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Do co-publications with industry lead to higher levels of university technology commercialization activity?

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Abstract Using the university–industry co-publications (UICP) propensity indicators developed by Tijssen (CWTS Working Paper Series, CWTS-WP-2012-009, 2009), this paper examines the impact of university–industry R&D collaboration on university technology commercialization output for leading US and Canadian universities. Our analysis suggests that UICPs do have a significant positive influence on universities' technology commercialization outputs, after controlling for the quantity and quality of their research and for their commercialization resources. The results are robust for all three common measures of university technology commercialization: patenting (both in terms of simple patent counts and citation-weighted counts), spin-off formation, and technology licensing. To supplement the aggregate regression findings, five case studies are provided that offer further insights on the causal mechanisms involved. Implications of these findings and possible future research directions are discussed.

Keywords University patenting · Spin-offs · Licensing · Publication quantity and quality · University–industry collaborative research · Co-publications

JEL Classification O32 · O34

Introduction

As argued by Etzkowitz et al. (2000) and Etzkowitz (2003), universities around the world are increasingly shifting from their traditional primary role as educational providers and scientific knowledge creators to a more complex "entrepreneurial" university model that incorporates the additional role of commercialization of knowledge and active contribution to the development of private enterprises in the local and regional economy. As a result universities are becoming an increasingly important component of the national innovation

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system, and need to operate increasingly within a triple-helix nexus involving close interaction with government and private industry (Wong et al. 2009).

This trend towards embracing a “Third Mission” for universities is reflected in the growing empirical literature on the determinants of university technology commercialization activities in recent years. Studies adopting the resource-based view in particular have investigated the possible determinant factors that influence university technology commercialization outputs (see e.g. O’Shea et al. 2005; Vinig and Van Rijsbergen 2009; Wong and Singh 2009). One potential determinant factor that has received somewhat less attention is university–industry R&D collaboration as measured by the propensity of the universities to generate co-publications with industry. This paper examines the relationship between university–industry co-publication and university technology commercialization for leading North American universities. Compared to traditional measures of university–industry R&D collaboration, university–industry co-publication (UICP) as an indicator has the advantages of wide availability and international comparability.

Our analysis suggests that UICPs do have a significant positive influence on universities’ technology commercialization outputs, after controlling for the quantity and quality of their research as well as for their commercialization resources. The results are robust for all three common measures of university technology commercialization outputs: patenting (both in terms of simple patent counts and citation-weighted counts), spin-off formation, and technology licensing. Implications of these findings and possible future research directions are discussed.

R&D collaboration and its impact on university technology commercialization

University–industry R&D collaboration

In general, relationships between universities and industry may be categorized into four components which vary in the degree of interactivity and specificity of focus (Santoro and Chakrabarti 2002). The first, *research support*, occurs when a firm contributes finances or equipment to a university, and incorporates the lowest degree of interactivity between the partners. *Cooperative research* involves a higher degree of interactivity, and aims to address immediate industry problems e.g. through contract research or consultancy. *Knowledge transfer* is still more interactive but also less targeted, covering a broad range of activities which includes ongoing personal interactions, cooperative education and curriculum development. *Technology transfer* is similarly highly interactive but much more focused, addressing specific industry issues through transforming university research into commercialized technology.

Of these four types of relationships, university–industry R&D collaboration broadly covers cooperative research and knowledge transfer. It involves mid- to high levels of interactivity, and can include joint research projects, university researchers working in firms or firm employees working in universities, university researchers engaging in short-term consultancies, participation in formal and informal networks, or formation of university–industry research centers (Calvert and Patel 2003; Perkmann and Walsh 2007). Collaborative arrangements can vary in scale (from small to large), temporal nature (from temporary to permanent) and structure (from individual projects to organizations).

One of the key benefits of research collaboration arise from the bringing together of complementary assets and knowledge, allowing research partners to gain access to a greater range of knowledge sources and catalyzing the exchange of ideas. This in turn facilitates research discovery, including the development of new technology. Further, R&D collaboration allows for the expansion of R&D activity by leveraging economies of scale and the reduction of research costs through the cost-sharing of equipment and facilities (Rigby and Edler 2005; Lee et al. 2012). Specifically for university–industry R&D collaboration, these benefits include firms gaining access to university research staff and their expertise, giving greater understanding of new areas of applied R&D and opening fresh directions for invention and technological innovation (Tijssen 2012). For universities, collaboration with industry provides a supplementary source for R&D funds, which is particularly valued as public funding for research becomes more constrained. In addition, such collaboration gives participating university researchers industrial expertise and exposure to practical problems, which can further enhance their research, and can also generate employment opportunities for university graduates (Santoro 2000; Wayne and College 2010).

Research interest in university–industry collaboration has grown, particularly in the light of the enhanced role that universities play in innovation and economic development as held by the Triple Helix thesis (Etzkowitz and Leydesdorff 2000; Calvert and Patel 2003). Many countries seek to strengthen cross-sectoral relations between the helices, including cooperative research between universities and industry. An increasing amount of public funding is thus being provided for university–industry R&D projects, e.g. the Advanced Technology Program in the US and the European Commission's Framework Programmes (Perkmann and Walsh 2007; Ambos et al. 2008). Meanwhile, universities which seek to become "entrepreneurial universities" are pursuing collaborative research with industry more actively in order to establish and consolidate their positions in knowledge markets and innovation networks (Tijssen 2006).

The importance of university–industry research is partially reflected in the proportion of industrial funding of university R&D, with industry-sponsored R&D being the most rapidly growing source of R&D funding for universities in recent years (Powers 2003). Concomitantly, the number of co-publications in scientific and technical journals involving authors from academia and industry has also been increasing (Lundberg et al. 2006; Calvert and Patel 2003). It is also becoming apparent in university technology transfer strategies. Whereas US universities in the 1980s and 1990s emphasized patenting and licensing strategies, leading universities such as University of California Berkeley and Stanford are now sharpening their focus on collaborative research relationships with industry and seeking to integrate their strategies on these different forms of technology transfer (Mowery 2007).

Co-publications as a measure of university–industry R&D collaboration

Co-publications—that is, co-authored publications with multiple affiliation addresses—have received increasing scholarly attention as a measure of research collaboration outputs in recent years. Unlike traditional R&D collaboration *input* measures such as the amount of university research funding sponsored by industry, co-publications represent tangible measures of joint research *output* (Lundberg et al. 2006; Tijssen 2006). Of course, many collaborative research projects do not eventuate in a co-authored paper. Or, in the reverse scenario, a publication may be co-authored where in fact no significant research collaboration has taken place. Another complication arises when a single author lists more than one institutional affiliation (as may occur when a researcher is on sabbatical and has undertaken a visiting fellowship or is on secondment) although no collaborative arrangement exists between the institutions. Set against these limitations are the advantages of co-publications for analyzing research collaborations, including the fact that they provide systematic, publicly available and internationally comparative data (Calvert and Patel 2003; Tijssen 2006). This gives it clear advantages over alternatives such as industry funding of university R&D, which is not always publicly available and may include contract research where no collaboration has taken place.

There is a growing consensus that co-publications could provide a reasonable proxy measure of university–industry research cooperation (Calvert and Patel 2003; Tijssen et al. 2009), and this is reflected in the increasing use of university–industry co-publications (UICPs) in recent literature to analyze university–industry research collaborations in several European countries, including the UK (Calvert and Patel 2003), the Netherlands (Ponds et al. 2007) and the Eastern European EU states (Glänzel and Schlemmer 2007). Isabelle (2007) investigated the relative production of patents and co-publications as outputs of public–private collaborative R&D in France, while Levy et al. (2009) analyzed co-publications as one of four channels of university–industry collaboration in an analysis of science-industry collaborative patterns of a European university. This paper follows these studies in using UICP as a proxy measure of university–industry research collaboration to investigate the impact of such collaboration on university technology commercialization output in the context of North American universities.

The impact of R&D collaboration on university technology commercialization

A number of arguments have been advanced in the prior literature on why R&D collaboration with industry is expected to have a positive effect on university technology commercialization output. The first pertains to the type of research conducted in the university. University–industry collaboration generally involves more applied research and targeted outcomes. The results are thus more likely to be conducive to being developed into commercially-oriented inventions than government-funded basic research (Powers 2003; Tijssen 2006; Di Gregorio and Shane 2003). Di Gregorio and Shane (2003) further argue that since industry-funded research tends to be less risky and has less information asymmetry problems than basic research, it is easier to subsequently commercialize. The second reason pertains to the benefits of having developed relationships with industrial researchers and other contacts. Interaction with industry gives faculty members access to such contacts and networks which can facilitate the commercialization of their inventions. For example, Sætre et al. (2009) argued that interaction with industry can assist university spin-offs in obtaining information needed about the new business, providing access to external resources, finding external support and services, providing them channels to advertise the new companies and searching for needed business advice. It also exposes university researchers to technological problems faced by firms and thus open research areas with commercial potential which they may not otherwise have encountered (D'Este and Patel 2007). More generally, university–industry interactions facilitated by collaborative research may have the potential to influence the university culture towards one that is more open to commercial opportunities: "It seems reasonable to assume that those universities that make attractive research partners…are probably also more inclined to embrace or promote a more business-oriented research culture themselves, and may eventually pursue their own entrepreneurial activities" (Tijssen 2006 p. 1574).

Empirical studies of the link between R&D collaborations and university technology commercialization

A body of empirical research has found that increased ties to industry do result in greater levels of commercialization (O'Shea et al. 2005; Powers 2003). In particular, at the organizational level, a number of studies have found the level or proportion of industry-funding of university research funding to have a significant influence on patenting and spin-off formation (Powers and McDougall 2005; Wayne and College 2010; O'Shea et al. 2005; Powers 2003; Di Gregorio and Shane 2003). The empirical evidence for the effect of such funding on licenses is less clear. Several studies have found, contrary to expectations, that such industry funding has no effect on the number of licenses (e.g. Powers 2003; Wayne and College 2010; Powers 2004; Sine et al. 2003). In contrast, Powers and McDougall (2005) did find evidence of a positive impact, although their sample focused on "IPO licenses", that is, the number of newly public companies to which the university had previously licensed a technology.

The evidence then, suggests that greater industry funding of university research can result in an increase of technology commercialization activities. However this does not necessarily imply a positive relationship between R&D collaboration and university technology commercialization, since industry-funded research may not involve collaboration (e.g. it may include contract research, in which a firm commissions a university to undertake research on behalf of the firm). Further, as an input measure, industry-funded research does not necessarily reflect the outcome of the research. Given this, UICPs provide an alternative indicator in investigating the relationship between university–industry R&D collaboration and technology commercialization, since the very fact that the research was published implies that the results were perceived to be sufficiently novel and significant to warrant dissemination (Lundberg et al. 2006).

Despite the growing interest in using co-publications to study university–industry research collaboration, few have attempted to quantify their effect on university technology commercialization. A number of studies (e.g. D'Este and Patel 2007; Carayol and Matt 2004a, b) have examined co-publications at the individual and laboratory level respectively and found that joint publications with industry generally increase the output of commercialization activities. At the organizational level, Tijssen (2006) studied the effect of public–private co-publication propensity[1] on university patenting in the field of immunology for 187 European universities over 1996–2001. Contrary to expectations his results revealed an inverse relationship between co-publication propensity and patenting. It is possible however that this result was partially due to the fact that that the period under analysis was the late 1990s, when entrepreneurial activities were as a whole less developed in Europe.

One limitation of the above prior studies on the link between UICP and technology commercialization is that they do not adequately control for a number of significant determinant factors that have been found to influence technology commercialization outputs, including the quantity and quality of university publications, and the resources allocated to commercialization activities such as the size and age of technology transfer offices (TTOs). The need to overcome this limitation will be elaborated further in the next section.

[1] In this and later studies (e.g. Tijssen et al. 2009), Tijssen uses the term 'intensity' in reference to the share of co-authored publications relative to total publications. We have replaced this term with 'propensity' as it more accurately reflects the meaning of the ratio.

Hypothesis formulation

The above literature review shows that despite the strong interest in university–industry research collaboration, empirical knowledge with regards to its impact on university technology commercialization remains limited (D'Este and Patel 2007). Synthesizing from the literature, there appears to be two pathways through which upstream university–industry research collaboration could result in downstream technology commercialization activities in the form of patenting, licensing and spin-offs:

(i) *direct* commercialization pathways, whereby the industry collaboration creates patented knowledge that is directly commercialized by the industry partners themselves through joint patent ownership or licensing;
(ii) *indirect* commercialization pathways, whereby the collaboration generates university-owned patents that are non-exclusive and could be licensed to other industrial firms not involved in the original collaboration; in addition, there could be wider knowledge spillover effects, whereby university researchers gain knowledge of industry needs and technology development directions through their industry collaboration, and use that knowledge to independently create new patented knowledge that is then commercialized by licensing to other industry firms, or through spin-offs by the university researchers themselves or their students.

Note that, while patenting activities (and to a large extent, licensing activities as well) are common to both direct and indirect commercialization pathways, spin-off formation is more clearly an indicator of indirect commercialization. As prior empirically research has not been able to clearly ascertain the relevant importance of direct versus indirect commercialization pathways, we make the following general hypothesis:

Hypothesis University–industry co-publication (UICP) propensity will have a positive effect on universities' commercialization output as measured by patenting, licensing and spin-off formation activities.

In contrast to the prior literature, we seek to test the above hypothesis after controlling for a number of factors that are found in prior research literature to have significant influence on university technology commercialization activities. Firstly, both the quantity and quality of research publications (commonly measured using publication counts and citations propensity rates) have been found to directly influence the level of patenting outputs of universities in a number of prior studies, at both the individual and institutional levels, generally finding a positive relationship between them (e.g. Owen-Smith and Powell 2003; Baldini 2006; Vinig and Van Rijsbergen 2009; Wong and Singh 2009). There has been somewhat less research on the relationship between publications and licensing and spin-off activities, but a number of prior studies do suggest a positive correlation. Vinig and Van Rijsbergen (2009) found that the quantity of publication output of universities is positively and significantly associated with licensing and spin-off formation in the US, while Powers and McDougall (2005) found publication quality to have a positive impact on "IPO licenses". Grandi and Grimaldi (2003) also found that scientific excellence, which included a measure of publication quantity, is positively related to the prediction of success of academic spin-offs.

Secondly, the amount of university resources allocated to support technology commercialization activities has also been found to have significant effect on university technology commercialization outputs (e.g. O'Shea et al. 2005; Powers and McDougall 2005; Powers 2003). Thus, aside from controlling for the quantity and quality of publications, obtaining an accurate estimate of the independent effect of UICPs on university technology commercialization necessitates taking account of the effects of university resources allocated to technology commercialization as well.

Data and analysis methodology

In this study we assembled data on the UICP propensity of 82 research-intensive North American universities (70 from the US and 12 from Canada). These universities are selected based on the following four criteria: (a) they have been listed in the World University Ranking (WUR) published by the Times Higher Education Supplement (THES); (b) they have been listed in Shanghai Jiao Tong University's Academic Ranking of World Universities (ARWU); (c) they have been granted at least one US patent since 1976, and (d) data on their co-publications with industry are available in the CWTS University–Industry Cooperation Scoreboard database (see below). Patent data for the universities was obtained from the database of the United States Patent and Trademark Office (USPTO). Data on the number of licenses executed, the number of spin-offs formed, and the characteristics of the universities' technology transfer offices (TTOs) were obtained from the AUTM (Association of University Technology Managers) licensing survey report summaries and AUTM's STATT (Statistics Access for Tech Transfer) database.

The following model is estimated:

$$\text{University technology output} = \beta_0 + \beta_1 \text{UICP propensity} + \sum \beta_{\text{j}} (\text{control variables}) + \varepsilon$$

The measures for each of the variables in the model are described below.

Dependent variables

Four alternative measures of university technology commercialization output were used as the dependent variables, based on three commonly used metrics to quantify such output: patenting; licensing; and spin-off formation.

The first dependent variable is the number of US patents issued to each university. As long as a university was named as an assignee to a patent, a full patent was counted to that university, regardless of the number of co-assignees for that patent.

However, patent quality varies widely, and analysis of quality-weighted patents provides a more accurate evaluation of universities' patenting productivity (Mowery 2007). As such, the second dependent variable is the number of citation-weighted patents. The method used for weighting the patents is discussed in Appendix 1.

Patenting reflects the first stage of the technology commercialization process, when the university technology transfer offices recognize the commercial potential of inventions disclosed to them and undertake to convert them into intellectual property protected by patents (Powers 2003). However, simply patenting an invention does not necessarily result in it being deployed in the market. The remaining dependent variables were included to capture this downstream part of the technology commercialization process: the number of licenses executed by the universities and the number of spin-off companies formed by the universities.

One limitation of using a cross-section study design is that changes over time are not captured (Powers 2003). In order to address this limitation, the dependent variables were calculated as the average annual numbers of each indicator over four years, from 2006 to 2009.[2] Likewise, the predictor and control variables were also averaged over a number of years before and up to 2005 or 2006 (see below).

Predictor variable

For the UICP explanatory variable we drew on Leiden University's CWTS University–Industry Cooperation Scoreboard 2008, a dataset developed by Tijssen et al. (2009) covering university–industry co-authored research publications in 350 universities around the world. Using Web of Science as their source, Tijssen et al. defined UICP as those publications which have at least one author affiliate address referring to a university and one to a private sector institution. UICP propensity is calculated as the percentage of university–industry co-publications within the university's total publication output published during 2002–2006.

Control variables

Publication-related control variables

Since previous research indicates that the quality and quantity of universities' research influences their technology commercialization output, measures of publication quantity and quality were included as control variables. The research output indicator was obtained from 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 Science Citation Index-Expanded (SCI-Expanded) and Social Science Citation Index (SSCI) databases,[3] with the scores being normalized to a maximum of 100 for the university with the largest number of journal articles. Our publication quantity indicator was obtained by averaging ARWU's SCI sub-index over four years to give an average score based on the number of journal articles produced from 2002 to 2005.

The measure of research quality was derived from the score for citations per faculty sub-index provided by the WUR. 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.

Control variables for commercialization resources

As highlighted earlier, previous research has found the amount of university resources for technology commercialization to affect the extent of commercialization output. Two

[2] Due to data availability restrictions, the citation-weighted patents were calculated based on patents issued between 2006 and 2008, with citations up to 2009.

[3] 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 correlation between the sub-index for 2005 is highly correlated with the data for 2006 ($r = 0.998$, $p = 0.000$), 2004 ($r = 0.995$, $p = 0.000$) and 2003 ($r = 0.993$, $p = 0.000$)].

alternative measures of such resources have been used in prior research: the number of personnel employed in technology transfer activities, and the length of time that the university has been involved in technology transfer activities (O'Shea et al. 2005; Powers and McDougall 2005; Powers 2003; Vinig and Van Rijsbergen 2009). The first measure, the number of licensing professionals is expected to have a positive effect on commercialization output, because the process of assessing technology, negotiating contracts and developing a climate conducive to technology transfer and academic entrepreneurship takes time and effort. It can therefore be expected that universities with technology transfer offices (TTOs) having greater personnel resources would have higher commercialization output (O'Shea et al. 2005; Di Gregorio and Shane 2003). The second is expected to positively influence commercialization output because staff in newly established TTOs face a steep learning curve, needing to develop the relevant skills to manage the university's commercialization efforts, as well as becoming acquainted with faculty and potential licensees. More established TTOs can therefore be expected to have accumulated greater expertise and more extensive contacts, and so exhibit better performance levels (Powers 2003; Powers and McDougall 2005).

In this study, we control for both measures. They are operationalized as the number of full-time equivalent (FTE) licensing professionals as of 2005 and the age of the TTO as of 2005 respectively. Both these measures are compiled from the AUTM surveys mentioned above for the year 2005.

Analysis methods

Multiple regression analysis was used with separate regression analyses for each of the four measures of technology commercialization output. Our initial regression model using the level values of the dependent and explanatory variables revealed the existence of heteroscedasticity problems.[4] To address this, we transformed the dependent variable by applying a square root function.

While the four control variables—quantity and quality publications, age of TTO and number of TTO personnel—were used as controls for all four regressions tests, we also used patenting output over the period 2003–2005 as an additional control in the regressions on licensing and spin-offs, since a number of prior studies (O'Shea et al. 2005; Di Gregorio and Shane 2003) have found it to be a significant determinant.

Results

The descriptive statistics of all the variables are shown in Table 1, while the Pearson correlations for all variables used in the regression analysis are shown in Table 2. The bivariate correlation between two independent variables, the publication quality and average number of US patents issued from 2003 to 2005 is somewhat high (0.70), but calculation of variance inflation factors showed that the maximum variance inflation factor (VIF) is 3.1. This is well below the threshold level of 10 (Powers and McDougall 2005), and so we concluded that the model does not suffer from multicollinearity.

A block step entry procedure was used with the non-publication control variables being entered in step 1, the publication control variables in step 2 and the independent variables in step 3. The regression results are shown in Tables 3, 4, 5. Including the publication

[4] See Appendix 2 for more details.

Table 1 Summary statistics

	n	Minimum	Maximum	Mean	Std. Deviation
Average no. US patents issued for 2006–2009	82	0	567.0	113.0	112.3
Average no. of citation-weighted US patents issued 2006–08	82	0	293.3	50.3	53.9
Average no. of licenses 2006–2009	82	1.5	186.0	34.6	30.8
Average no. spin-offs formed 2006–2009	82	0	21.3	4.5	3.9
TTO age as at 2005	82	6	80	22.2	13.2
2005 Licensing FTE	82	1.0	20.6	6.9	4.9
Average no. US patents issued for 2003–2005	82	0	142	26.0	27.9
Average of normalized score for publication quantity 2002–2005	82	28.3	100	48.8	13.7
Average normalized score for citations/faculty 1996–2005	82	0	100	14.5	14.7
UICP propensity indicator 2002–2006	82	2.6	6.2	4.3	0.91

variables generally improves the goodness of fit, particularly in the case of the models for simple and citation-weighted patents.

Patenting output

The regression results for simple patent counts support the hypothesis—UICP propensity is indeed a significant positive determinant for patents ($b = 1.03$, $p < 0.05$) (Table 3). In terms of the publication-related control variables, both publication quantity and quality were found to positively influence patenting ($b = 0.10$, $p < 0.01$ and $b = 0.12$, $p < 0.01$ respectively). Among the other two control variables, only the age of the TTO was significant, although the magnitude of the variable was very small ($b = 0.06$, p < 0.05).

The results for the regression for quality-adjusted patents similarly support the hypothesis, with the coefficient for UICP propensity being positive and significant ($b = 0.91$, $p < 0.01$). So too are the coefficients for the publications quantity variable ($b = 0.07$, $p < 0.01$) and the publications quality variable ($b = 0.09$, $p < 0.01$) (Table 4). TTO age is also significant.

Licensing output

The regression results for licensing output suggest that the hypothesis remains supported, albeit only at the 10 % significance level ($b = 0.42$, $p < 0.1$) (Table 5). Moreover, although publication quantity positively influences licensing ($b = 0.06$, $p < 0.01$), publication quality has no effect. TTO age is also not significant as a control, although TTO personnel has a weak positive effect ($b = 0.10$, $p < 0.1$). In addition, although the number of patents previously issued is significant in partial model 1 ($b = 0.02$, $p < 0.01$), this effect is removed once the publication control variables are included in the full model.

Table 2 Pearson correlations

	Average no. US patents issued for 2006–2009	Average no. of citation-weighted US patents issued 2006–2008	Average no. of licenses executed 2006–2009	Average no. spin-offs formed 2006–2009	TTO age as at 2005	2005 Licensing FTE	Average no. US patents issued for 2003–2005	Average of normalized score for publication quantity 2002–2005	Average normalized score for citations/faculty 1996–2005	UIC propensity indicator 2002–2006
Average no. US patents issued for 2006–2009	1									
Average no. of citation-weighted US patents issued 2006–2008	0.971**	1								
Average no. of licenses executed for 2006–2009	0.453**	0.403**	1							
Average no. spin-offs formed 2006–2009	0.644**	0.658**	0.401**	1						
TTO age as at 2005	0.434**	0.396**	0.331**	0.270*	1					
2005 Licensing FTE	0.482**	0.421**	0.514**	0.392**	0.393**	1				
Average no. US patents issued for 2003–2005	0.956**	0.936**	0.405**	0.586**	0.392**	0.402**	1			

Table 2 continued

	Average no. US patents issued for 2006–2009	Average no. of citation-weighted US patents issued 2006–2008	Average no. of licenses executed 2006–2009	Average no. spin-offs formed 2006–2009	TTO age as at 2005	2005 Licensing FTE	Average no. US patents issued for 2003–2005	Average of normalized score for publication quantity 2002–2005	Average normalized score for citations/faculty 1996–2005	UIC propensity indicator 2002–2006
Average of normalized score for publication quantity 2002–2005	0.565**	0.521**	0.523**	0.382**	0.293**	0.613**	0.569**	1		
Average normalized score for citations/faculty 1996–2005	0.696**	0.721**	0.276*	0.443**	0.199	0.263*	0.749**	0.448**	1	
UICP propensity indicator 2002–06	0.407**	0.420**	0.301**	0.495**	0.119	0.243*	0.379**	0.250*	0.299**	1

$n = 82$

** Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

Table 3 Regression of the square root of average US patent counts 2006–2009

	1	2	3
Constant	5.16** (0.96)	0.41 (1.42)	−3.42† (2.01)
TTO age as at 2005	0.08* (0.04)	0.06* (0.03)	0.06* (0.03)
No. Licensing FTE	0.37** (0.1)	0.1 (0.1)	0.08 (0.09)
Average of normalized score for publication quantity 2002–2005		0.10** (0.04)	0.10** (0.03)
Average normalized score for citations/ faculty 1996–2005		0.14** (0.03)	0.12** (0.03)
UICP propensity indicator 2002–2006			1.03* (0.4)
Adj R^2	0.252	0.547	0.578
F	14.66**	25.47**	23.23**
N	82	82	82

Standard errors in brackets

** Significant at the 1 % level

* Significant at the 5 % level

† Significant at the 10 % level

Table 4 Regression of the square root of average citation-weighted US patent counts 2006–2008

	1	2	3
Constant	3.37** (0.71)	0.11 (1.05)	−3.26* (1.46)
TTO age as at 2005	0.06* (0.03)	0.04† (0.02)	0.04* (0.02)
No. Licensing FTE	0.23** (0.07)	0.05 (0.07)	0.02 (0.07)
Average of normalized score for publication quantity 2002–2005		0.07** (0.03)	0.07** (0.03)
Average normalized score for citations/ faculty 1996–2005		0.11** (0.02)	0.09** (0.02)
UICP propensity indicator 2002–2006			0.91** (0.29)
Adj R^2	0.202	0.518	0.568
F	11.245**	22.762**	22.287**
N	82	82	82

Standard errors in brackets

** Significant at the 1 % level

* Significant at the 5 % level

† Significant at the 10 % level

Spin-off formation

For our final measure of technology commercialization output, Table 6 shows that UICP propensity also has a positive significant impact on the number of spin-offs formed ($b = 0.27$, $p < 0.01$). Neither publications quantity nor quality had any significant effect. With regards to the other control variables, only the number of patents previously issued is significant ($b = 0.01$, $p < 0.01$).

Table 5 Regression of the square root of the average no. of licenses executed 2006–2009

	1	2	3
Constant	3.10** (0.45)	1.02 (0.87)	−0.64 (1.28)
TTO age as at 2005	0.02 (0.02)	0.02 (0.02)	0.02 (0.02)
No. Licensing FTE	0.19** (0.05)	0.11* (0.06)	0.10† (0.05)
Average annual US patents issued 2003–2005	0.02** (0.01)	0.02 (0.01)	0.01 (0.01)
Average of normalized score for publication quantity 2002–2005		0.06** (0.02)	0.06** (0.02)
Average normalized score for citations/ faculty 1996–2005		−0.01 (0.02)	−0.01 (0.02)
UIC propensity indicator 2002–2006			0.42† (0.24)
Adj R^2	0.355	0.403	0.418
F	15.86**	11.93**	10.71**
N	82	82	82

Standard errors in brackets

** Significant at the 1 % level

* Significant at the 5 % level

† Significant at the 10 % level

Table 6 Regression of the square root of average no. of spin-offs formed 2006–2009

	1	2	3
Constant	1.37** (0.16)	1.25** (0.33)	0.17 (0.46)
TTO age as at 2005	−0.003 (0.01)	−0.003 (0.007)	−0.002 (0.006)
No. Licensing FTE	0.04* (0.02)	0.03 (0.02)	0.02 (0.02)
Average annual US patents issued 2003–2005	0.02** (0.003)	0.02** (0.01)	0.01** (0.01)
Average of normalized score for publication quantity 2002–2005		0.004 (0.008)	0.004 (0.007)
Average normalized score for citations/ faculty 1996–2005		−0.004 (0.008)	−0.01 (0.01)
UIC propensity indicator 2002–06			0.27** (0.09)
Adj R^2	0.340	0.327	0.397
F	14.912**	8.862**	9.90
N	82	82	82

Standard errors in brackets

** Significant at the 1 % level

* Significant at the 5 % level

† Significant at the 10 % level

Discussion

Implications of key findings

The key finding from our analysis is that R&D collaborations between university and industry, as measured by university–industry co-publications, is indeed a significant determinant factor of technology commercialization output after controlling for the effects of quality and quantity of publication output as well as TTO personnel size and age. The results are robust for all three measures of university technology commercialization outputs: patenting (both in terms of simple patent counts and citation-weighted counts), spin-off formation, and technology licensing.

Our findings of the positive influence of UICP propensity on university patenting output are consistent with a number of earlier studies (e.g. D'Este and Patel 2007; Carayol and Matt 2004a, b) that examined co-publications at the individual and laboratory level. However, they are contrary to Tijssen (2006)'s finding that UICP propensity has a negative influence on patenting among European universities. Further analysis would be needed to determine if the different findings reflect differences between European and North American universities, changes over time (our study covers 2006–2009 while Tijssen's study covers 1996–2001) or field of research (our study covers all fields while Tijssen's focuses only on one scientific field).

The weaker effect of UICP propensity on licensing activity are broadly consistent with earlier studies that fail to find strong relationship between industry share of university R&D funding and university licensing activity (e.g. Powers 2003; Wayne and College 2010; Powers 2004; Sine et al. 2003). One explanation may lie in the diverse motivations of firms to engage in R&D partnerships with universities. Powers (2003, 2004) notes that in sponsoring R&D in universities, firms do not necessarily aim to obtain a licensed technology. They may have other objectives, such as obtaining results from a clinical trial, or gaining access to faculty expertise for consultation. The relatively weaker relationship between UICP propensity and licensing activities as found in our results may thus suggest that industry partners may indeed be pursuing other indirect pathways of gaining commercializable knowledge besides direct licensing.

In contrast, the significant positive relationship between UICP propensity and spin-off formation offers evidence of wider knowledge spillovers from industry collaboration, leading to indirect pathways of commercialization that are independent of the direct collaboration partners.

Causal link between co-publication and technology commercialization: insights from selected case studies

Our regression results not withstanding, it is theoretically possible that the causal direction could run the other way, e.g. a spin-off that licensed a technology from a university could later lead to a research collaboration relationship, which in turn generates new co-publication. While such cases could occur, they are likely to be less frequent. Moreover, the possible existence of causal relationship in the opposite direction need not invalidate our findings, as we have factored in a time lag between our dependent variable (technology commercialization for period 2006–2009) and our explanatory variable (co-publication over 2002–2006).

To supplement our aggregate regression results and to better interpret the underlying causal mechanisms, we conducted five case studies involving matched records of industry co-publication and technology commercialization. These yielded findings largely consistent with the hypothesized causal direction, and provide additional qualitative insights on the causal mechanisms involved. One of the five cases did show possibility of a subsequent reverse causal link.

The cases were drawn from a random sampling of university faculty members at Stanford, MIT and Harvard known to have both industry co-publications and involvement in technology commercialization in the form of either patenting, licensing or spin-off. A match is ascertained where the nature of the technology involved can be linked unambiguously to the content of the scientific findings disclosed in some co-publication involving the same faculty. Records on industry co-publications involving the faculty members in the period 2002–2006 were first obtained from Thomson's Web of Science, and a content analysis of each co-published article was conducted. We then searched for patenting records involving the same faculty over the ten-year period 2000–2009 on the USPTO website to see if there is any match. Information on spin-off by the same faculty was likewise searched on the internet. After searching through about 20 such cases, we were able to find five matched cases, all showing the technology commercialization events occurring after the co-publication dates.

For three of the cases, the time frame of the co-publications and subsequent commercialization activity fall within the period used in the regression analysis; that is, co-authored papers published between 2002 and 2006, matched with commercialization outcomes occurring between 2006 and 2009.

The first case is that of two patents assigned to Stanford University and co-invented by Professor Paul Wender of Stanford's Chemistry Department. US Patent no. 7067698, issued in 2006, pertains to the development of a method in which molecular compounds used to transport drugs into cells can be prepared in a way that is cost effective and scalable. US Patent no. 7169814, issued in 2007, outlines methods to improve the transporting of molecular compounds containing drugs into cells. Both of these patents cite an article published in 2002, reporting on the design, synthesis and biological evaluation of a new family of molecular compounds that proved to be highly efficient in transporting drugs into cells and tissues (Wender et al. 2002). This paper was co-written by Prof Wender, a colleague from Stanford, and three employees from CellGate Inc, a pharmaceutical start-up. It thus appears that the co-publication came out of a research collaboration agreement between CellGate and Stanford, which yielded results that contributed to the invention of two patents. The relationship between CellGate and Stanford continued in subsequent years, with CellGate signing a second agreement to sponsor research in Prof Wender's lab in 2006 (Office of Technology Licensing, Stanford University 2006). It is conceivable that this second research collaboration project could lead to future co-publications.

A similar case was found for another Stanford-assigned patent issued in 2008, US patent no. 7405420. The patent was co-invented by Associate Professor Yi Cui of Stanford's Department of Materials Science and Engineering, and the invention related to systems and methods for phase-change memory, or chalcogenide-based nanowire memory, which can be used in memory storage devices. The patent cites a paper published two years earlier. This paper reporting on the synthesis and characterization of phase-change nanowires was co-written by Yi Cui, another Stanford colleague, and four employees from Hitachi High Technologies America (Meister et al. 2006).

The previous two cases show how R&D collaboration between university and industry, as reflected in co-publications, subsequently facilitated university patenting. A third case illustrates how an R&D collaboration between Harvard Medical School and Novartis facilitated the creation of a spin-off company, Acetylon Pharmaceuticals. Acetylon specializes in the development of small molecule pharmaceuticals and was co-founded in 2008 by Prof Kenneth Anderson of the Harvard Medical School. The drugs being developed by the company include small molecule histone deacetylase (HDAC) inhibitors (http://www.acetylon.com/). Tracing the history of the spin-off reveals that it began with Harvard researchers discovering members of the histone deacetylase family of enzymes over the period 1995–2004. In the later part of this period, the first small molecule inhibitor of HDAC6 was developed. It was then discovered that HDAC6 inhibition had the potential to play a role in the treatment of cancers such as multiple myeloma, some forms of lymphoma and leukemia, and also inflammatory disorders. Further research over 2004–2008 resulted in the discovery of a new HDAC6-selective inhibitor, as well as the development of compounds which displayed greater potency and selectivity for HDAC6 inhibition. Acetylon Pharmaceuticals was subsequently founded to commercialize this technology.

Of relevance to this paper is the fact that, during the period of discovery of HDAC inhibitors, Prof Anderson and his Harvard colleagues collaborated with Novartis in their research, and at least two of the HDAC inhibitors studied, NVP-LAQ824 and LBH589, were Novartis products. The results of the research on these compounds were published in a number of papers, co-authored by researchers from Harvard, Dana-Farber Cancer Institute (an affiliate of Harvard Medical School), and the Novartis Institutes for Biomedical Research. Catley et al. (2003) and Weisberg et al. (2004) report on the success of using NVP-LAQ824 against multiple myeloma and myeloid leukemia cells, while Catley et al. (2006) reports using LBH589 with another compound against multiple myeloma cells. These results were part of the chain of discovery which led to the eventual establishment of Acetylon Pharmaceuticals.

In addition to the three cases outlined above, we present two other cases to show that the lag between the R&D collaboration and the university patenting can be substantial and in fact longer than that allowed for in our study. Prof Arogyaswami Paulraj, from the Department of Electrical Engineering at Stanford co-invented a technology for improving communication in systems with multiple-antenna transmitters through optimized linear precoding based on a multi-parameter statistical description of the channel. The patent, US patent no. 7680212 was issued to Stanford University in 2010 and builds on earlier work published by Assoc Prof Paulraj with an employee of Iospan Wireless, an internet infrastructure company. The paper, published in 2002, outlined the design of an optimal linear precoder for a space–time coded system using a statistical channel description (Sampath and Paulraj 2002). Similarly, an MIT-assigned patent for drug delivery system comprising pH triggerable particles, suitable for DNA vaccines was co-invented by Prof Robert Langer, from MIT's Department of Chemical Engineering. The patent, US patent no. 7943179, was issued in 2011 and cited a 2004 paper co-authored between Prof Langer, colleagues from MIT and an employee of AP Pharma Inc, a specialty pharmaceutical company. The paper reported the design of synthetic biodegradable polymers for enhancing the efficacy of DNA vaccines. These last two cases suggest that a longer time lag between co-publication and commercialization outcome may more fully capture the effects of co-publication on university technology commercialization activities. This is at least partially due to the length of time taken to approve a patent. In the case of the MIT patent, although the application was filed in December 2004, several months after the paper was published, the patent was only approved seven years later.

Policy implications

Overall, our regression results, supplemented with qualitative case studies, do suggest that university co-publications (UICPs) could be a leading indicator of subsequent technology commercialization activities, capturing the enhanced capacity for technology commercialization that arises when universities engage in collaborative research with industry ("The impact of R&D collaboration on university technology commercialization"). Our findings thus suggest that the UICP propensity measure could be a valid and useful scientometric indicator that university administrators as well as public policy makers should regularly monitor, both inter-temporally to gauge industry collaboration trends over time, as well as cross-sectionally to benchmark against other reference universities' industry collaboration propensities. For university administrators, UICP data on their own university's researchers represent an easily accessible source of information on potential future technology commercialization activities and trends. For public policy makers, comparative benchmarking of the overall UICP propensity scores of universities under their watch versus a relevant reference set of other universities/countries, as well as a more detailed examination of the type and composition of firms that co-publish with the universities, could reveal systematic differences in industry collaboration propensities and broader university cultures towards commercialization across universities and countries.

While our findings are at an aggregate level and do not reveal the specific pathways through which research collaborations actually get translated into particular technology commercialization outputs, the fact that there is a positive link between upstream research collaboration and subsequent downstream technology commercialization activities in the form of both licensing and spin-off formation does suggest that both direct and indirect pathways of commercialization are involved, i.e. besides the direct mechanism of licensing by the collaborating industry partners, there appears to be significant knowledge spillover benefits leading to wider commercialization impacts beyond the collaborating firms. This finding has clear policy implications, as it suggests that industry collaboration can be used as a policy tool to promote the wider development of the third mission of the university, including greater entrepreneurial spin-off formation.

Limitations and future research directions

One limitation of this study is that it does not take into account the different fields of science. Previous studies have found that the degree of collaborative research varies with industrial sector and scientific discipline. For example, collaborative research is more commonly used than contract research in the chemicals, metals and automotive sectors, while the latter is more common in software development (Perkmann and Walsh 2007). Similarly, UICPs have been found to be particularly predominant in disciplines such as clinical medicine, physics and materials science, biomedical sciences and basic life sciences (Tijssen et al. 2009). By taking account of the different scientific fields in which universities and industries co-publish, future research may yield a more nuanced understanding of the relationship between UICP and technology commercialization.

Another limitation of the current regression study is that it is conducted at the macro-level, treating each university as a unit of observation, rather than at the micro-level of individual researchers and their co-authoring industrial partners. As such, it is not possible to trace how particular UICPs between specific professors and industrial firms are translated into subsequent technology commercialization forms (licensing, spin-off formation), and whether the parties who are involved in those commercialization activities are the same individuals or firms. While our small sample of five micro-level case studies provided useful qualitative insights, it would be useful in future research to collect micro-data systematically from individual university TTOs on the specific university researchers who generated patents and spin-offs and the specific firms that licensed from those patents, and to correlate these micro-data with UICP data on the individual researchers and firms who co-publish to examine the extent to which the same individuals or firms are cross-linked between scientific publications and the different modes of technology commercialization activities. Panel data analysis at this micro-level would help elucidate the actual direct and indirect pathways that lead from UICP to technology commercialization.

Appendix: 1 Construction of a citation-weighted patent count

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

$\mathrm{WPC_t} = \sum_{i=1}^{n_t} (1 + C_i)$, where n_t = number of patents issued to the university in year t for the years 2006 to 2008, and C_i is the number of citations received by each patent i up to the year 2009.

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 2006 and 2008, and data availability restricts our citation data to 2009, we have captured only a small fraction of the citations that will eventually be made to the patents in our database.

Appendix 2: Results of white test for heteroscedasticity

As can be seen in Appendix Table 7, the results for the White test reveal the presence of heteroscedasticity when using the level values of the dependent variables (DVs) in the regressions for simple patent counts (LM = 48.7, $p = 0.00$), citation-weighted patent counts (LM = 35.7, $p = 0.02$) and spin-offs (LM = 50.0, $p = 0.00$). After applying a square root transformation to the DVs, there is no evidence for heteroscedasticity for the regression for simple patent counts (LM = 30.3, $p = 0.06$) and citation-weighted patent counts (LM = 17.0, $p = 0.65$). Although the heteroscedasticity in the regression for spin-offs persists (LM = 42.07, $p = 0.03$), we did not attempt to further correct this, as the results remain unbiased. For consistency the square root transformation was also applied to the DV for the regression for licenses.

Table 7 Results for White test for heteroscedasticity: models with level DVs versus models with transformed DVs

Dependent variable	Level DV		Transformed (square root) DV	
	LM statistic	p value	LM statistic	p value
Average US patent count 2006–2009	48.71	0.00	30.34	0.06
Average citation-weighted US patent counts 2006–2008	35.67	0.02	16.97	0.65
Average no. of licenses executed 2006–09	29.68	0.33	20.83	0.79
Average no. of spin-offs formed 2006–09	50.02	0.00	42.07	0.03

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