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Universities and industrially relevant science: Towards measurement models and indicators of entrepreneurial orientation

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Abstract

Which university departments engaged in industrially relevant science are likely candidates to become entrepreneurial? At present, there are neither measurement models nor leading indicators that can answer such questions at an international comparative level. This paper introduces concepts, theory, and a measurement model for identifying (the early stages of) a university's enterpreneurial orientation within a quantitative analytical framework. This approach focuses specifically on university–industry interactions, in which the connectivity between academic science and industrial research is captured and measured empirically in terms of (1) public–private co-authored research articles, and (2) references ('citations') within corporate research articles to university research articles.

The paper examines a range of country-level and institutional determinants of industrially relevant science, across 18 research areas of significant industrial interest, and at two different levels of analysis: research systems of OECD countries, and large sets of research universities within those countries. The results of these large-scale analyses, along with those of a case study dealing with European universities active in the field of immunology research, suggest that many structural factors determine university–industry interactions and (the potential for) entrepreneurial orientation. The two connectivity indicators appear to be of minor significance compared to a university's country of location and the magnitude of its research activities in industrially relevant fields of science.

Keywords: University entrepreneurial orientation; Stage model; Knowledge spillovers; University–industry linkages; Research performance indicators

1. Introduction

This paper introduces a novel conceptual and analytical framework to conduct comprehensive and in-depth analyses of university's 'industrially relevant research' (IRR) in relation to the science-based entrepreneurial orientation (SEO) of university units. The scope of this paper is restricted to research-related activities, outcomes and impacts (thus excluding teaching, training, and consultancy activities with a commercial value). The earliest stages of SEO can be examined by looking at structural characteristics and abstract functions related to academic research activities, which are operationalised in terms of their research output, and their linkages and interactions with private-sector users of their research-based knowledge. The approach taken in this study focuses specifically on quantifiable information related to the production of codified research-based knowledge and its dissemination to science-dependent industrial R&D.[1]

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[1] There are many kinds of knowledge-intensive spillovers (e.g. intentional transfers as well as unintended spillovers), each of which may flow through various dissemination and communication channels, and may take different routes to transform and materialise into shapes and

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The phenomenon of entrepreneurial universities has now become widespread within the advanced industrialised countries as well as developing countries, and has attracted increasing policy attention. So far, most of the policy debate and empirical analysis focused on economic outputs and impacts of entrepreneurial universities (such as patents, licenses and start-up firms), or their technology transfer mechanisms and facilities. The pervasive diffusion of this entrepreneurial orientation justifies larger-scale and more in-depth empirical studies focusing on enterpreneurial potential. The analytical framework introduced in this paper enables a systematic investigation of early 'upstream' knowledge-generating stages of entrepreneurial science and university/industry interactions, both within and across and fields of science, as well as across countries.

The remainder of paper is organised as follows: Section 2 presents a brief review of theoretical concepts, empirical studies and policy issues related to entrepreneurial science that may guide the development of an indicator-based comparative framework. Section 3 introduces the two key indicators of IRR, and describes the methodology and data sets that are applied in the statistical analyses. Section 4 presents the results of the analyses dealing with the aggregate levels of countries and research fields. In addition, the statistical relationships between IRR indicators and university-owned patents are investigated for a sample of European universities active within the field of immunology research. Finally, Section 5 summarises the main findings, observations and interpretations leading to tentative conclusions as to the limitations and relevance of this new approach.

2. Theoretical and empirical background

2.1. University–industry interactions and entrepreneurial orientation

Clark (1998, 2004) introduces, from a higher education system perspective, five necessary conditions for the creation of an 'entrepreneurial university'. Three of these are particularly relevant in the case of research-oriented entrepreneurial universities[2] in the advanced industrialised countries: 'expanded developmental periphery', 'stimulated academic heartland', and 'integrated entrepreneurial culture'. Entrepreneurial research universities are viewed as those that embrace the spirit of enterprise and innovation, promote an entrepreneurial culture, reach across the traditional academic-industry boundaries to form mutually beneficial relationships, and create a variety of functions to accommodate the transfer of knowledge and technologies across these boundaries, while integrating new managerial and market-related practices.[3] Many of these research universities with science and technology departments are now in this process of transition, in which an increasing number of units 'at the developmental periphery' take the form of interdisciplinary or transdisciplinary research centres focusing on societal problems and pursuing enterpreneurial science to meets the needs of business sectors. They have the stock of knowledge and expertise, the knowledge-generating capabilities, and the research facilities to engage in science-based entrepreneurial activities. As a result, many find themselves in an advantageous position to participate in the growth of the science-dependent industries and are tempted to cash in on their contributions.

Parallel to the internal push towards application-oriented university science, many research-oriented universities nowadays also experience an external pull forcing them to engage (more) actively in programmes of external financing, to conduct contract research that is outsourced by the corporate sector, and to participate in collaborative public–private research partnerships.[4]

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added values that are deemed useful for intermediate users or end users of those inputs. These informational properties of science constitute a powerful analytical tool for studying the spillovers impacts and pay-offs of publicly funded basic science (Dasgupta and David, 1994). This applies especially to codified research-based information.

[2] The term 'research-oriented university' (or 'research university') is used in a broad sense, i.e. including 'research active' universities with relatively low quantities of research papers in international peer-reviewed journals, as well as 'research intensive' universities that produce many research papers. University research activities may span the entire spectrum from curiosity-driven academic 'discovery' research to problem-driven to highly focused 'applied' research for specific (end) users, as well as intermediate forms of research such as generic, mission-oriented 'strategic' research or 'engineering research' dealing with general purpose technologies.

[3] A university's industrially relevant research activities and its entrepreneurial orientation are likely to depend very significantly on a range of cultural determinants. More specifically, these include the 'managerial culture' at research universities (e.g. incentive systems), and the 'governance culture' of the research and higher education sector at the regional or national level (e.g. legislative and regulatory frameworks, business-promoting measures), as well as the overarching socio-economic culture of a country (e.g. risk-aversion attitudes in welfare states).

[4] Such measures gave a significant boost to the adoption or further professionalisation of IPR-related procedures and policies, while contract research conducted at universities is increasingly viewed as an inherent part of the routine activities of today's universities (Etzkowitz, 1998; Branscomb et al., 1999; Van Looy et al., 2003).

The implicit assumption here is that universities possess knowledge-based assets that are economically underexploited. Driven by this demand for access to university research and transferring research-based knowledge to domains of application, research universities have started shifting their knowledge production bases more towards problem-oriented research and the commercialisation of results.[5]

Most entrepreneurial universities have adopted new organisational structures and incentive policies to raise awareness among students and staff (such as specialised professorships, entrepreneurship courses, incorporating entrepreneurs into university curricula, and supporting graduates in their start-up activities). Those policies are often aimed at promoting managerial and attitudinal changes among academics toward the commercialisation of research findings and toward collaborative projects with business enterprises. Alongside the adoption of systematic practices with respect to technology development and IPR, universities may undertake an ever-larger variety of transfer-oriented arrangements, including industrial liaison offices, technology transfer offices, business incubator facilities, academic spin-off firms, science parks, or joint ventures in which universities start acting as a shareholder.[6]

For these truly entrepreneurial universities, commercialising research outputs and science-based technologies has increasingly become one of the (secondary) objectives of research universities—alongside their conventional mission and traditional drive to achieve and maintain international scientific leadership within industrially relevant fields of science and engineering. University–industry interactions are often the seedbed or catalyst of these commercialisation processes. Leading research universities in industrial-relevant fields of science are often actively involved in contract research, consultation, and other R&D linkages with industry in order to generate additional funding for research, as well as obtaining and consolidating strategic positions within the knowledge markets and innovation networks. Several of these ‘third income stream’ activities are relatively easy to quantify and monitor in terms of indicators capturing financial flows, as are the outputs of entrepreneurial science in terms of patents, spin-off companies, and amounts of revenues and new jobs generated (e.g. Molas-Gallart et al., 2002). Measuring the (intermediate) research outputs and associated knowledge flows during the ‘upstream’ early stages of SEO is a much more complex undertaking.

2.2. Towards a conceptual framework and measurement model

At present there is neither a convincing explanatory theory of fledging SEO, nor generally accepted concepts or compelling definitions of its salient characteristics, that offer guidance for the design of comparative metrics and quantitative indicators. Fortunately, a growing literature exists on university–industry research linkages and relationships (see e.g. Polt, 2001; OECD, 2002), as well as wide variety of recent case studies dealing with various organisational, psychological, cultural and economic issues related to academic entrepreneurship, ‘third stream’ research funding, technology transfer, and spin-off companies.[7] Building upon results of the above studies, the following general description of the potential for SEO is adopted in this paper: “the latent or emerging capability within a university organisation to create new resources and/or to utilise existing resources and facilities in such a way that results of intra-mural research and development activities are exploited and commercialised as assets (services, products, or related processes) that can be traded on the open market within a competitive business setting through a new or existing enterprise”. The nascent ability and motivation of university professors, researchers or students to pursue entrepreneurial activities will mostly entail a slowly evolving interplay between internal (endogenous) developments related to scientific and technological capabilities and activities, and external (exogenous) business-oriented and market-driven forces. One may

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[5] The shift toward commercialisation, and the possible implications for basic academic research, has spurred heated debate and controversy with the academic world and amongst science policy makers, and within the press (e.g. Nature editorial, 2001). Recent case studies indicate that these shifts are not necessarily detrimental to the basic research done at universities, but, on the contrary, tend to create positive effects (e.g., Van Looy et al., 2004).

[6] Increasing attention is being devoted to activities within science institutions for promoting linkages between universities and industry and for fostering the creation of university spin-offs. Empirical studies on the human and financial resources that universities devote to this purpose, and on the managerial and organisational structure of the transfer institutions and mechanisms they use (industrial liaison offices, technology transfer offices) are still scarce. Most of the research literature on this topic refers to institutions in the USA and UK (e.g., Lee, 1996; Bercovitz et al., 2001; Feldman et al., 2002; Link et al., 2003; Siegel et al., 2003; Lockett et al., 2005).

[7] Recent articles include: Klofsten and Jones-Evans (2000), Chiesa and Piccaluga (2000), Etzkowitz (2002), Molas-Gallart et al. (2002), Mowery and Ziedonis (2002), Ndonzuau et al. (2002), Etzkowitz (2003), Glassman et al. (2003), Goldfarb and Henrekson (2003), Meyer (2003), Powers (2004), Clarysse and Moray (2004), Lehrer and Asakawa (2004) and Powers and McDougall (2005).

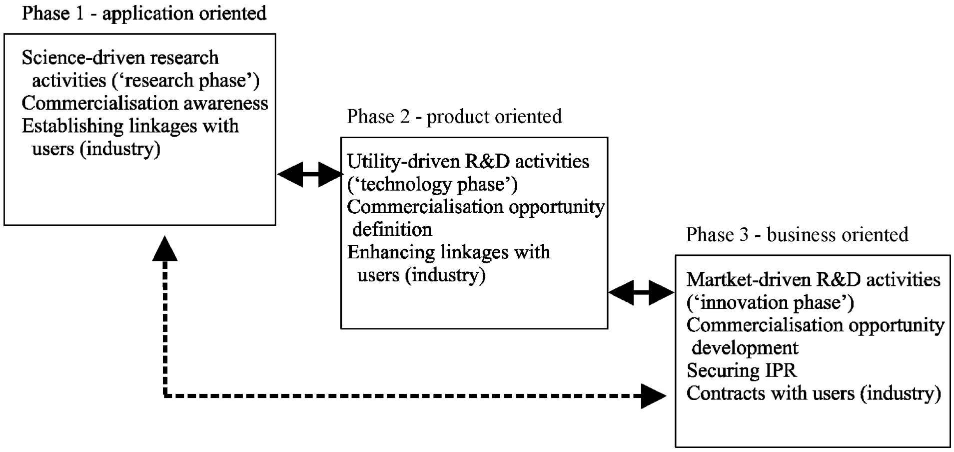

Fig. 1. Stage model of university science-based entrepreneurial orientation.

also assume that the nature of the knowledge-generating processes, and the organisational structure in which they take place, changes significantly as IRR develops towards commercialisation of knowledge-based products and services. This 'mind to market' trajectory leading to genuine academic entrepreneurship, i.e. launching or organising a new enterprise, can be modelled by the following three phases of development (see Fig. 1 for a stylised graphical representation).

2.2.1. Phase 1—'application-oriented/science-driven'

The direction of research activities acts as an institutionalised learning environment in which doing excellent R&D precedes or coincides with a growing awareness of possible links between research activities and business opportunities. Gradually, an institutional evolution will take place where a university unit seeks and recognises the commercial potential of its research-related knowledge assets (e.g. databases, software, discoveries, technologies, inventions and skills). It is a period in which (part of) the research agenda and new ideas are increasingly focused on problem-oriented research, developing user-oriented applications and defining the range of (potential) opportunities for commercialisation. Linkages with (industrial) users and potential customers are sought, established and cultivated; necessary research competences are created or upgraded.

2.2.2. Phase 2—'product oriented/utility-driven'

This stage partially overlaps with the first in several ways, as it concerns the (early) development of commercialisation opportunities; i.e. the translation and development of tangible and tacit assets into prototype building, and (customised) services, technologies or products with exploitable economic value. The university unit is becoming an entrepreneurial laboratory where exploring and improving the compatibility between its assets and demands by (potential) users is one of the driving forces. Managerial and organisational capabilities, incentive structures, delivery and pricing strategies, and an articulated long-term vision arise in order create an entrepreneurial environment that ensures a capacity to innovate in which new assets are created and existing assets are upgraded and translated into comparative advantages, intellectual property and economic utility. Business ideas and concepts are developed. Support facilities offered by entrepreneurship centres, industrial liaison offices and other specialist advisory facilities located on science parks and business incubators, are sought and explored.

2.2.3. Phase 3—'business oriented/market-driven'

Intellectual property rights are secured, some of which might prove detrimental for other academic activities such as publishing research papers in the open scientific literature (e.g. Tijssen, 2004a). Cont(r)acts with users and associated transfer capacities are created. The first (prototype) services or products are sold, either through contract research, consultancy work, or otherwise. The university unit is transforming into a quasi-enterprise, i.e. acting as a business enterprise, but lacking the legal status of a firm and its motive to generate and maximise profits. Market studies are conducted. During this final phase a further reduction of uncertainty will take place where still fewer services, products, ideas, concepts and entrepreneurial activities will become validated as innovations with an economic value. Business plans are prepared and executed. University staff members may become (part-time or full-time) entrepreneurs and establish a company, within or outside the university environment, in order to sell their products and services in the marketplace.

Note that this stage model of SEO suggests a linear sequential view of pathways towards entrepreneurship, which is obviously an oversimplification. It is probably the case that researchers work simultaneously on various forms of R&D, with diverse modes of funding and different objectives. Although empirical evidence is lacking, we may assume that progress towards entrepreneurial science is driven by iterative, organic and self-reinforcing processes characterised by many (time-delayed) feedback loops and idiosyncratic trajectories that are context-dependent and contingent upon country-, field-, market- and institute-specific factors, and last but not least by the unique capacities of highly motivated individuals. At some points during this development process, decisions are made, and subsequent actions taken, that are critical to phase transitions.[8] Moreover, when traversing from one phase to the other, new functions are added to university research units rather than being substituted; basic science in phase 1 is not being abandoned in favour of applied research or prototype development of phase 2; similarly the shift to entrepreneurial functions of phase 3 does not necessarily imply that all professors will become full-time entrepreneurs, nor that units are likely to abandon applied or basic research altogether.

3. Methodology: information sources and indicators

A valid empirical analysis of SEO must take into account as many as possible of inputs, throughputs and outputs that shape and drive SEO-activities within phases 1, 2 and 3 of the entrepreneurial process. Phase 1 factors may relate to entrepreneurial awareness within the university unit, or industry's awareness of university research and researchers; phase 2 relates to university–industry interactions, such as contract research and joint research; phase 3 may include patents and licences, and other related indicators of commercialisation efforts. A statistically robust indicator-based model of R&D-driven SEO should cover those factors which are manifest in identifiable activities and tangible results and that can be categorised and quantified with a statistically sound metrics. However, comparative data that may give rise to measurements and indicators for comparisons across organisational, geographical and cognitive boundaries are still scarce, a problem impeding the progress towards theories and indicators of science-based innovation (Tijssen, 2004b). Although some SEO characteristics are obviously amenable to measurement (such as patents), the current lack of generally acceptable and statistically sound metrics and information sources of quantitative data prevent the development to robust data for comparative measurements and indicators (see Table A1 in Appendix A for a non-exhaustive list of possible indicators characterised by their current feasibility for international comparisons of universities).

We therefore turn our attention to those very few measurable characteristics dealing with phases 1 and 2 that do enable an exploratory indicator-based assessment within an internationally comparative framework. This approach focuses on how universities contribute to the production of knowledge for the business sector and engage in cooperative research projects with business enterprises. The quantitative data are derived from the research publications that are (co) produced by academics and published in the scientific and engineering journal literature.[9] These publications arise from an 'open science' mechanism that produces a huge pool of knowledge, resulting mostly from basic scientific research that can be used freely by the international scientific community. Corporate researchers also draw from this source, sometimes quite heavily in case of science-based areas of technology (Jaffe, 1989).

Researchers and engineers employed by R&D performing companies also add to this source by publishing their own research findings in these journals. Although the quantities of corporate research publications appear to declining in recent years, industrial researchers still produce some 40 000 publications annually, the majority of which are co-authored with academics (Tijssen, 2004a). Often, these co-authored publications can be seen as tangible outcomes of a process in which

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[8] Obviously a wide variety of interrelated factors are likely to determine whether or not research units move on to the next phase (and the success or failure of these phase transitions). The outcome of these processes will be affected by a mix of socio-economic, physical, psychological, managerial, legislative and financial considerations. Such a dynamic, complex decision-making environment defies any comprehensive theoretical modeling. Central to these decision processes is the degree of alignment between a unit's past achievements and future potential, and the unit's drive to meet knowledge exploitation aspirations and goals, within an organisational and regulatory framework that fosters further development towards commercialisation and entrepreneurship.

[9] These publications represent one of most important international channels of knowledge transfer within the natural sciences, medical sciences and life sciences. In the other broad fields of science, particularly in the engineering sciences and computer sciences, conference proceedings and reports series are often used as highly valued vehicles for disseminating university research-based knowledge.

researchers are likely to have shared and exchanged tacit knowledge and skills (e.g., Rosenberg, 1990). The dissemination of these co-authored papers into the public domain therefore reflect direct spillovers of information, knowledge and technologies that are not easily captured by the information perspective of science. These co-publications also signal a more deliberate orientation of a university towards engaging in cooperative research with the private sector and (potential) industrial applications for academic research. It seems reasonable to assume that those universities that make attractive research partners or sources of industrial-relevant scientific knowledge for the business sector, are probably also more inclined to embrace or promote a more business-oriented research culture themselves, and may eventually pursue their own entrepreneurial activities.

In the process of publishing the research findings, the authors not only mention details about their research partners (i.e. the co-authors and their affiliations), but they usually also cite other research papers in the footnotes or reference lists of their journal articles. In doing so, they also leave a paper trial of other external information sources and associated knowledge flows.[10] The many millions of citations within research articles published each year in the international journal literature provides a rich source of empirical information for tapping into knowledge spillovers patterns worldwide and systemically analysing structural characteristics of those patterns. References within research papers by industrial researchers that cite research articles (co) produced by universities reflect indirect spillovers of knowledge produced by academic science and its absorption by industry.[11] Hence, citation-based knowledge spillovers between curiosity-driven academic research and strategy-driven corporate research indicate an awareness of new academic knowledge amongst industrial researchers and its utilisation during the course of their own corporate research (Tijssen and Van Leeuwen, 2006). Those university researchers that produce knowledge that is cited by industrial researchers are very likely to be active in research topics with a potential for industrial applications and commercial value in the long run. These cross-sectoral citations may also provide an early warning indicator of a university unit's industrial relevance.

The publication and citation data used in this study were extracted from the *CWTS Bibliometric Database*, which includes the *Thomson Scientific's* Citation Indexes (such as the *Science Citation Index*®) representing a unique source of bibliographic information on journal articles and the citation linkages between these articles.[12] The university sector contributes the vast majority of the millions of bibliographic records of research publications stored in this multidisciplinary international database; about 5% of the papers list an author affiliation in the business sector.

The publication records were retrieved from the CD-ROM issues of these bibliographic databases. Each record contains the full list of author affiliate addresses, which allowed us to identify the contributing universities and business enterprises. The data collection and data analysis is restricted to *research articles*, *review articles* and *letters*, since these document types are by far the most frequently used for reporting substantial and original research results. Using the bibliographic information from this database, two size-independent IRR indicators were designed for each university and field of science:

- *University–industry research cooperation intensity* (RCI): the quantity of public–private co-authored research publications relative to total output of research publications produced by a university within the same time-interval.
- *Industry-to-university corporate citations intensity* (CCI): the quantity of references ('citations') within corporate research papers to a university's research output relative to the university's total output of 'citable' publications.

Framed within this stage model of SEO, these indicators most likely to relate to phase 1.[13] The next sections will examine the statistical relationships between

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[10] Naturally, researchers will only tend to cite those printed sources that were of significant relevance to them—either to describe background information or introduce their research objectives, or, more specifically, to cite those sources that are directly related to the activities, achievements and outcomes reported in their research papers.

[11] The strong interpretation of citations is that they reflect a causal relationship between producer and user, revealing sources of academic science applied in industrial research. The weaker interpretation is that reasons for these citations are multivaried and ambiguous, thus emphasising a more casual relationship between cited sources and citing users.

[12] The CWTS/Thomson-Scientific database is owned and operated by CWTS under licence agreement with *Thomson Scientific*, a company of *Thomson International*. The database covers some 7 000 fully covered peer-reviewed journals out of a total of some 15 000 'sources' (i.e. journals or conference series).

[13] University research units traversing from phases 1 and 2 to phase 3 may produce significantly less 'citable' research articles (this being predominantly a product of phase 1). However, it is more likely that these units will increase staff numbers to accommodate for additional functions, while continuing to pursue basic (and applied) science and publishing research articles in peer-reviewed journals.

RCI, CCI and other determinants of SEO in more detail within the broader analytical context of domestic R&D systems, fields of science, and indicators of university entrepreneurial activities.

4. Findings: determinants of university–industry research interactions

4.1. Comparison of OECD countries

The science-based entrepreneurial activities of academics, and the likelihood of possible future entrepreneurial activities, tends to be driven by a matching of personal ambitions and perceived business opportunities, the ultimate realisation of which is heavily dependent on enabling factors and limitations at both the institutional or sectoral level. These meso-level determinants are in turn driven and affected by regional or country-specific regulatory frameworks and economic conditions. A proper appreciation of IRR indicators, and statistical modelling of its key determinants, should therefore begin by taking note of differences between countries with regard to their R&D systems and their innovation systems. This section is dedicated to exploring macro-level determinants within OECD countries as a function of relevant general characteristics of their R&D systems.

The scattergram presented in Fig. 2 depicts the CCI and RCI scores for each selected OECD country at the aggregate level. The significant positive correlation between CCI and RCI (Pearson's $r = 0.412$) suggests that these indicators represent interrelated characteristics of public–private knowledge creation and knowledge spillover processes. Very significant differences are found between countries, with top rankings for the United States, Switzerland, Japan, Canada, and some of the medium-sized countries in North-Western Europe. At the lower end of spectrum, we find the European-Mediterranean countries, Australia, and some Pacific-Asian countries. All high-ranking countries are advanced industrialised nations that have developed knowledge-based economies with R&D-intensive industries and large science-dependent enterprises. It is in these countries that one would expect to find most of the entrepreneurial universities. These nations tend to enjoy competitive advantages in terms of longstanding and close ties between the academic world and industrial research, which have helped shape domestic science bases that comprise of high-quality research-intensive universities pursuing research programmes geared towards the immediate needs or longer-term requirements of (local) industrial R&D. Cutting-edge scientific and engineering research in these leading countries is more likely to produce the discoveries and new insights and other science-dependent knowledge and outputs that may lead to commercial exploitation of research-based knowledge assets.

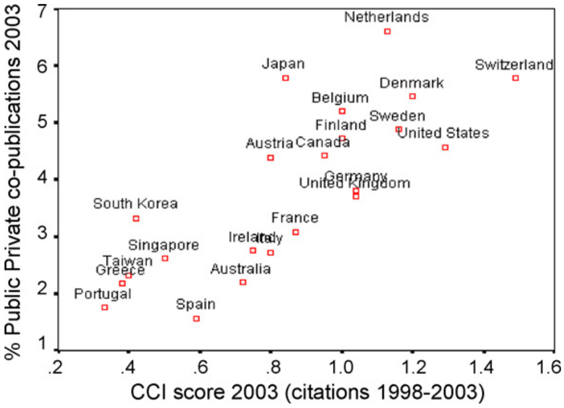

Fig. 2. Country performances on the CCI and RCI measure of public–private research interactions.

Clearly, the differences in CCI and RCI scores not only reflect country-specific differences in terms of the institutional structure of the public research sector, and cooperation arrangements between universities and research-based technology companies (especially the large science-dependent companies), but they also depend on R&D expenditures, resources and funding arrangements that may promote or impede industrial-relevant academic research and university/industry linkages. For lack of other macro-level data, one can only to resort to the conventional input/output-comparisons, based on the OECD's aggregate-level statistical data, to establish a general 'cause/effect' understanding of how differences between national research systems might determine country-level CCI and RCI scores. The quantitative data for the regression analyses were retrieved from the *OECD's Main Science and Technology Indicators* database, and *Thomson Scientific's* Citation Indexes (see Section 2). In order to control for the size of countries, all variables represent size-corrected scores. The input characteristics are represented by R&D expenditures as a percentage of a nation's Gross Domestic Product, broken by the main institutional sector (variables 1a–1c). Two additional input variables relate to the level of basic research activities within the business sector rather than R&D activities as a whole, in which scientific and engineering research usually contributes an estimated 5–10% at most: (variable 2a) share of university R&D (basic research mainly) that was funded by the business sector (either domestic or foreign companies);

Table 1
Explaining CCI and RCI scores at the country-level linear regression analysis across selected OECD countries (1996–2003)

	CCI		RCI	
	Beta	S.E.	Beta	S.E.
(1a) R&D intensity of higher education sector	0.159	0.324	5.487*	2.280
(1b) R&D intensity of government sector	−0.139	0.239	0.687	1.685
(1c) R&D intensity of business sector	0.008	0.068	−0.213	0.477
(1d) Science intensity of business sector	0.010	0.036	0.391	0.251
(2a) % higher education R&D funded by business	−0.003	0.008	0.066	0.053
(2b) Science activity of business sector	0.002	0.019	0.173	0.134
(3) Citation impact domestic science base	0.999**	0.160	0.839	1.126
Constant	−0.416*	0.157	−1.002	1.104
Fit of regression model (adjusted R^2)	0.86		0.69	

**,*Beta coefficients significant at 0.05 and 0.10 levels, respectively. Selected OECD countries: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, Korea, Netherlands, Portugal, Singapore, Spain, Sweden, Switzerland, Taiwan, United Kingdom, United States. *Data sources*: Thomson Scientific/CWTS database (2004 issue); OECD MSTI (2003/2 issue).

(variable 2b) the average number of research papers produced by the companies located in a country.[14] Variable 3 relates to the international scientific standing and to some extend also the international 'quality' of the science base as a whole, which is gauged by the citation impact of all research publications produced in both the public sector and private sector. This measure is calculated as the quantity of citations received by these papers relative to the worldwide citation impact averages in the respective (sub)fields of science.[15] Having removed field-dependent citation characteristics, this normalised measure allows us to compare impact scores across different fields of science. A 3-year time lag is applied between R&D funding (average of 1996–2001) and the research outputs and impacts (publication year 2001).[16] An additional 2-year time-lag is assumed between the overall performance of a domestic science base and its impact on university–industry interactions in terms of RCI score and the CCI score (publication year 2003). The detailed specifications are provided in Table A2 of Appendix A.

Table 1 displays the results of linear regression analyses for both indicators separately.[17] The regression model provides a very good fit in the case of the CCI scores, where the scientific quality of domestic science system turns out to be the major explanatory factor. In other words, the attractiveness of a domestic science base for industry correlates very significantly with its overall citation impact of that science base for worldwide science in general. Although proximity effects are likely to influence this outcome to some extent – notably, US industry citing US science – this outcome strongly suggests that industrial researchers tend to cite the most relevant research available, irrespective of the country of origin. The regression model for explaining the differences in RCI scores explains less variance, but again singles out one major determinant for explaining a country's share of private–public co-publications: the share of R&D expenditure in the higher education sector—in other words, the relative size of the academic research

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[14] This publication output variable refers to the share of the private sector within each country's total research publication output, which typically varies between 1 and 10% depending on the OECD country and whether or not joint public-private research publications are also attributed to the business enterprise sector (see Tijssen and Van Leeuwen, 2005). In this case, public–private co-publications were included.

[15] The subset of citing corporate papers represents about 5% of all citing research papers. Corporate research papers are heavily concentrated within a few industrially relevant science domains (see Tijssen and Van Leeuwen, 2005). Given these distinct differences, the possibility of extremely high correlations between the CCI variable and Citation impact, and thus multicollinearity in regression analysis models, is negligible.

[16] This is probably an optimistic estimate of the most appropriate time lag. It usually takes several years before (changes in the volume or distribution of) R&D resources may produce significant effects (if any) on the macro-level characteristics of an entire domestic science base that can be captured by bibliometric measures such as CCI and RCI. An average research project or programme may take 3–4 years to reach a point where statistically significant numbers of tangible outputs (trained staff, research papers, patents, etc.) materialise and disseminate. Finally, one may expect a very substantial time delay between science inputs and economic outputs. Econometric estimates by Adams (1990) suggest that it may take as long as 20 years before (changes in) stocks of US academic knowledge to generate a minor but measurable effect (0.5%) on the US macroeconomic productivity growth.

[17] This model is quite robust in terms of its sensitivity to time lag effects of R&D expenditure data. Replacing the OECD expenditure data with earlier data, referring to 1996, or more recent data referring to 2001, does not significantly alter the fit of the regression model or the value of the beta coefficients.

base within a national science system. A relatively large university research system is more likely to provide a diverse and high-quality pool of research-related sources and activities that are relevant for (local or foreign) science-dependent industry. Returning to the research question underlying this regression analysis, we now have convincing empirical evidence that a country's RCI and CCI scores are in large part determined by distinctly different structural properties of domestic science bases. Hence, the analytical distinction between RCI and CCI will be retained during the next step of our statistical modelling, which deals with the meso-level of the university sectors in the selected OECD countries broken down by field of science.

4.2. *The university sector and fields of science*

The meso-level analysis and modelling relates to a set of 18 pre-selected research fields of acknowledged industrial relevance, i.e. fields of science where private-sector organisations accounted for a substantial share of research papers published worldwide.[18] The geographical coverage is expanded to 25 OECD member states, covering a total of 6366 higher education sector institutions (research universities mainly) across these fields of science.[19] Framing the university–industry interactions in terms of knowledge flows also opens up the possibility for introduction of another interesting type of citation-based explanatory variable: the references in patents to the research literature published in scientific and technical journals. Similarly to citations from corporate research papers, these patent citations may also reflect the spillover and utilisation of scientific knowledge in business sector applications. The list of these 'non-patent references' (NPRs) often include one or more research articles published in peer-reviewed international journals. These NPRs have a direct or indirect bearing on the knowledge claims stated in the application, or provide relevant background information of knowledge domains described in the patent. As such, NPR-based data may provide information on science-technology linkages and public–private knowledge flows within and across national boundaries (e.g., Tijssen, 2001).

Table 2 exhibits the summary statistics of university performance within those 18 fields, grouped by broad field of science. The first noticeable feature of these key characteristics is the large variety across fields. Each field defines its own distinctive profile. The statistical relationship between CCI and RCI scores varies significantly between fields, where some fields within the *Engineering Sciences* exhibit quite low CCI–RCI correlation coefficients. The main conclusion to be drawn from these findings is that both CCI scores and RCI scores are field-specific and, therefore, statistical modelling needs to incorporate field-dependent parameters when focusing on the performance of individual universities.

The large research universities located in the advanced industrialised countries are more than likely to benefit from a competitive edge over their counterparts in other countries in terms of economies of scale and scope. These 'academic powerhouses' sustain a range of relevant research activities, equipment and infrastructure needed to assemble the critical mass of research talent and resources that enable the kind of cutting-edge basic research that (1) gets noticed and cited in corporate research papers and patents, and (2) attracts research partners from industry which may lead to joint research articles. Given the unfortunate lack of internationally comparative data for universities as to the size of their (human, financial and infrastructural) resources, such detailed like-by-like comparisons are beyond the scope of the current study. By way of crude estimate, the cross-university comparisons in this paper correct for the size of individual universities in terms of their publication output, i.e. the output in each of the respective fields relative to the output of the other universities within that same field. In other words, the powerhouse research universities are those that produce the largest quantities of research papers.[20]

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[18] These 18 fields of science were selected from a comprehensive set of 279 fields (i.e. sets of journals grouped under the heading of *Journal Categories*) that comprise the Thomson Scientific/CWTS field classification system. The 18 fields met the following selection criteria: (1) a minimum of 500 corporate papers worldwide in 2001; (2) at least one EU15 country with 50 or more papers authored by corporate researchers in 1996–2001; (3) at least one EU15 country with 25 or more public/private co-authored papers in 1996–2001.

[19] The three additional OECD countries are: Israel, Norway, and Peoples Republic of China. The total selection of 25 countries covers more than 95% of the worldwide publication output in the CWTS/Thomson Scientific database. The selection of universities was extracted from the top-1000 most highly cited public research organisations (at the main organisational level) within each field during the years 1996–2001 (see Tijssen and Van Looy, 2005). The total number of universities includes double counts owing to the fact that many universities publish in several of the selected fields. Each field-dependent set of universities includes only those cases that: (a) produced a minimum of six (co-authored) research articles published in 1996–2001, and (b) received a total of at least six citations from corporate research papers that were published during the same 6-year time-interval.

[20] The analysis accounts for disciplinary-based differences within the broad (engineering) universities, but only with respect to their degree of IRR (rather than SEO). The publications of university departments

Table 2
Indicators of university–industry interactions and linkages by industrial-relevant field of science

Main field and fields of science	Average publication output (freq.)	CCI (index)	RCI (%)	CCI–RCI (Pearson r)	Patent citations[a] (% universities cited)
Medical sciences and life sciences					
Biochemistry and molecular biology	525	0.50	6	0.42	89
Immunology	423	0.66	8	0.44	49
Neuroscience	477	0.37	3	0.40	30
Oncology	413	0.47	8	0.43	37
Pharmacology and pharmacy	494	0.51	8	0.40	33
Chemistry					
Analytical chemistry	492	0.52	4	0.39	45
Chemistry—general	412	0.31	3	0.34	50
Physical chemistry	476	0.25	4	0.44	42
Polymer science	334	0.43	7	0.23	29
Physics and materials science					
Applied physics	449	0.36	12	0.51	41
Materials science—general	414	0.21	9	0.48	22
Optics	243	0.32	6	0.25	35
Engineering sciences					
Electrical and electronic engineering	397	0.30	15	0.43	67
Chemical engineering	239	0.26	11	0.22	14
Computer science—theory and methods	133	0.19	11	0.20	29
Food science and technology	189	0.32	6	0.10	19
Metallurgy and metallurgical engineering	104	0.32	13	0.12	4
Nuclear science and technology	152	0.24	12	0.28	10

University averages across selected OECD countries; publication years and citation years, 1996–2001; citing year is 2001.

[a] The NPR indicator reflects the share of publishing universities within a field, of which at least one of their publications in the respective field have received one or more NPRs. The patent citations were extracted from USPTO patents published in the years 1996–2001 and citing papers published in 1996–2001 (courtesy of INCENTIM, Cath. Univ. of Leuven, Belgium). *Data sources*: Thomson Scientific/CWTS database (2004 issue); patent database of INCENTIM, Cath. Univ. of Leuven, Belgium (2002 issue).

To address these issues and questions a regression analysis was done for four explanatory variables: country of location, field of science, research publication output, and patent citations to the research literature. The statistical analysis relates to the actively publishing universities in the 18 selected research fields as a whole. The categorical regression analysis was done by means of CATREG.[21] Table 3 displays the outcome of both categorical regression analyses, clearly indicating that three out of four of the variables do indeed exert a significant impact on a university's CCI and RCI performance, even though the regression model explains only 40% of the variance. The magnitude of research activity is positively correlated with RCI: the larger the university, the higher the share of public–private co-publications. Size does matter apparently, either as an attractor of industrial interest, or by offering a critical mass of resources and facilities that enable the production of large numbers of public–private co-publications. Interestingly, we find a slightly negative coefficient in the case of CCI, suggesting that industrial-relevant research performed by the smaller universities attracts relatively more citations compared to the larger universities active within the same subfield. This outcome hints at the possible relevance of research specialisation as yet another of the exploratory variables, an issue that will be dealt with in the next section.

All the all, these results indicate that the field of science, the country of location and research size of a university are important variables when gauging the value of CCI and RCI scores as IRR indicators. The lack of explanatory power of patent citations comes as surprise in the light of the empirical evidence suggesting that

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or research groups will only occur in the analysis for those cases where they contributed significantly to the university's presence in industrially relevant fields of science, according to the selection criteria listed in footnote 19.

[21] CATREG performs a categorical 'optimal scaling' regression analysis, based on an ALS algorithm, that allows for entry of numerical variables, variables with an ordinal measurement level (i.e. rank ordered numbering of categories), as well as variables with a nominal measurement level (i.e. random numbering of categories). CATREG is included in the SPSS Statistical Package (PC Version 11.0).

Table 3
Explaining the CCI and RCI scores of individual research universities located in OECD countries (standardized beta coefficients and standard error); $n = 6366$ cases

	CCI		RCI	
	Beta	S.E.	Beta	S.E.
Field of science	0.459[a]	0.010	0.256[a]	0.010
Country of location	0.375[a]	0.010	0.308[a]	0.010
Publication output	−0.135[a]	0.009	0.487[a]	0.010
Patent citations to research papers	0.081	0.011	0.026	0.010
Fit of model (adjusted R^2)	0.37		0.41	

[a] Beta coefficients are statistically significant at 0.01 level. *Data source*: Thomson Scientific/CWTS database (2004).

these citations reflect the strength of science-technology linkages at macro- and meso-levels (e.g. Narin et al., 1997; Tijssen et al., 2000). The next section is devoted to scrutinising and testing the statistical relevance of some of those variables in more detail.

4.3. Validation study: European universities active in immunology research

The key notion underlying of this article is that university entrepreneurial activities will at some point start producing patents or other IP protecting measures prior to launching commercial activities or firms. Applying for patents constitutes a first step towards formalised university entrepreneurship.[22] Typically, IPR measures will emerge at phase 3 of the developmental process (see Section 2.2.3), which means that the production of patents can be used as a proxy of the transformation to university entrepreneurial activity. Hence, universities that apply for patents are more likely to exhibit entrepreneurial activities (at a later stage) as compared to those universities without patents. Obviously, this assumption holds only for those fields of science and industrial sectors where patents reflect university-based technological development, and for those national science systems where universities protect their IPR and commercialise those technologies by way of patenting. In effect, this restricts the scope of our validation study of science-related or science-dependent sectors where patents are prime vehicles for protecting and trading IPR: pharmaceuticals, biotechnology, chemicals, electronics, and computers. These high-tech R&D-intensive industries account for the majority of the patents, as well as the majority of research articles in international scientific and technical journals produced by business sector enterprises (e.g., Godin, 1996).

A recent empirical study conducted by Noyons et al. (2003) produced patent data for universities in Western European countries that were actively publishing in the fields of immunology and neuroscience.[23] The source consists of patents filed in the period 1995–2000 (priority years) at the *European Patent Office* (EPO). Immunology is selected as an illustrative representative for an in-depth study of CCI and RCI at the level of the 187 universities across 16 countries in Western Europe. The data in Table 2 indicate that immunology research is one of the major sources of information for R&D in the life sciences industries.

One of the key hypotheses following from this SEO model is that CCI and/or RCI scores should be positively correlated with university patenting activity, especially university-owned patents, either in terms of absolute quantities of patents or the quantities relative to the research magnitude of the university. With regard to the latter indicator, *the patent intensity* (PI) was calculated as the patent output of each university relative to its publication output in 1996–2001 related to immunology research.[24] The correlations presented in Table 4 indeed reveal low, but nonetheless significant, coefficients.

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[22] In some countries academics may also file for patents as individuals. Alternatively, academics have opted for transferring the patent rights to firms and take out (exclusive) licenses. Note that the quantities of university patents tend to be low thus compromising the statistical robustness of the model. Moreover some fields of science are more prone to R&D activities resulting in (USPTO) patent filings than other fields. Hence, the validity of patent intensity as a proxy of SEO is field-dependent. The NPR shares listed in Table 5 are most likely indicative of these differences in patenting propensities.

[23] The set of countries comprises all EU-15 member states (minus Luxembourg), Switzerland and Norway. Further methodological information about this study, and detailed results, can be viewed and downloaded at the project website www.cwts/ec-coe.

[24] The patent intensity value is equal to the ‰ share of patent output relative to the publication output. These fractions were recoded into seven categories with the frequencies following a normal Gaussian distribution (default option in the categorical regression package CATREG).

Table 4
Relationships between CCI and RCI scores and university patenting in immunology-related R&D

	CCI	RCI	PI
Corporate citation intensity (CCI)			
Research cooperation intensity (RCI)	0.436[a]		
Patent intensity (PI)	0.213[a]	−0.022	
Patents (P)	0.246[a]	0.260[a]	0.274[a]

Pearson correlation coefficients ($n = 187$ universities).

[a] Correlations are significant at the 0.01 level (two-tailed). Time-intervals: RCI and CCI scores (1996–2001); P and PI scores (1995–2000). *Data source*: Thomson Scientific/CWTS database (2004 issue).

Using patents as a partial indicator of phase 3 activities and outputs opens up the possibility for a more extensive validation study of SEO with additional explanatory variables. Expanding on the model described in Table 1, the following four variables are added relating to a university's research size or to its specialisation rate: (a) the total number of research articles published; (b) the total number of public–private co-authored articles; (c) the share of the research articles within the field; (d) the share of public–private co-authored articles within the field. The following hypotheses of university patenting behaviour can now be tested:

(a) the regression model will produce a better fit of university patenting in terms of the absolute numbers of patents, rather than using the relative numbers of patents;
(b) the model which includes the country of location included will produce a better fit (in view of the different patenting regimes across European countries);
(c) given their low correlation with patent intensity (see Table 3), neither CCI nor RCI will be major explanatory variables of patenting output.

The results of the regression analyses on patent output and patent intensity are presented in Table 5, which produce a reasonably good fit (about 75% of the variance explained) in the case of patent output as independent variable, either with or without the country of location included in the model. Hence, the university's country is not *the* key determinant that explains university patenting. Rather, the research magnitude and the orientation towards industry are the major explanatory factors: both the volume of research activity in general (i.e. total publication output across all fields), and the volume of research interaction with industry (i.e. total output of public–private research publications across all fields), exhibits the largest positive coefficients. The university's specialisation rate is of lesser significance. The contributions of RCI and CCI to the explanatory model show mixed results: CCI coefficients are statistically significant, positive, but relatively low; RCI coefficients are negative suggesting that university patenting tends to be inversely related with pursuing research partnerships with industry. Finally, patent citations to the research literature, again, do not seem to add any statistically relevant information to this model, which therefore also questions the credibility of this indicator as a measure of university-to-industry knowledge spillovers.

The regression on patent intensity as independent variable produces a much lower fit. This suggests that other, unknown variables also affect the level of patent

Table 5
Regression analyses models of university patenting activity in immunology research ($n = 187$ universities)

	Independent variable			
	Patent output, beta coefficients (S.E.)		Patent intensity, beta coefficients (S.E.)	
	Incl. 'Country'[a]	Excl. 'Country'[a]	Incl. 'Country'[a]	Excl. 'Country'[a]
Country	0.25 (0.04)**	N/A	0.63 (0.05)**	N/A
Total publication output all fields	0.41 (0.15)**	0.40 (0.16)**	−0.25 (0.17)	−0.54 (0.30)**
Public–private cooperation output all fields	0.39 (0.16)‘	0.42 (0.17)**	0.21 (0.18)	0.56 (0.31)**
Share total public output in field	0.18 (0.04)**	0.13 (0.05)**	−0.10 (0.05)**	−0.16 (0.09)*
Share public–private output in field	0.16 (0.08)**	0.09 (0.09)	0.23 (0.09)**	0.10 (0.15)
Corporate citation intensity (CCI)	0.09 (0.04)**	0.10 (0.04)**	0.18 (0.05)**	0.21 (0.08)**
Public–private cooperation intensity (RCI)	−0.21 (0.08)**	−0.13 (0.08)	−0.35 (0.09)**	−0.10 (0.15)
Patent citations to research papers	0.16 (0.04)	0.07 (0.04)	0.06 (0.05)	0.16 (0.08)**
Fit of model (adjusted R^2)	0.77	0.74	0.40	0.10

**,*Standardized beta coefficients are statistically significant at 0.05 and 0.10 levels, respectively. *Data sources*: Thomson Scientific/CWTS database (2004); patent database of INCENTIM.

[a] Regressor variables.

Table 6
European universities in immunology research with relatively high CCI scores and/or RCI scores, but lacking university-owned EPO-patents[a]

	Total publication output[b]	Public–private co-publication output	CCI (index)	RCI (%)	EPO-patents	TTI[c]
Univ. Brescia	214	32	2.33	15	0	No
Univ. Verona	159	6	0.86	4	0	No
Univ. Catania	65	6	0.65	9	0	No
Univ. Cagliari	51	0	0.31	0	0	No
Univ. Linkoping	214	11	0.19	5	0	Yes
Univ. Athens	121	6	0.19	5	0	Yes
Univ. Granada	63	0	0.38	0	0	Yes

[a] Top five universities ordered by decreasing CCI scores, and top five universities ordered by decreasing RCI scores (two duplicates were removed). Time-intervals: RCI and CCI scores (1996–2001); EPO patent filings (1995–2000); TTIs (2001–2003).

[b] Lower threshold for inclusion: total publication output frequency of 50 publications in 1996–2001.

[c] 'No' refers to the lack of a TTI or unknown formalised TT activity, according to the sources used in this study.

intensity, which casts doubt on the appropriateness of using patent intensity as an indicator of university entrepreneurial performance. The negative coefficients of the variables related to the total publication output indicate that the magnitude of research activities is negatively correlated with patent intensity, which follows from the difference in production functions of research papers and of patents. It usually requires much more time, effort and money one patent than to produce one research paper, as a result of which the less prolific universities may produce relatively many patents compared to the productive large 'powerhouses' with large numbers of research publications. Patent intensity tends to decline as the volume of research activities increases suggesting a 'saturation point' in terms of a maximum number of university-owned patents relative to the level of research inputs. The country of location is by far the most important explanatory variable, which suggests that the relative numbers of patents produced per unit research output ('patenting efficiency') is country-specific.

Overall, the outcome leads to general conclusion that university patenting is predominantly determined by endogenous research-related factors (such as the university's research portfolio, its volume of research activities, sophisticated equipment and technical facilities, and entrepreneurial culture), whereas patent intensities seem to be determined by exogenous factors such as domestic policies, regulatory frameworks, and support systems. The differences between universities in terms of how academic knowledge is disseminated and spilt over to the private sector turns out to be less significant. Furthermore, both CCI and RCI exhibit insignificant added value as indicators that might explain patenting behaviour of universities or act as reliable stand-alone predictors of university entrepreneurial potential.

The statistical analyses described above relate to the time-interval 1996–2001. With the benefit of hindsight, these data can be used to investigate whether or not universities with high scores on IRR-relevant variables have indeed started to develop their own entrepreneurial activities in more recent years. Although not directly linked any field of specific science or technology, the existence of university technology transfer institutes (TTIs) provide an indicator of university entrepreneurial activities. A recent list of European university TTIs was extracted from the results of the ITTI-survey that was finalised in 2004.[25] Most likely the majority of these TTIs, or their predecessor university departments or units, started technology transfer activities before 2001/2002. Note that immunology research-related activities are often not among the areas of specialisation of the European TTIs in this survey; only 24% of them indicated that their focus included the health sciences, a mere 16% mentioned clinical medicine, and only 14% list basic medicine as one of a focal areas.

In spite of these limitations of this information source, it is interesting to assess how the European universities with relatively high CCI or RCI scores but without patents, have fared in terms of launching their own TTIs. Table 6 lists the selection of universities with a fairly substantial research publication output in immunology during 1996–2001. Interestingly, five of the eight uni-

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[25] The data were extracted from a public domain CD-ROM *Technology Transfer Institutions in Europe—An Overview* that was produced by a consortium of *inno AG* (Germany), *Logotech-Innovation and Development* (Greece) and *Angle Technology Limited* (United Kingdom) as an attachment to their final report entitled *Technology Transfer Institutes in Europe* resulting from the EC-funded project *Improving institutions for the transfer of technology from science to enterprise* that was concluded in 2004 (http://europa.eu.int/comm/enterprise/enterprise_policy/competitiveness/doc/tti_typology.pdf). The data collecting survey presumably covers the years 2000–2002, although the time-interval is not explicitly specified in the final report (European Commission, 2004).

versities on this list are Italian ones, which suggest that this country in particular seems to have been lagging behind other Western European countries in terms of translating their research findings into formalised university entrepreneurial activities. This apparent failing was corrected in October 2001 when Italy passed innovative legislation (Law 383) by which patent ownership is assigned to the university inventor(s), while the inventor shares the proceeds from industrial exploitation by the university that employs the inventor.[26] As a result, TTIs have become more important in the university system, and many Italian universities (including Brescia, Cagliari and Verona) have joined the Italian inter-university cooperative *Network per la Valorizzazione della Ricerca Universitaria*, which was founded in 2002 and is devoted to promoting technology transfer activities, university patenting and spin-off companies (e.g. Cesaroni et al., 2005).

5. Discussion and cautionary remarks

The underlying notion and guiding principle of this study is the process view of a research university, i.e. a university that is becoming more entrepreneurial through time, during which it will engage in university–industry research cooperation and contract research. Some features of the process towards university entrepreneurial science, and possibly also the potential for academic entrepreneurship, are amenable to comparative measurement and can be captured by the two connectivity indicators introduced in this study: the *research cooperation intensity* (RCI) and the *corporate citation intensity* (CCI). The results indicate that both indicators are, at best, partial proxies of a university's entrepreneurial orientation. The industrial relevance of academic science, and the associated entrepreneurial potential of universities, is more likely to be affected by the country of location and the sheer magnitude of a university's research activities. Although they are still rather speculative indicators in need of further validation, CCI and RCI have nonetheless proven to be of significant instrumental relevance for investigating the structural characteristics of university–industry interactions, especially at the macro-level. Even so, it is important to keep in mind that the tentative conclusions drawn from these observations are valid only within the context of the analytical framework applied in this study, one that relies heavily on a conceptualisation of SEO in terms of university–industry interactions and connections, and hinging critically on comparative information derived from research articles in international scientific literature, patents, and citation flows. The scope of inference is therefore restricted to those fields of academic science and those research-based industries that produce significant numbers of research papers and patents. In many cases universities simply produce too few patents to warrant any definitive conclusions, irrespective of the field of science.

Owing to the rather narrow analytical focus adopted in this approach, one may easily overlook or neglect the possible contributions of education and training, transfer activities, and other research-related activities that may ultimately prove to be more important drivers and effective channels for universities to generate (complementary) economic returns. Given the fact that a host of country-, field- and organisation-specific factors are likely to impact on different phases of these processes, it is unreasonable to assume that this daunting complexity can be easily reduced to a single convincing measurement model that may give rise to reliable leading indicators. This inherent constraint is exacerbated by the dynamics of modern-day science and its manifold interactions with economic development; the world of university entrepreneurial science will have moved on, and may have altered significantly, before a plausible general theory, comprehensive models, and appropriate indicators have been developed.

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[26] Under the new law universities have a right to claim at least 30% in the event that no internal regulations are established and up to a maximum of 50% if internal regulations are established. Some universities allow scientists to offer their IP rights to the employer and, if the offer is accepted, the university agrees to cover patent costs in exchange for a higher percentage of the proceeds from industrial exploitation.

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Appendix A

See Tables A1 and A2.

Table A1
Indicators of university–industry linkages and university science-based entrepreneurial orientation

	Measurements and comparative data across universities
Informal contacts with (potential) users in advisory boards, scientific committees; industry fairs, exhibitions, conferences	[a]
Joint supervision by industrial researchers of PhDs and Masters theses	[a]
Contract research and consultancy	[a]
Licensing of university patents to enterprises	[a]
Purchase of (consultancy) services, or products and prototypes developed by universities	[a]
Use of university research facilities by industry	[a]
Attending entrepreneurship courses and/or IPR courses by students or staff	[b]
Organising lectures, meetings, workshops, training courses or conferences, with contributions from industry and other external users of university knowledge	[b]
Collaborative research and joint research programmes	[b]
Mobility of researchers between industry and university; temporary stays and sabbatical leaves	[c]
Joint research publications with industry	[c]
University research publications citing corporate research publications	[c]
Corporate research publications citing university research publications	[c]
Citing of a university research publication within a corporate patent	[c]
University patenting	[c]
Presence of industrial liaison offices or technology transfer institutions	[c]
Presence of business incubator facilities or science parks	[c]

[a] Non-existant or very limited possibilities for measurement and comparative data.
[b] Measurements are possible; comparative data often only available on a case study basis.
[c] Indicators under development or already in use; comparative data often at national or regional level.

Table A2
Variables in the regression analyses (see Table 1)

Variables	Label	Data points
Relative number of citations received from research publications co-authored by business enterprises	CCI	2003 (1998–2003)
% of research co-publications co-authored by public research organizations and business enterprises	RCI	2003
Higher education R&D expenditure as % of gross domestic product	R&D intensity higher education sector	Average 1996–2001
Intra-mural government R&D expenditure as % of gross domestic product	R&D intensity	Average 1996–2001
Government sector	Average 1996–2001	Average 1996–2001
% higher education R&D expenditure funded by business enterprises	% higher education R&D funded by business	Average 1996–2001
Business sector R&D expenditure as % of gross domestic product	R&D intensity business sector	Average 1996–2001
% publication output produced by business enterprises	Science intensity of business sector	2001
Average number of research publications per business enterprise	Science activity of business sector	2001
Relative number of citations received by all research publications of a country (public sector and private-sector publication output)	Citation impact domestic science base	2001 (1996–2001)

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