between publishing and patenting.

The literature has also generally indicated a positive relationship between the quality of research output and technology patenting of individual researchers. The hypothesis is that it is primarily high quality researchers who have the knowledge and expertise to create innovations suitable for commercialization (O'Shea et al. 2005). In addition, these researchers may be more inclined towards commercialization to capture rent from their tacit intellectual capital (DiGregorio and Shane 2003). A number of prior empirical studies support this hypothesis. Zucker and Darby (1996) used citations in the SCI databases to articles in the GeneBank database to find that highly productive ('star') bio-scientists who engaged in commercial activities had substantially higher citation rates than pure academic stars.

Rationale for and limitations of institutional-level analysis

Because universities differ in their policies with respect to ownership of patents invented by their faculty members, an analysis of the link between publication and patenting at the institutional level may differ when compared to a similar analysis at the individual level. This difference in university patent ownership policy is particularly marked when comparing US and non-US universities; while most universities in the US claim ownership of faculty invention arising from the Bayh-Dole Act, there is a greater variation in ownership practices among universities in Europe and other parts of the world. In a comparative study on Finnish data, Meyer (2003) found that using university patents gives an underestimate of the inventive output of a university as compared to university-invented patents. Geuna and Nesta (2006) also found indicators based on output of university-owned patents to be biased downwards for European universities, as researchers in many of these universities are often involved in patenting inventions on their own, without the university being named as the patent applicant (see also Verspagen 2006). Thus, in investigating the relationship between the publication and patenting output of universities, supplementing university-owned patent data with inventor-level data would be desirable. Unfortunately, there is no easy and reliable way to do so, because patent documents do not disclose the institutional affiliation of the inventors. While it is possible to validate the institutional affiliation of inventors by matching their names to authors of publications (which do show institutional affiliation), the matching process is tedious, and not reliable (Meyer 2003).

The above limitations notwithstanding, this paper has chosen to focus on analyzing the link between university publication and patenting using institutional assignee as the unit of analysis. In particular, following prior researchers (see, e.g., Cesaroni and Piccaluga 2005; Trajtenberg 2001), we have chosen to use USPTO patenting as the common measure for patenting output, not only to avoid the problem of incompatible data due to differing standards and criteria of individual national patenting offices, but also to enable us to focus our analysis on the subset of patents that carry higher expectation of commercial potential on the part of the non-US universities. It is true that the threshold for patenting in the US would be much lower for US universities than for non-US-universities, and as such, there is a potential bias problem in using USPTO patenting data to compare the determinants of patenting behavior of non-US versus US universities, although we believe that the problem may be less serious when comparing between the two non-US regions-–European and

Others—since both would be subjected to the same higher threshold bias. As a check against this potential "home-base" bias in USPTO patenting by US universities versus non-US universities, we replicated our analysis using patenting data from the European Patent Office (EPO).

We also replicated our analysis using citation-weighted patents. Patents vary widely in importance, ranging from marginal innovations to commercially useful inventions. The extent to which patenting by universities can be taken as evidence of their contribution to commercial technology development is thus heavily influenced by the importance or significance of these patents (Trajtenberg 1990; Henderson et al. 1998). Since the number of citations received by a patent is one indicator of its importance, citation-weighted patents have been used in several studies as a means to incorporate information on quality in patent analysis (see, e.g., Trajtenberg 1990; Hall et al. 2005; Snow 2006).

There is reason to believe that higher publication output by universities will result in higher citation-weighted patents. Owen-Smith and Powell (2003) found that higher life-science publication quantity and quality led to higher patent citations for life science patents by R1 universities, although the magnitude of the impact for publication quality was relatively small. We examine whether similar results occur when using quality-adjusted patents rather than patent citations per se, and when publications and patenting for the university as a whole is considered, rather than restricting to a specific technology field.

Methodology

Data sources

The ARWU, first released in 2003, ranks the top 500 universities in the world, covering universities from North and South America, Asia-Pacific and South Africa. It attempts to rank institutions according to their "scientific strength" (van Raan 2005) and so makes heavy use of measures of research productivity, supplemented with some measures of esteem indicators.

The World University Ranking (WUR), introduced by the Times Higher Education Supplement in 2004, was designed to cover a broader range of performance indicators than that of the ARWU, which has a narrower focus on research output and hence gives an advantage to science-dominated universities. Of the six sub-indices of WUR, only two (peer review and citations per faculty) are related to research output. The remainder capture teaching quality (as measured by faculty/student ratio), opinions of graduate recruiters, and globalization of the university faculty and students.

While their ranking methodologies has attracted various criticisms (see, e.g., Buela-Casal et al. 2007; Florian 2007; Van Raan 2005), the AWRU and WUR collectively provide one of the most comprehensive databases of university indicators.

Dataset construction

We constructed a dataset of leading universities in the world based on the following three criteria: the universities have been listed in the WUR ranking, they have been listed in the AWRU, and they have been granted one or more US patents. We have opted to use WUR and AWRU jointly, rather than relying on just one or the other, because the two rankings use somewhat different sets of sub-indicators, and hence a subset that satisfies both is likely

to be more robust and less susceptible to bias. More importantly, for our analysis purpose, WUR and AWRU complement one another in that the former provides an indicator of publication quality and internationalization of faculty, while the latter provides an indicator of publication quantity.

The dataset construction started with the list of universities that have appeared in the WUR in at least one of the years 2004, 2005 or 2006 when WUR was published. This comprised a total of 520 universities for 2005 and 2006, and a total of 200 universities for 2004.[1] It also included universities which made it into the top 100 or top 50 universities for the individual disciplines of Arts & Humanities, Technology, Biomedicine, Science and Social Sciences.[2] From this sample, those universities which have been granted at least one US patent in the period 1976–2005 were identified through a search of a database of all US patents granted by the USPTO from 1976 to 2005 that had been developed at the Entrepreneurship Centre of the National University of Singapore. Universities for which we could find no patents at all in the database were then dropped from the dataset, and the surviving subset was matched to the ARWU list. As 4 years of ARWU listings are available (2003–2006), a match is found if the university name appears in any one of the 4 years.

Two issues arose in this matching process as a result of multi-campus university systems, especially in the US. One was where the ranking tables gave the score for a particular campus of the university, whereas the patents were assigned to the university system as a whole. The University of California (UC) system is the prime example, with many of its patents being filed under the name "The Regents of the University of California", so that it is not possible to distinguish the individual campus from which the patent originated. In these situations, we attempted to establish a reasonably clear link between an institutional assignee name and a specific university by correlating additional information such as the locational address registered in the patent.[3] The second issue was when one of the ranking tables gave multiple scores for individual campuses from the same university system, whereas the other ranking table gave one composite score for the entire university system. Where reasonable, we tried to resolve this problem by matching the score for the university system's "flagship" campus to the composite score (e.g., the score for the University of Illinois in the WUR was matched with the score for the University Illinois Urbana Champaign in the ARWU). Cases where no flagship campus can be clearly identified within a multi-campus system are dropped from our dataset.

The above method resulted in a dataset of 281 universities from 29 countries (see Appendix Table 6). For analysis purposes, the 29 countries have been divided into three regional groupings: North America, Europe & Australia/New Zealand (Europe + ANZ), and a residual group called "Others". The grouping of North America comprises only US and Canada; although Mexico is technically part of North America, its university patenting and research publication patterns are very different from those of the US and Canada, and hence has been grouped with "Others". We have also chosen to combine universities in Australia and New Zealand with the European grouping, not only because of obvious

---

[1] The discrepancy between 2005 and 2006 on the one hand, and 2004 on the other, is due to limitations in data availability for 2004.

[2] Whether the top 50 or top 100 universities were considered depended on the data that was made available in the WUR.

[3] In the case of UC, three-quarters of patents are registered under a location address (that of the university's administrative headquarters) that does not match any individual campus address. Due to this matching problem, we had dropped all UC campuses from our dataset.

historical links and institutional similarities of universities in these two countries to UK universities, but also because they were found via cluster analysis to be more similar in patenting and publication characteristics to their European counterparts than to those grouped under "Others".

To overcome the problem of potential bias in using USPTO patenting data, we have also compiled the European Patent Office (EPO) patenting records of the 281 universities in our sample, using the same heuristic method to resolve ambiguous matching as was described above for USPTO data.

Analysis methods

The yearly USPTO patenting data of the 281 universities in our dataset were pooled to provide a representative measure of the aggregate growth trend of university patenting versus the overall patenting growth trend over the period 1977–2005. In addition, we disaggregated the patenting data into the three regional groupings to compare and contrast the growth trends across the three regions.

To investigate the relationship between patenting output, and research output quantity and quality, we constructed measures of these variables in the most recent years from the three data sources (USPTO patent counts, AWRU and WUR) and conducted multiple regression analysis. Because of the differences in patenting output intensity among the three regional groupings, we conducted separate regression analyses for each of the three groupings. As ten of the universities in our dataset had missing data for our measure of research quality (see section "Quality of research publications" below), only 271 universities' data were used in the regression analysis.

We also included a measure of the extent of internationalization of faculty from the WUR to see if it has any impact on patenting output. We have chosen to include a test of this variable, because some recent literature (e.g. Marginson and Van Der Wende 2007) have argued that, with increasing liberalization of higher education markets in many countries and growing competition among universities both domestically and internationally, universities are increasingly tapping foreigners to enhance the quality of their faculty. It is conceivable, however, that some universities may emphasize hiring foreign faculty members to boost their basic research capabilities, whereas others may emphasize recruiting foreigners to strengthen their applied research/industry collaboration capabilities. The impact of this faculty internationalization variable on patenting output may thus vary depending on the strategic focus of the universities concerned.

Since universities outside North America may have systematic differences in their US patenting propensity as compared to universities within North America, we checked the robustness of our USPTO patent-based regression results by repeating the same regression analysis using EPO patenting as the dependent variable.

We further tested our model using US citation-weighted patents instead of simple patent counts, to examine whether the relationships we found between patenting on the one hand, and publication quality, quantity and internationalization of faculty on the other, would still hold once information on the importance of the patent was incorporated into the analysis.

Dependant variable

Our indicator of university patenting output is the average number of USPTO patents issued for the three years 2003–2005. As long as a university was named as an assignee to a

patent, a full patent was counted to that university, regardless of whether there were any other assignees for that patent.

To validate our findings, we replaced USPTO patent counts with EPO patent counts as an alternative dependent variable. Due to EPO data availability constraints, however, we were not able to match the USPTO patent variable exactly; instead, the average number of EPO patents issued for the three years 2002–2004 was used.

In order to further test our findings, we replaced the average simple USPTO patent count variable with an average citation-weighted patents variable. The method used for weighting the patents is discussed in the Appendix.

Independent variables

Quantity of research publications

Research publications output quantity is measured using the SCI sub-index from the ARWU. This SCI sub-index gives the university's score based on the number of its publications listed in the SCI and SSCI databases,[4] with the scores being normalized to a maximum of 100 for the university with the largest number of journal articles. The SCI sub-index is calculated on the basis of annual publication counts, with the data lagged by 1 year. To smooth annual fluctuations and to ensure compatibility with the time period of the dependent variable, we averaged the SCI sub-indices from 2003 to 2006, resulting in an average score based on the journal articles produced from 2002 to 2005. For universities which do not have data for all 4 years, the average of scores for the available years was calculated.

Although the SCI sub-index actually includes publications in SSCI that are in social science fields, it is the closest measure of quantity of research output available in the ARWU and WUR. An alternative measure of research output quantity is the ARWU's N&S sub-index, which measures the number of articles published in the *Nature* and *Science* journals over the preceding five years. While this construct has the advantage of excluding research output from social sciences and arts that have less technology commercialization potential, it is unfortunately too restrictive, as it also excludes many engineering and other applied technical fields, thus rendering it unsuitable for the purpose of our analysis.

Quality of research publications

Research quality is measured using the score for citations per faculty sub-index provided by the WUR, which is the only objective measure of research quality available in the two ranking databases. The citations per faculty sub-index is compiled using information from Thomson Reuters' Essential Science Indicators (ESI) database, with the 2005 sub-index covering data over the preceding ten years up to 2005. As with the SCI sub-index, the scores for the citations per faculty sub-index are normalized to a maximum of 100. As ten universities in our dataset were not included in the WUR 2005, they were excluded from the regression analysis.

---

[4] The 2005 SCI sub-index also includes publications listed in the Arts & Humanities Citations Index (AHCI). However, we do not believe this change of definition materially changes our results. The sub-index for 2005 is highly correlated with the sub-index for 2006 ($r = 0.998$, $p = 0.000$), 2004 ($r = 0.995$, $p = 0.000$) and 2003 ($r = 0.993$, $p = 0.000$).

Internationalization of faculty

A measure of the extent of internationalization of faculty was taken from the WUR. This construct measures the percentage of faculty members of each university who are foreigners. As with the other variables from the WUR and ARWU, the score is normalized, with the highest-scoring university receiving a score of 100. We averaged the scores for the international faculty sub-index for 2004–2005 from WUR to derive our measure.

Presence of medical school

Since biomedical inventions are more likely to be patented (Sine et al. 2003; Owen-Smith and Powell 2003; Powers 2003), we checked each university in our database to ascertain whether it has a medical school. The presence of a medical school for North American universities was determined through information provided in the FY1999 AUTM licensing survey report, supplemented by Internet search. The presence of a medical school was included as a control variable in preliminary analysis. However, inclusion of this dummy variable was found to have no material effect on our results. Consequently, the analysis results in this paper are presented without the medical school variable.

Findings

University patenting trends

Before analyzing the relationships between patenting and research output quantity/quality, we first present data on the growth trend of university patenting in the US over time versus the overall US patenting trend (Appendix Table 8 and Table 1). As can be seen, patenting output by the 281 universities covered in our dataset has grown over the years, rising from about 350 per year in the period 1977–1985 to about 840 in the period 1986–1990, 1470 in 1991–1995, 2730 in 1996–2000 and 3160 in 2001–2005. The estimated university patenting growth rate based on our sample of 281 universities has been consistently higher than the overall patenting growth rate.

In terms of regional differences, while North American universities generally achieved higher patenting growth rates in the decade prior to 1995, universities outside North America had higher growth rates in the last decade; in particular, in the latest period 2001–2005, university patenting in the "Other" regions experienced the fastest growth. In fact, the slower growth of university patenting versus overall patenting over 2001–2005 can be attributed entirely to the low growth performance of US universities alone. The higher growth rate of patents for universities outside North America may be partially attributable to their smaller starting base. For the period since 1995, it may also be due to differing development of university technology commercialization in the three regions. As universities increase in patenting experience, TLOs become more discriminating about which technologies to patent, causing patenting growth rates to fall. The top universities in the US generally have a longer history of patenting than universities in the 'Other' region, and this may be reflected in the higher patenting growth rates for the latter universities. For European universities, Geuna and Nesta (2006) noted that data on university-owned patents during the 1980s and 1990s tends to be downward-biased, because university-invented patents were often assigned to firms that financed the research rather than to the university. However, institutional ownership of patents has become more common due to a need to

Table 1 University patenting growth rate and share of all USPTO patents 1977–2005

Year	No. of patents					% of all USPTO patents			
	All USPTO	All unis	North America	Europe + ANZ	Other	All unis	North America	Europe + ANZ	Other
1977–1985	605,598	3,173	2,937	116	120	0.52	0.48	0.02	0.02
1986–1990	452,988	4,178	3,870	168	140	0.92	0.85	0.04	0.03
1991–1995	551,900	7,371	6,985	199	187	1.34	1.27	0.04	0.03
1996–2000	754,385	13,627	12,591	599	437	1.81	1.67	0.08	0.06
2001–2005	894,579	15,796	13,769	1,004	1,023	1.77	1.54	0.11	0.11
Average growth rate percent per annum									
1977–1985	1.3	6.5	6.0	11.7	17.6				
1985–1990	5.1	17.6	18.3	10.5	7.1				
1990–1995	2.8	9.8	9.8	14.0	4.7				
1995–2000	9.1	12.5	11.5	26.1	26.4				
2000–2005	−2.2	−0.9	−2.0	3.4	12.1				

Note: Based on $n = 281$ universities

diversify sources of income. This may be reflected in a growth of European university-assigned patents that out-paced US university patenting in the last decade.

Relationship between research publication quantity/quality and patenting

Table 2 shows the profile of research publication and patenting output of the 281 universities in our sample. As can be seen, North American universities on average have substantially higher research publication quantity/quality and USPTO patent output than universities in other regions. Interestingly, while the high USPTO output of North American universities is likely to reflect in part a home-base bias, the average EPO patent output of North American universities is also higher than that of Europe + ANZ. Table 2 also shows that the Europe + ANZ grouping scored lower in terms of USPTO patenting output (both for simple patent counts and citation-weighted patent counts) and publications quantity than the "Others" grouping, but higher in terms of publication quality and EPO patenting.

Table 3 shows the Pearson correlations for all variables used in the regression analysis. While the patenting output variable and the publication quantity and quality variables all show significant bivariate correlations with one another, no multi-collinearity problem is detected in any of the regressions. The faculty internationalization variable shows negative correlation with simple US patent counts, but has no correlation with the other variable. It can also be noted from Table 3 that the three measures of patenting output show substantial correlation (0.70 for simple US patent counts and EPO patent counts; 0.94 for simple US patent counts and citation-weighted US patents).

Table 4 summarizes our regression results relating patenting output to publication quantity and quality for each of the three regional groupings. Our initial regression model using the level values of the dependent and explanatory variables revealed the existence of heteroskedasticity problems. To address this, we transformed the dependent variable by applying a square root function. As the two different model specifications yielded identical

Table 2 Descriptive statistics of variables by region

	North America		Europe + ANZ		Other		Total		Welch statistic
	N	Mean	N	Mean	N	Mean	N	Mean	
Average no. of US patents issued 2003–2005	101	22.7	118	1.8	52	4.4	271	10.1	33.58**
Average EPO patents 2002–2004	101	3.7	118	1.3	52	0.7	271	2.1	19.95**
Average no. of citation-weighted US patents issued 2003–2005	101	47.4	118	3.0	52	7.8	271	20.5	25.09**
Average score for no. of publications 2002–2005	101	45.8	118	37.1	52	41.9	271	41.3	12.28**
Average score for citations/ faculty 1996–2005	101	13.1	118	6.0	52	5.3	271	8.5	13.55**
Average score for international faculty 2004–2005	101	14.7	118	29.1	52	15.2	271	21.0	20.96**

** Significant at 1% level. *Note*: Based on $n = 271$ universities

qualitative findings, Table 4 only shows the results for the transformed dependent variable model.

The results show interesting differences among the three regional groupings. For the North American universities, we found both publication quantity and quality to have significant impact on patenting output. In contrast, for the Europe + ANZ grouping, only the publication quantity variable is found to be significant, while for the "Others" regional grouping, only the publication quality variable is significant.

Table 4 also shows that faculty internationalization has a significant effect for all the three regional groupings, but there is an interesting twist: among North American universities, it has a significant *negative* effect on patenting output, whereas for the other two groupings, it has a significant *positive* effect.

Table 5 shows the corresponding regression results when the dependent variable is replaced by EPO patents. The results for the EPO regressions appear to be generally weaker than the USPTO results. The faculty internationalization variable becomes statistically insignificant in the North American and "Others" regions. Moreover, the publication quality variable for the "Others" region is now only significant at the 10% level (as compared to 5% level using USPTO data).[5] We suspect that such weaker findings for the EPO dependent variable could be due to the much lower average EPO patenting propensities. In particular, the number of universities in the "Others" region with EPO patents is substantially smaller than those with US patents: Only 22 "Other" universities were found to have EPO patents issued in the time frame under consideration, compared to 49 universities with US patents.

Appendix Table 7 shows the regression results when citation-weighted patents are used as the dependent variable. The regression results are again very similar to the results when using simple USPTO patent counts. For each of the three regions, the statistical significance of the variables is the same, with the exception of the 'Other' region (the coefficient for publication quality has a higher level of significance than with simple patent counts

---

[5] In an unreported analysis, we ran the regressions using EPO patents without the faculty internationalization variable. In this case, the results for this model are even more similar to the regression using USPTO patents; specifically, the publication quality variable for the "Others" region remains significant at the 5% level.

Table 3 Correlations and summary statistics

	Average US patents 2003–2005	Average EPO patents 2002–2004	Average no. of citation-weighted US patents issued 2003–2005	Average normalized score for publication quantity 2002–2005	Average normalized score for citations/faculty 1996–2005	Average normalized score for international faculty 2004–2005
Mean	10.09	2.09	20.45	41.28	8.52	21.04
SD	19.18	3.08	45.50	13.48	9.91	19.11
Minimum	0.0	0.0	0.0	19.1	0.0	0.0
Maximum	142.0	20.0	428.0	100.0	100.0	97.50
Pearson correlation						
Average US patents 2003–2005	1.000					
Average EPO patents 2002–2004	0.700**	1.000				
Average no. of citation-weighted US patents issued 2003–2005	.944**	.728**	1.000			
Average normalized score for publication quantity 2002–2005	0.487**	.551**	.461**	1.000		
Average normalized score for citations/faculty 1996–2005	0.704**	.519**	.753**	0.473**	1.000	
Average normalized score for international faculty 2004–2005	–.137*	.005	–.111	–.015	–.035	1.000

Table 3 continued

Pearson correlations

		Average EPO patents 2002–2004	N
Average US patents 2003–2005	North America	0.695**	101
	Europe + ANZ	0.645**	118
	Other	0.449**	52
	All regions	0.700**	271

** Correlation is significant at the 1% level

Based on $n = 271$ universities

Table 4 Estimated regression model of factors affecting patent activity using USPTO patents

Regression to predict the square root of average US patents 2003–2005

	North America				Europe + ANZ				Other			
	B	t	Significance	VIF	B	t	Significance	VIF	B	t	Significance	VIF
Constant	.429	.781	.437		−.385	−1.543	.126		.233	.431	.668	
Average normalized score for publication quantity 2002–2005 (ARWU)	.073**	5.889	.000	1.318	.030**	4.334	.000	1.213	.013	1.017	.314	1.179
Average normalized score for citations/faculty 1996–2005 (WUR)	.070**	5.268	.000	1.314	.007	.469	.640	1.204	.086*	2.618	.012	1.178
Average normalized score for international faculty 2004–2005 (WUR)	−.038**	−2.957	.004	1.004	.010**	2.879	.005	1.060	.025**	3.099	.003	1.002
Adjusted R^2	0.555				0.241				0.265			
F-value	42.537**				13.401**				7.121**			
n	101				118				52			

** Significant at the 1% level

* Significant at the 5% level

Table 5 Estimated regression model of factors affecting patent activity using EPO patents

Regression to predict the square root of average EPO patents 2003–2005

	North America				Europe + ANZ				Other			
	B	t	Significance	VIF	B	t	Significance	VIF	B	t	Significance	VIF
Constant	−.25	−1.03	.306		−0.38†	−1.72	0.088		−0.08	−0.24	0.810	
Average normalized score for publication quantity 2002–2005 (ARWU)	.04**	7.28	.000	1.32	0.03**	4.58	0.000	1.21	0.01	1.05	0.300	1.18
Average normalized score for citations/ faculty 1996–2005 (WUR)	.01*	2.27	.025	1.31	0.00	0.24	0.812	1.20	0.04†	1.99	0.052	1.18
Average normalized score for international faculty 2004–2005 (WUR)	−.004	−.69	.494	1.00	0.01*	2.46	0.015	1.06	0.00	0.16	0.876	1.00
Adjusted R^2	0.486				0.233				0.088			
F-value	32.573**				12.829**				2.636†			
n	101				118				52			

** Significant at the 1% level

* Significant at the 5% level

† Significant at the 10% level

(1% level vs. 5% level)). Overall, the magnitude of the variables, though still small, is slightly higher. Moreover, the adjusted R-squares are slightly higher, showing that overall the explanatory power of the model is better for quality-adjusted patents.

Discussion and implications

Our results show that the patenting output of the leading universities in the world (based on ARWU and WUR rankings) are indeed significantly related to their research output quantity (as measured by peer-reviewed journal publication output quantity) and research output quality (as measured by citations per faculty). However, there appears to be significant variations between universities in North America, Europe + ANZ and other parts of the world. While both research publication quantity and quality matter among North American universities, only quantity matters for European and Australia/NZ universities; conversely, only quality matters for universities in other regions. The results appear to be quite robust whether we use USPTO or EPO patent data as the dependent variable, suggesting that the home-base bias effect may not be a significant driver. We believe these empirical findings to be novel and suggest the need for more research to confirm their validity as well as to provide more fine-grained theoretical explanations.

In terms of empirical novelty, our empirical findings that both quantity and quality of publications appear to influence patenting outputs among North American universities extend the findings by Owen-Smith (2003), who found that from the mid-1990s, publication citations had a positive effect on patenting output of US R1 universities, although he did not test the effects of publication quantity on patenting. Secondly, our empirical findings that patenting in European and Australia/New Zealand universities appears to be influenced only by research publication quantity, but not research quality, also appear to be novel. While some studies in the prior literature have examined how differences in environmental contexts and institutional/policy regimes between US and European universities may affect their patenting propensities (see, e.g., Owen-Smith and Powell 2003; Geuna and Nesta 2006; Verspagen 2006), these were based on case studies of a small number of universities rather than systematic comparison across large samples. Moreover, while they focused on explaining differences in the *level* or *intensity* of patenting activities between universities in the two regions, they did not predict differences in the linkage of patenting activity to research output quantity and quality. Thirdly, our contrasting results for the grouping of universities in other parts of the world when compared with North American as well as Europe + ANZ universities also appear surprising.

While a theoretical explanation for the above novel empirical results is beyond the scope of this paper, a plausible hypothesis for the observed findings may draw on possible regional-level differences in the approach of universities towards linking research to commercialization. To the extent that an emphasis on basic scientific research tends to result in higher citations (Bourke et al. 1999), while an emphasis on higher publication output per se tends to correlate with greater applied research emphasis, the two constructs we used may serve as imperfect proxy measures of basic research versus applied research emphasis. Thus, we adopt a stylized interpretation in which quality of publications proxies emphasis on basic research, while quantity of publications proxies emphasis on applied research. Within this framework, a relative emphasis on basic versus applied research may influence universities' patenting behaviors in terms of the types of technologies patented

and the way in which the patents are commercialized. While both basic/fundamental research as well as more downstream/applied research can lead to technology commercialization, they may involve different linking mechanisms. For example, an emphasis on basic research in emerging scientific fields such as life sciences could lead to more commercialization via venture capital funded spin-offs, given that there are fewer potential licensees in industry with the capabilities to commercialize the research. Conversely, an emphasis on applied research in more mature technological fields like mechanical engineering and food processing may lead more to commercialization via licensing to, and collaboration with, established firms in existing industries.

To the extent that the above hypothesis is valid, our results may reflect underlying framework conditions in which universities operate in the three regions. The findings that both publication quality and quantity matter in North America may be interpreted to mean that, in the North American environment, universities seek to patent inventions in both new, basic science-based fields as well as in existing industries. This could be because the region has a well-developed entrepreneurial environment with strong infrastructure for start-up firms, including the availability of venture capital and government schemes such as SBIR in the US, which facilitates the creation of spin-offs to commercialize basic research in these fields. At the same time, there are established firms in existing industries which have the necessary capabilities to license technology based on applied research in more mature S&T fields from the universities, and to engage in R&D collaboration with them. In contrast, it is plausible that European and Australian/NZ universities, for whom only the quantity of publications is significant, may emphasize more on patenting technologies via applied research in more mature S&T fields. The existing industries in the countries of this regional grouping are strong and well-established. Hence, universities in Europe and Australia/New Zealand may tend to patent technologies where there are established, proven mechanisms for commercialization through licensing and collaboration. While they also emphasize basic scientific research, such research may have weaker linkages to commercialization, due to the less sophisticated development of venture capital and other business environmental factors in these countries to support commercialization of basic research in new fields. Finally, in the case of universities located in the "Others" grouping, which is dominated by East Asian economies (Japan, China/Hong Kong, Taiwan, Singapore and Korea), and for whom only the quality of publications impacts patenting, industry tends to be less developed and less able to commercialize technologies licensed from universities. Moreover, the universities may have weak institutionalized R&D collaboration links with local industries. Hence, the scope for commercializing patented inventions developed via applied/collaborative R&D with existing industries may be limited. In order for universities in this region to commercialize their research in a timely fashion, they may therefore be more likely to focus more on patenting in emerging S&T fields which are more optimally commercialized through the creation of spin-offs.

While plausible, the above argument needs to be substantiated by additional research based on more fine-grained data. In particular, prior scientometric research has suggested that citation impact may be field-specific, and hence its use as a quality indicator should be normalized to the field. As such, it would be useful in future research to disaggregate the patenting and publication data by specific research fields, to see if there is indeed a systematic difference between North American, European and other universities in their patenting propensities by emerging versus existing S&T fields.

The contrasting findings on the effect of faculty internationalization on USPTO patenting output among North American universities and other universities similarly suggest the need for theoretical explanation. It is plausible that there are regional differences in the strategic focus of the universities, with North American universities tending to attract foreign faculty members with lower interest in involvement in patenting activities, whereas universities outside North America tending to attract foreign faculty with higher propensity to patent. However, more research is needed to ascertain the causes for such divergent findings. This could include using an indicator which is confined to the degree of internationalization of S&T-related faculties. The faculty internationalization variable of the WUR is based on the percentage of foreign faculty members in the entire university, including those faculties which would have little patenting activity, such as arts or social sciences. At this level of aggregation of the variable, it is thus not possible to determine whether there is indeed a systematic regional difference in the effect of faculty internationalization on patenting, or if there is a confounding effect from the inclusion data from non-S&T-related faculties.

Last, but not least, we believe that the analysis methodology of our study can be further enhanced if the underlying data sources can be improved and refined. For example, a major limitation of our analysis is that we are not able to track the full extent of patenting in universities; some universities which were dropped from our dataset may nevertheless engage in US patenting activity. These include universities which have a policy of allowing patent ownership to be assigned to faculty members rather than to the institution, and universities in countries where the legal ownership of the intellectual property generated by universities is vested in some other institutional entities (e.g. government bodies). It is also conceivable that some universities may have a partial policy of claiming patent ownership in some instances while allowing faculty inventors to own patents in other instances. Such universities could be included in our dataset, but the patent counts assigned to them in our dataset may under-report the extent of their US patenting activities. Another problem is the frequent change in definitions of indicators used in the AWRU and WUR. For example, within 3 years, the ARWU changed their definition of the SCI variable twice. In the 2003 and 2004 indices, only articles in SCI and SSCI were counted. In the 2005 index, the AHCI (Arts & Humanities Citation Index) was included. However, in the 2006 index, AHCI was removed. Similarly, although the WUR initially presented raw data, later on it presented data standardized to 100, similar to the ARWU (Buela-Casal 2007). The WUR citation sub-index uses citations in the previous ten years for its 2004 and 2005 indices; however, from 2006 it uses only five years. Such frequent changes in definitions of indicators reduce the compatibility of data over multiple years.

Appendix

Following Trajtenberg (1990), a linear weight was used, with the citation-weighted patent count (WPC) in year t being

$$\text{WPC}_t = \sum_{i=1}^{n_t} (1 + C_i),$$ where n_t = number of patents issued to the university in year t for the years 2003–2005, and C_i is the number of citations received by each patent i up to the year 2006.

This is a somewhat crude approximation of the true citation-weighted patents count, for two reasons. Firstly, truncation bias means that citations to more recently issued patents are under-represented. Secondly, citations received by patents typically peak 4–5 years after the patent is issued (Mowery and Ziedonis 2002). Since our patents are those issued between 2003 and 2005, and data availability restricts our citation data to 2006, we have captured only a small fraction of the citations that will eventually be made to the patents in our database.

Table 6 Distribution of leading universities by region and country ($n = 281$)

Region	Country	Frequency	Percent
North America	Canada	17	6.05
	US	86	30.60
	Australia	11	3.91
Europe + ANZ	Belgium	4	1.42
	Denmark	2	0.71
	Finland	2	0.71
	France	12	4.27
	Germany	21	7.47
	Hungary	1	0.36
	Ireland	5	1.78
	Italy	8	2.85
	Netherlands	8	2.85
	New Zealand	2	0.71
	Slovenia	1	0.36
	Spain	8	2.85
	Sweden	1	0.36
	Switzerland	6	2.14
	UK	33	11.74
Others	Brazil	1	0.36
	China	5	1.78
	Hong Kong	4	1.42
	India	1	0.36
	Israel	4	1.42
	Japan	23	8.19
	Mexico	1	0.36
	Singapore	2	0.71
	South Africa	2	0.71
	South Korea	5	1.78
	Taiwan	5	1.78
	Total	281	100.00

Note: Based on 281 universities'

Table 7 Estimated regression model of factors affecting citation-weighted patent activity

Regression to predict the square root of average citation-weighted US patents 2003–2005

	North America				Europe + ANZ				Other			
	B	t	Significance	VIF	B	t	Significance	VIF	B	t	Significance	VIF
(Constant)	-.04	-.05	.960		-.72*	-2.17	.032		.271	.37	.713	
Average of normalized score for publication quantity 2002–2005 (ARWU)	.10**	6.04	.000	1.32	.04**	4.54	.000	1.21	.009	.54	.589	1.18
Average normalized score for citations/faculty 1996–2005 (WUR)	.14**	7.41	.000	1.31	.01	.47	.638	1.20	.131**	2.93	.005	1.18
Average normalized score for international faculty 2004–2005 (WUR)	-.05**	-2.80	.006	1.00	.02**	3.36	.001	1.06	.044**	3.94	.000	1.00
Adjusted R^2	0.642				0.274				0.326			
F-value	60.734**				15.690**				9.223**			
N	101				118				52			

** Significant at the 1% level

* Significant at the 5% level

Table 8 No. of patents by leading universities versus all USPTO patents, 1976–2005

Year	All USPTO	All universities (n = 281)	North America (n = 103)	Europe + ANZ (n = 123)	Other (n = 53)
	No. of patents				
1976	na	299	281	10	8
1977	69,886	290	277	7	6
1978	70,604	309	281	14	14
1979	52,498	224	206	9	9
1980	66,219	334	310	11	13
1981	71,114	371	334	23	14
1982	63,307	375	353	15	7
1983	62,016	343	323	5	15
1984	72,681	448	413	15	20
1985	77,273	479	440	17	22
1986	77,041	571	523	27	21
1987	89,598	678	613	35	30
1988	84,439	726	672	36	18
1989	102,690	1,126	1,044	42	40
1990	99,220	1,077	1,018	28	31
1991	106,840	1,236	1,156	42	38
1992	107,511	1,376	1,303	38	35
1993	109,890	1,429	1,371	25	33
1994	113,704	1,611	1,529	40	42
1995	113,955	1,719	1,626	54	39
1996	121,805	2,045	1,920	69	56
1997	124,147	2,289	2,155	81	53
1998	163,205	3,017	2,768	140	109
1999	169,145	3,175	2,945	137	93
2000	176,083	3,101	2,803	172	126
2001	184,046	3,194	2,851	187	156
2002	184,424	3,180	2,832	180	168
2003	187,048	3,318	2,852	215	251
2004	181,320	3,138	2,694	219	225
2005	157,741	2,966	2,540	203	223

References

Agrawal, A., & Henderson, R. (2002). Putting patents in context: Exploring knowledge transfer from MIT. *Management Science, 4*(1), 44–60.

AUTM. (2005). AUTM Canadian licensing survey: FY2004. Survey summary. http://autm.net/events/File/AUTM%20PUBLICATIONS/FY04AUTMLicSurvSum-Canada.pdf.

Azagra-Caro, J. M., Archontakis, F., & Yegros-Yegros, A. (2007). In which regions do universities patent and publish more? *Scientometrics, 70*(2), 251–266.

Baldini, N. (2006). The patenting universities: Problems and perils, MRPA Paper No. 853, Munich Personal RePEc Archive. http://mpra.ub.uni-muenchen.de/853/.

Bourke, P., Butler, L., & Biglia, B. (1999). A bibliometric analysis of Biolgical Sciences Research in Australia. Research School of Social Sciences, The Australian National University. http://www.dest.gov.au/archive/highered/respubs/bibliometric/contents.htm.

Buela-Casal, G., Gutiérrez-Martínez, O., Bermúdez-Sánchez, M. P., & Vadillo-Muñozb, O. (2007). Comparative study of international academic rankings of universities. *Scientometrics, 71*(3), 349–365.

Cesaroni, F., & Piccaluga, A. (2005). Universities and intellectual property rights in Southern European countries. *Technology Analysis & Strategic Management, 17*(4), 497–518.

DiGregorio, D., & Shane, S. (2003). Why do some universities generate more start-ups than others? *Research Policy, 32*(2), 209–227.

Etzkowitz, H. (2003). Innovation in innovation: The triple helix of university-industry- government relations. *Social Science Information, 42*(3), 293–337.

Etzkowitz, H., Webster, A., Gebhardt, C., & Terra, B. R. C. (2000). The future of the university and the university of the future: Evolution of ivory tower to entrepreneurial paradigm. *Research Policy, 29*(2), 313–330.

Florian, R. V. (2007). Irreproducibility of the results of the Shanghai academic ranking of world universities. *Scientometrics, 72*(1), 25–32.

Foltz, J. D., Barham, B. L., & Kim, K. (2000). Universities and agricultural biotechnology patent production. *Agribusiness, 16*(1), 82–95.

Foltz, J. D., Barham, B. L., & Kim, K. (2007). Synergies of trade-offs in university life sciences research. *American Journal of Agricultural Economics, 89*(2), 353–367.

Friedman, J., & Silberman, J. (2003). University technology transfer: Do incentives, management, and location matter? *Journal of Technology Transfer, 28*(1), 17–30.

Geuna, A., & Nesta, L. J. J. (2006). University patenting and its effects on academic research: The emerging European evidence. *Research Policy, 35*(6), 790–807.

Hall, B., Jaffe, A., & Trajtenberg, M. (2005). Market value and patent citations. *Rand Journal of Economics, 36*, 16–38.

Henderson, R., Jaffe, A. B., & Tratjenberg, M. (1998). Universities as a source of commercial technology: A detailed analysis of university patenting, 1965–1988. *Review of Economics and Statistics, 80*(1), 119–127.

Jaffe, A. B., & Trajtenberg, M. (2002). *Patents, citations & innovations: A window on the knowledge economy*. Cambridge, MA: MIT Press.

Lach, S., & Schankerman, M. (2003). Incentives and invention in universities. *NBER Working Paper Series*, Paper No. 9727.

Landry, R., Amara, N., & Reherrad, I. (2006). Why are some university researchers more likely to create spin-offs than others? Evidence from Canadian universities. *Research Policy, 35*(10), 1599–1615.

Landry, R., Amara, N., & Saïhi, M. (2005). *Patenting and spin-off creation by Canadian researchers in engineering and life sciences*. Paper presenting at bringing science to life workshop, Institute for International Business, Rotman School of Management, University of Toronto, 29 April–1 May 2005.

Marginson, S., & Van Der Wende, M. (2007). *Globalization and higher education. OECD education working paper no. 8*. Paris: OECD.

Meyer, M. (2003). Academic patents as an indicator of useful research? A new approach to measure academic inventiveness. *Research Evaluation, 12*(1), 17–27.

Meyer, M. (2006). Are patenting scientists the better scholars? An exploratory comparison of inventor-authors with their non-inventing peers in nano-science and technology. *Research Policy, 35*(10), 1646–1662.

Mowery, D. C., Nelson, R. R., Sampat, B. N., & Ziedonis, A. A. (2001). The growth of patenting and licensing by U.S. universities: An assessment of the effects of the Bayh–Dole Act of 1980. *Research Policy, 30*(1), 99–119.

Mowery, D. C., & Ziedonis, A. A. (2002). Academic patent quality and quantity before and after the Bayh–Dole act in the United States. *Research Policy, 31*, 399–418.

Noyons, E. C. M., van Raan, A. F. J., Grupp, H., & Schmoch, U. (1994). Exploring the science and technology interface: Inventor-author relations in laser medicine research. *Research Policy, 23*(4), 443–457.

O'Shea, R. P., Allen, T. J., Chevalier, A., & Roche, F. (2005). Entrepreneurial orientation, technology transfer and spinoff performance of U.S. universities. *Research Policy, 34*(7), 994–1009.

Owen-Smith, J. (2003). From separate systems to a hybrid order: Accumulative advantage across public and private science at research one universities. *Research Policy, 32*(6), 1081–1104.

Owen-Smith, J., & Powell, W. W. (2003). The expanding role of university patenting in the life sciences: Assessing the importance of experience and connectivity. *Research Policy, 32*(9), 1695–1711.

Payne, A. A., & Siow, A. (2003). Does Federal research funding increase university research output? *Advances in Economic Analysis & Policy*, 3(1), Article 1.

Powell, W. W., & Owen-Smith, J. (1998). Universities and the market for intellectual property in the life sciences. *Journal of Policy Analysis and Management, 17*(2), 253–277.

Powers, J. B. (2003). Commercializing academic research: Resource effects on performance of university technology transfer. *The Journal of Higher Education, 74*(1), 26–50.

Shane, S. (2004). Encouraging university entrepreneurship. The effect of the Bayh–Dole Act on university patenting in the United States. *Journal of Business Venturing, 19*(1), 127–151.

Siegel, D. S., Waldman, D. A., Atwater, L. E., & Link, A. N. (2003). Commercial knowledge transfers from universities to firms: Improving the effectiveness of university-industry collaboration. *Journal of High Technology Management Research, 14*(1), 111–133.

Sine, W. D., Shane, S., & DiGregorio, D. (2003). The halo effect and technology licensing: The influence of institutional prestige on the licensing of university inventions. *Management Science, 49*(4), 478–496.

Snow, D. (2006). Capturing benefits from tomorrow's technology in today's products: The effect of absorptive capacity. *Harvard Business School Working Papers*, HBS Working Paper Number: 07-009.

Stephan, P. E., Gurmu, S., Sumell, A. J., & Black, G. (2005). Who's patenting in the university? Evidence from the survey of doctorate recipients. Forthcoming in *Economics of Innovation and New Technology*. Retrieved April 3, 2007, from http://www2.gsu.edu/∼ecosgg/research/pdf/sgsb_eint.pdf.

Trajtenberg, M. (1990). A penny for your quotes: Patent citations and the value of innovations. *Research Policy, 21*(1), 172–187.

Trajtenberg, M. (2001). Innovation in Israel 1968–1997: A comparative analysis using patent data. *Research Policy, 30*(3), 363–389.

van Raan, A. F. J. (2005). Fatal attraction: Conceptual and methodological problems in the ranking of universities by bibliometric methods. *Scientometrics, 62*(1), 133–143.

Verspagen, B. (2006). University research, intellectual property rights and European innovation systems. *Journal of Economic Surveys, 20*(4), 607–632.

Wong, P. K., Allen, K., et al. (2002). *Survey of technology transfer and wealth creation (T2WC) Among APRU member universities: Survey report*. Singapore: NUS Entrepreneurship Centre.

Zucker, L., & Darby, M. (1996). Star scientists and institutional transformation: Patterns of invention and innovation in the formation of the biotechnology industry. *Proceedings of the National Academy of Sciences*, *93*(23), 12709–12716.