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CWTS Working Paper Series	
Paper number	CWTS-WP-2012-009
Publication date	July 17, 2012
Number of pages	19
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R&D globalization processes and university-industry research cooperation: measurement and indicators

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Abstract

Despite continued and widespread attention to R&D globalization, both within academic studies and policy reports, micro-level measurement and monitoring still lacks robust quantitative indicators. This paper introduces a measurement methodology with regard to the internationalization of public-private research cooperation, which is believed to be a key element in creating and fostering innovative knowledge-intensive business sectors. University-industry co-authored research publications constitute one of the key sources to assess and measure organizational, geographical and temporal features of cross-sectoral cooperation.

The descriptive analysis presents country-level comparative measurements of globalization patterns in recent years. An illustrative case study deals with the multinational company *Boehringer Ingelheim*, one of the world's major research-active pharmaceuticals companies, which collaborates with a range of universities worldwide including several South African ones. Overall, the findings reveal macro and micro level impacts of R&D globalization on academic research collaboration portfolio's.

Keywords

Research collaboration; internationalization; multinational companies; South Africa; statistics; knowledge flows

1 Introduction

Economic globalization is more than movements of people, money, services and goods. It is also about the flow of ideas and information (Storper, 2000). As global competition for new ideas and innovative technologies seems to be intensifying, the necessary knowledge and resources needed to conduct cutting-edge R&D are gathered from an increasingly wider range of suppliers. Over the last two decades R&D-intensive firms are looking more to universities for solving fundamental problems and producing science-based technologies to fill their corporate innovation pipelines. Many large R&D-intensive enterprises are now for economic reasons increasingly inclined to outsource their basic science to, or establishing close collaborative ties with, universities and government research institutes wherever they can find the best suitable provider (Broström, 2010). This is especially true in the advanced nations with well-developed research and innovation systems.

Most of the academic studies on research collaboration focus on formal relationships at the organizational level, such as the occurrence of joint labs, contract research, university spin-off companies (Audretsch et al., 2010). These relationships are visible and relatively easy to identify, classify and measure. However, a large slice of industry-science interactions and relationships take place through informal and indirect channels, or through unrecorded, 'confidential' direct channels (OECD, 2002). These hidden linkages often relate to intangible processes and relationships between individuals that tend to attract much less attention.

Geographical and economic factors exert a significant impact on these processes. Despite the magnitude of the corporate R&D expenditure and on-going economic globalization processes, the internationalization of corporate science is largely uncharted territory in terms of comparative R&D statistics, both at the macro level and company level (Tijssen, 2009).[1] Internationalization is often examined and monitored by measuring R&D expenditures in home countries and host countries. The conventional economic frameworks that are applied by R&D analysts, such as the OECD, include several proxies of science-related flows between the public sector and private sector (OECD, 2002):

- Capital (research income, contract research funds, equipment and facilities; commercialization of research-generated intellectual property);

[1] The term 'internationalization' is understood as reflecting "the systematic geographical expansion of the corporate research base in terms of in-house research, the location of external research partners, or composition of research networks". The term 'globalization' denotes an advanced stage of internationalization where a company's R&D sites and partners are dispersed across several continents (cf. Tijssen, 2009).

- Human resources and tacit knowledge (business sector employment of PhD graduates, R&D staff, engineers and technicians);
- Codified knowledge (access to research-based documents).

Unfortunately, these traditional R&D-expenditure statistics are less appropriate to help determine and measure the globalization of corporate research and its collaborations with the public sector. Data on corporate research expenditures is not (fully) specified in company accounts, let alone at the level of (foreign) affiliates and subsidiaries. Using publicly accessible sources of corporate information (announcements, annual reports, accounts and financial statements, or websites of companies) provides at best a crude insight into corporate research activities. Not surprisingly, OECD's current list of globalization indicators does not include research-based public-private cooperation (PPC) between companies and public sector institutions (OECD, 2005; 2010).[2]

The only information source in the public domain offering valuable systematic data are research articles published in the open scientific literature. Data mining these publications provides valuable detailed information on the distributional characteristics of research globalization, at a level of detail hidden beneath the macro level surface of national R&D statistics.

The remainder of this paper is structured as follows: section 2 introduces a general theoretical framework that summarizes three decades of academic studies on public-private research cooperation. Section 3 highlights the research methodology and data source to produce novel indicators and statistics. Section 4 introduces PPC measurements at the macro level of countries as well as a cross-validation study for the PPC indicator. Section 5 describes a micro-level case study of *Boehringer Ingelheim*'s globalized network of research partnerships and linkages, which include South African universities. Concluding remarks on the methodology are collected in section 6.

2 Theoretical and conceptual framework

2.1 Innovation and R&D cooperation

Markets force companies to develop innovative products and services faster than ever. Companies are increasingly opening their innovation processes and collaborating on innovation with external partners (suppliers, customers,

[2] The list of OECD indicators on international co-operation in science, technology and innovation includes patents, co-authorship of scientific publications and formal co-operation arrangements. An alternative source of statistical information on globalization processes worldwide – the KOF index (http://globalization.kof.ethz.ch/) provides no information on science, technology or innovation.

universities, etc.) and 'open innovation' platforms (e.g. Chesborough, 2003), providing mechanisms by which corporations can pool R&D talent and capacity to seek rapid innovation solutions to their R&D problems and questions. Only through cooperation can innovative technology companies gain full access, through the international exchange of new knowledge and ideas, to all relevant science outside the company. Such distributed models also mark a next step within corporate strategies to (co)operate more flexibly within globalizing R&D and innovation environments.

Many R&D-intensive business companies are increasingly utilizing science-based resources to support their in-house R&D efforts and technological innovations. As global competition intensifies and innovation becomes riskier and more costly, the business sector has been internationalizing knowledge-intensive corporate functions including R&D. Networks of knowledge are increasingly important agents of change within these evolving science-innovation ecologies (e.g. Ramlogan et al., 2007). The development and maintenance of a high-quality corporate R&D base, with sufficient levels of absorptive capacity, requires the active engagement of R&D staff who are aware of, and actively participate in, international frontiers of scientific and engineering research.

University-industry R&D linkages and cooperation have attracted considerable interest in academic studies over the last three decades, either within the framework of national innovation systems (e.g. Link, 1999; Mowery and Sampat, 2005), technology transfer and commercialization (e.g. Adams et al., 2001), or the internationalization of corporate R&D (e.g. Audretsch, and Feldman, 1996). These studies have identified two main motivations among companies for engaging in industry-university research cooperation relationships: access to key research staff and access to complementary research activity and relevant results. The large research-intensive universities offer unique assets and economics of scope and specialization that can induce the kind of agglomeration effects to within national or regional research and higher education systems that attracts foreign R&D partners and positively influence location decisions of firms (e.g. Mansfield, 1995; Mansfield and Lee, 1996; Audretsch and Feldman, 1996; Audretsch and Stephan, 1996; Thursby and Thursby, 2006a). Academic research provides firms with promising new areas of applied R&D, they avoid wasteful experimentation, and an understanding of novel directions on inventions and technological innovations (Rosenberg, 1990; Fleming and Sorensen, 2004). The literature review by Cohen et al. (1997) indicates that university research augments the capacity of businesses to solve complex problems and enhances R&D productivity, patenting activity and firms' sales.

University motivations to engage in applied commercial research and research partnerships with industry are also divers (Cohen et al., 2002; D'Este and Patel, 2007; Fontana et al., 2006; Meyer-Kramer and Schmoch, 1998); partially because the academics perceive opportunities for furthering their research interests and (monetary) rewards, partially because of administration-based financial pressures on faculty. Case studies of individual universities indicate that joint research is among the most frequently mentioned modes of interaction and knowledge transfer, but other linkages such as consultancy are also very relevant (e.g. Martinelli et al., 2008). Nonetheless, collaborative research is often just one of many ways to interact and liaise with corporate partners (Bekkers and Bodas-Freitas, 2008).

Empirical studies indicate that most industry-university collaborations involve the larger R&D-dependent firms of over 500 employees (e.g. Hanel and St-Pierre, 2006), that operate R&D units and laboratories to absorb and utilize the research-related inputs from academia. OECD statistics reveal that the large innovating companies (more than 250 employees) are still much more likely to collaborate with universities than SMEs (OECD, 2007). These statistics also exhibit a wide variation in share of those large companies active in collaboration, ranging from 50% in Finland (*Nokia*) to a mere 5% in Australia, owing to the presence of these R&D-intensive and science-dependent companies within a country.

2.2 Geographical proximity and globalization

Some say that geographical proximity is also often no longer the main criterion for selecting a suitable research partners; because of 'value for money' high-tech businesses are now more inclined to cooperate with the most appropriate or best-performing universities regardless of their physical location. A multitude of case studies of public-private research cooperation have examined these trends and the role of (close) proximity, and associated knowledge spillover effects (Arundel and Geuna, 2004; Tijssen, 2004a; Tijssen, 2009; Ponds et al., 2010). The findings strongly suggest that physical proximity is indeed becoming increasingly irrelevant in contemporary R&D. This assertion is recently confirmed by results from a macro-level study, which shows that the maximum distance between research partners in general has increased fivefold since 1980 to more than 1500 kilometers in 2009 (Van Eck et al., 2011).

However, spatial proximity between partners, and their geographical location, will remain key determinants in the years to come, which may seem surprising in a world that is increasingly relying upon electronic communications, perhaps even

paradoxical at first glance. The propensity to collaborate with foreign corporate partners, and the chances of success, still heavily depends on the right R&D framework conditions, notably research capabilities and pivotal positions in global R&D networks (e.g. Gertler and Levitte, 2005). Empirical studies show that spatial proximity is relevant to the R&D performance of science-based high-tech firms (e.g. Cohen et al., 2002; Katz, 1994; Mansfield, 1995). The transfer of contextual and embodied 'tacit' knowledge and skills is still best done via face-to-face interaction and through frequent contact (e.g. Von Hipple, 1994). Moreover, international partnerships are more difficult to manage and more costly. For these reasons, as well as historical developments leading to personal relationships and trust, many companies continue to prefer working with local academic research partners, which is seen as critical for easy access to desirable facilities and for recruiting highly skilled people from nearby universities (e.g. Arundel and Geuna, 2004).

PPC globalization is driven and shaped and by trade-offs between close proximity partnerships and long-distance connections, and by these processes of mutual attraction and integration between cutting-edge academic science and innovative corporate R&D (Bjerregaard, 2010). The leading actors this process are the world's largest science-based multinational enterprises (MNEs), operating decentralized R&D structures with geographically dispersed R&D sites (Kleinert, 2003; OECD, 2008). The large MNEs active in science-oriented industrial sectors (biopharmaceuticals, electronics, chemicals, food) are at the frontier of these developments, setting up R&D units abroad and outsourcing research (Cloodt et al., 2006; Laursen and Salter, 2004; Roijakkers and Hagedoorn, 2006). R&D performed abroad by their foreign affiliates now represents on average some 16% of total industrial R&D expenditure within the OECD area (OECD, 2007). R&D by their foreign affiliations was traditionally focused on 'home base exploitive' R&D to adapt technologies to foreign markets, but with the establishment of increasing numbers of science-oriented R&D units, suggest that the strategic objectives now also include 'home base augmenting' R&D that is meant to create or improve science-based innovative technologies (Von Zedtwitz and Gassman, 2002).

Nonetheless, science-based technology companies often continue to perform the bulk of their basic scientific research in their home country or in other advanced economies (Thursby and Thursby, 2006a; Tijssen, 2009). The preference for locating R&D in (home) nations with the strongest academic science systems is however gradually giving way to decisions that involve partnerships in emerging countries, most prominently China nowadays, but also

others that are catching up in terms of rapidly increasing R&D budgets and stocks of relatively cheap, high-quality human resources (OECD, 2007). Several studies strongly suggest that the strength of the science base in host countries is one of the key factors for foreign corporations to establish these innovation oriented R&D affiliations (e.g. Belderbos et al., 2008). The research strength of local universities ranks high among MNEs as a determinant of foreign R&D locations (Thursby and Thursby, 2006b). Similarly, the availability of a large and high-quality pool of scientists and engineers is also an attractor for off-shoring corporate foreign R&D to host countries, especially when such human capital is scarce in the home country.

2.3 Collaboration and co-authored publications

The research articles published in the peer-reviewed journal literature is one of the main outputs of high-quality 'discovery' scientific and technical research. At present, research publications in these journals and periodicals are the only publicly accessible micro-level source enabling systematic international statistical data across geographic and institutional borders. The large majority of the publications are research articles (co)produced by scientists, engineers and technicians employed by universities and public sector research institutes. However, corporate R&D staff also publish; often for a variety of reasons and sometimes in large numbers (e.g. Hicks, 1995; Tijssen, 2009). A significant fraction of their publication output is jointly authored with research partners in the public sector. These co-publications represent (successful) research cooperation, or associated research related interactions, between the private sector organizations (mainly business enterprises) and public sector organizations (research universities mainly). Public-private co-publications (PPCs) contain at least one address of private sector for-profit company and one public sector organization. Where the latter refers to a university (either publicly or privately funded) and the company is (predominantly) active in industrial sectors, the sub-class of PPCs is denoted as university-industry co-publications (UICs).

It seems reasonable to assume that producing (relatively) large quantities of UICs at the very least reflects their attractiveness of specific universities as sources of research-based knowledge for science-intensive industries. Since corporate partners will engage in joint research with academics if they are sufficiently convinced of their research capabilities - in terms of quality, potential utilization value, and (cost) effectiveness - UICs therefore also partially reflect the

degree in which universities are able to meeting quality specifications imposed by industry (Tijssen et al., 1996; Tijssen et al., 2008).

PPCs and UICs implicitly represent two intertwined dimensions of knowledge transfer mechanisms that occur with research cooperation arrangements. The 'knowledge stock' dimension represents capabilities, both in terms of inputs of the partners, the ability to cooperate (successfully), as well as joint results that are published as co-authored research publications. The 'knowledge flows' dimension represents interactions and processes before and during the research effort, which becomes partially manifest in the content and structure of the publication and the list of authors. These knowledge creation processes obviously imply some degree of (in)formal research partnership, but also reflect associated knowledge exchanges and spill-overs of research-based components between universities and the business sector. As such, these co-publications can be seen as both an indicator of collaborative activity as well as impacts of academic 'brain power' on knowledge-intensive economies and economic sectors.

A series of empirical studies have explored and exploited this information source for quantitative studies of public-private cooperation in general and university-industry cooperation in particular (e.g. Calvert and Patel, 2003; Tijssen, 2004a; Lundberg et al., 2006; Sun et al., 2007; Tijssen et al., 2009; Abramo et al., 2010; Tijssen, 2012).

3 Measurement methodology and data source

The PPCs and UICs in this study were identified by extracting and processing bibliographic records from the *Web of Science* (WoS), an international multidisciplinary bibliographic database of worldwide research literature. The WoS database contains of tens of thousands of PPCs and UICs each year, the majority of which relate either to clinical trials or exploratory basic research.

The empirical information on the geographical and institutional origins of collaborating staff was extracted from the author affiliate addresses on each PPC. Using these organizational addresses reflect collaborative 'brain connections' that at some point in time result in published research outputs for dissemination within the public research community worldwide. The author addresses enable detailed data analysis at the institutional level of individual organizations (universities, research institutes, large enterprises, SMEs) as well as geographical domains (cities, regions, countries, worldwide).

The information on the institutional affiliations was cleaned and harmonized in-house by CWTS, where the names of the main organizations in the addresses were standardized and organizations classified according to their main

institutional sector: higher education sector (universities mainly) or the corporate sector (business enterprises and other business sector organizations). The delineation of the private sector and public sector is done at CWTS by allocating individual main organizations. Rather than adopting legal status as a sole criterion, the allocation is determined by a mix of economic objectives (i.e. for profit or non-profit) and institutional sector of institutions.[3]

The computation of PPC and UIC frequency counts and indicators in this paper are based on the following data specifications:

- WoS document types: 'articles', 'reviews', 'notes' and 'letters'.
- Counting units: (a) PPC/UIC publications related to publications with at least one corporate author address and one non-corporate address; (b) PPC/UIC co-occurrences related to and pairs of addresses within the same publication;
- Attribution of a PPC/UIC publication or co-occurrence to a country: according to the countr(y)(ies) mentioned in the corporate author address(es). Each PPC/UIC is assigned fully to all countries listed in a corporate author address.

The extent and growth rate of globalization is measured in terms of the physical distance between author addresses that are listed in PPCs and UICs. The authored addresses were reduced to a city and country name. The 11000 most frequently occurring addresses were tagged with their latitude and longitude coordinates, using the website www.gpsvisualizer.com/geocoder/. Using these coordinates, the geographical collaboration distance (GCD) was calculated of each selected publication; i.e. the largest distance between two addresses mentioned in a publication's address list. Two GCD-based measures are applied in this paper:

- mean geographical collaboration distance ('MGCD') of a set of publications;
- percentage of PPCs/UICs that include very long-distance collaborations with a GCD of more than 5 000 km ('%>5000 km')

For technical reasons a PPC is defined here as a WoS-indexed publication where either the public or private organization are based in the country. Further technical details on the information source, data processing and the geo-coding methodology are provided in Waltman et al. (2011) and Tijssen et al. (2011).

4 Macro level indicators of globalization

PPCs represented 4.2% of all WoS-indexed publications in 2006-2010, an average of about 40000 publications per year. Correlation analysis in Table 1

[3] Further details on the CWTS classification scheme of institutions assigned to the public sector or private are available at the author.

shows that the PPC indicator corresponds very significantly with the "Extent to which business and universities collaborate on research and development" as measured in the *Global Competitiveness Survey*, an annual survey among thousands of corporate representatives worldwide (WEF, 2007). Restricting the analysis to all OECD countries (member states and affiliated countries) results in a correlation coefficient of R=0.70. Similar analyses applied to the 27 member states of the European Union produce comparable positive coefficients. In other words, the PPC indicator appears to be a robust proxy measure of public-private R&D cooperation. A further confirmation of the indicator's cross-validity is derived from the significant positive correlation (R=0.74) with another country-level indicator of public-private cooperation: 'the share of all firms cooperating with higher education institutes' within the Community Innovation Survey administered among the EU27 member states. The correlation coefficient hardly changes when the scope is restricted to the subclass of 'innovating firms' (rather than 'all firms').

Table 1. Correlation between PPC intensity and other international comparative indicators of public-private R&D interaction, 2007-2008 (Pearson correlation coefficients R)[‡]

	EU-27 nations	OECD countries
Extent to which business and universities collaborate on research and development*	0.82	0.70
% of all firms cooperating with higher education institutes**	0.74	N/A
% of innovative firms cooperating with higher education institutes***	0.65	N/A

* Data source: Global Competitiveness Survey, 2007-2008
** Data source: Community Innovation Survey, 2008
N/A Data not available.
‡ An extended version of this table is published in Tijssen (2012).

Having established that PPC statistics constitutes a reasonably valid and meaningful indicator, at least at the aggregate country-level, we can now present PPC data at this level and expand the scope of the analysis to capture globalization rates. In both cases the units of analysis are the countries in which the PPC-producing companies are located according to the author address information on the WoS-indexed publications.

Table 2 presents the share of PPCs in a country's total WoS-indexed scientific publication output – the PPC intensity – and two indicators of the physical distance between PPC partners: the *Mean Geographical Collaboration Distance* (MGCD), and the share of PPCs where the GCD exceeds 5000 kilometers (%>5000 km) The latter is considered a key indicator of globalization of public-private research cooperation, where the locations of the company and its public sector partner are at a large distance.

Table 2. PPC summary statistics by country of company location*,**

	PPC Intensity (%)	MCGD (km)	%>5000 km	OECD country
Australia	2.0	9844	63	Member
Austria	4.5	2449	22	Member
Belgium	3.9	3961	40	Member
Brazil	1.0	6078	56	
Canada	3.5	4003	33	Member
China	1.8	5745	47	Associated
Czech Republic	3.3	2365	20	Member
Denmark	6.5	2663	26	Member
Finland	5.0	2171	19	Member
France	3.2	2907	28	Member
Germany	6.4	2745	26	Member
Greece	1.3	4315	37	Member
Hungary	3.7	2277	21	Member
India	1.8	3979	32	
Iran	1.0	3898	33	
Israel	2.3	5829	50	Member
Italy	2.7	3052	28	Member
Japan	8.8	1636	13	Member
Korea	6.8	1839	16	Member
Netherlands	5.1	2407	24	Member
New Zealand	4.2	7279	44	Member
Norway	5.5	2743	26	Member
Romania	2.0	2207	18	Associated
Russian Federation	1.1	5646	53	Associated
Singapore	3.4	6019	44	Associated
Slovenia	3.4	1228	9	Member
South Africa	1.9	7052	55	Associated
Spain	1.7	3124	28	Member
Sweden	5.6	2786	27	Member
Switzerland	7.1	3303	33	Member
Taiwan (Chinese Taipei)	2.6	2573	20	Associated
Turkey	0.6	5095	45	Member
United Kingdom	3.7	3194	32	Member
United States	6.4	3605	25	Member

* Countries with a minimum of 2000 WoS-indexed publications and 500 PPCs in 2006-2010.
** PPC intensity refers to 2006-2010; MGCD statistics refer to 2000-2009.

The findings show that the world's PPC profile is skewed across countries. These differences reflect the presence of large R&D-active companies within their borders. These PPC co-producing companies account for 8.8% of all publications with at least one Japanese affiliate address. Many of those PPC active Japanese companies are in the electronics sector. Switzerland is second, with an PPC intensity of 7.1%, largely owning to its Swiss-based pharmaceuticals and biotechnology companies. The world's most PPC-intensive countries are advanced industrialized nations with open economies, all of which are OECD member states. The BRICS countries (Brazil, Russia, India, China, and South Africa) is represented in this list, each with a PPC intensity less than 2%. This list of PPC active countries, and the ranking, seems credible and valid at face value: at the top we find those with the largest number of R&D-based technology companies, the most advanced universities and public sector research organizations, along

with the resources and commercial incentives to cooperate and co-publish research findings.

The geographical location of countries on the globe is a key determinant of PCC globalization rates. Overall, the MGCD between 2000 and 2009 has fluctuated around 3000 km (Tijssen et al., 2011). But clearly the geographically peripheral countries, like Australia and South Africa, show much larger MGCD values than those located near other advanced countries and OECD member states. In the case of Australia, the average distance in PPCs between public and private research partners amounts to almost 10000 kilometers, where 63% of the PPCs have a distance of more than 5000 kilometers. In Slovenia, a small centrally located European country, the MGCD is less than 1500 kilometers where only 9% of the PPCs reach beyond 5000 kilometers. South Africa is the most globalised of the non-OECD member states. Note that these distances may also occur within the same country. Hence the geographically large countries – such as the United States, Canada, China and Russia – are likely to produce a larger share of long-distance PPCs irrespective of their degree of R&D globalization.

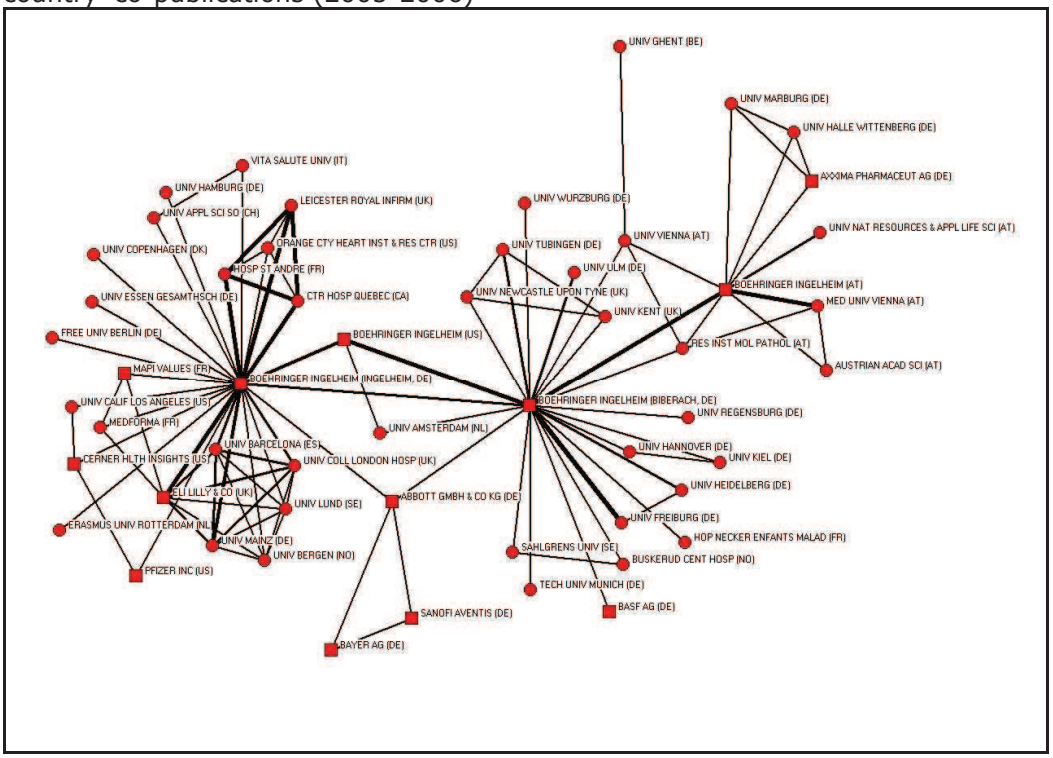
5 Micro level indicators of globalization

The pharmaceutical sector has a long tradition of close and successful collaboration with public sector research partners (Toole, 2012). Intense local and international competition in conjunction with rising R&D costs, are forcing the pharmaceutical industry to innovate faster and more efficiently. As one of many managerial responses, R&D-active pharmaceutical companies have started to internationalize their research activities (Gassman and and Reepmeyer, 2005), en cooperate more. Most of the large research-intensive pharmaceutical companies have, in varying degrees, become MNEs with organizational units scattered across the globe. The volume and geographic dispersion of an MNC's research activity, and the cooperation between central R&D labs in the home country and foreign sources of knowledge, are considered key characteristics of underlying organizational structures (Cockburn and Henderson, 1996). *Boehringer Ingelheim*, with its R&D headquarters in Germany, presents an illustrative case. This is one of the world's most globalised pharmaceutical companies in terms of its share of research cooperation projects involving their foreign research centres (Tijssen, 2009).

Figure 1 depicts a 'micro level' view of the organizational network structure of *Boehringer Ingelheim*'s within-company collaboration links and external partners derived from it's WoS-indexed co-publications with a German in-house author

address. The co-authorship network reveals strong ties between the company's subsidiaries in Germany, Austria and the USA, each spanning a range of external co-publication partners. Although this network is by design predominantly European, some of the public sector partners are located outside Europe, such as UCLA in the USA. An extended research cooperation network including *Boehringer Ingelheim*'s R&D-units outside Europe would provide a more comprehensive picture of the company's PPC globalization profile.

Figure 1. Research co-authorship network of Boehringer Ingelheim's 'home country' co-publications (2005-2006)*



* Based on Boehringer Ingelheim's co-publication with a German author address.

One of *Boehringer Ingelheim*'s foreign subsidiaries is located in Randburg, South Africa: *Ingelheim Pharmaceuticals* (Pty) Ltd. These local subsidiaries of MNEs tend to act as collaborative bridges between South African universities and the globalising world of corporate pharmaceutical R&D. The summary overview of the corporate research partnerships in Table 3 that involve South Africa's Big Five' universities: *University of Cape Town*, *Stellenbosch University*, *University of the Witwatersrand*, *University of Pretoria*, and *University of Kwazulu Natal*.

These five South African universities create and sustain a localized competitive mass of knowledge and skills, acting as critical assets and change agents within local knowledge-based economies, not only in terms of knowledge creating and utilizing organizations, but also as suppliers of highly skilled work force, and

participants in local R&D networks. With the increasing global competitiveness in R&D-intensive industrial sectors, and the rise of science-based industrial sectors during the last decades, one may safely assume that these research-intensive universities, and many others based in the advanced industrialized nations, have become more responsive to their economic environment to make effective use of internal and external sources, attract funding and human resources, improve and expand research capabilities, and accelerate knowledge creation and transfer processes. The list of companies in this table provides ample evidence that many business enterprises engage in joint research with these South African universities.

Table 3. Corporate research partners of South African universities: occurrences of corporate co-author addresses in university research publications and breakdown by geographical origin, 2009-2010*,**,***

Company	Foreign affiliation	South African affiliation
AstraZeneca	14	
SRI Int.	12	
Merck	11	
Novartis	11	
GlaxoSmithKline	10	
Novo Nordisk	9	
Tibotec	9	
Microsoft	7	
H Lundbeck	6	
Pfizer	20	3
BHP Billiton	2	3
Boehringer Ingelheim	6	2
Bayer	4	1
Sasol		20
Anglo American		12
Necsa S. African Nucl. Energy Corp.		11
Mondi Business Paper		6
Ergotech Ergon Consultants		5
Eskom Holdings		5
Pannar Res. Serv.		5
Sappi Forests Pty		5
Distell		4

* Truncated names of companies as they occur in the CWTS Web of Science database.
** Data related to the occurrences of company names in the author addresses of co-authored publications in 2009-2010 co-produced by the universities of Cape Town, Stellenbosch, Pretoria, Witwatersrand, and ZwaZulu-Natal.
*** Lower threshold: 4 occurrences of company in 2009-2010 publications.

This overview of partner companies also nicely illustrates how these research-intense universities attract a diversity of corporate partners; large and small, from South Africa or abroad. The corporate organizations listed within UICs were split into two broad geographical classes: 'domestic' (corporate partners based in the same country as the university) or 'foreign', depending on the physical location of corporate partners as mentioned in the author affiliate addresses. The

international partners include a host of pharmaceuticals MNEs (*AstraZeneca, Merck, Novartis, GlaxoSmithKline, Novo Nordisk, H Lundbeck, Pfizer, Boehringer Ingelheim, Bayer*), where the latter four also collaborate through their local South Africa subsidiaries. Not surprisingly, the list of the Big Five's indigenous research partners features South Africa's largest R&D-active company, *Sasol*, as the number 1 most frequently occurring partner. This short list of prolific partners also includes South African SMEs.

6 Concluding remarks

Current geographic trends in the physical (re)location of industrial R&D, and the rise of 'open innovation' models, signify accelerating shifts toward global 'networked' architectures of collaborative relationships (Chesborough, 2003). Given the growing importance of public-private collaboration in R&D, the need for new metrics to compare and to track collaboration patterns is high. In times of 'flattened world' views, it is therefore necessary to better understand the phenomenon of globalization, also in this field of activity. Globalization in the realm of economic activity is also not as 'flat' as some previous work has stated (e.g., Friedman, 2005; Ghemawat, 2011). The findings in this paper show that it is too coarse a hypothesis and that agglomeration effects in internationalization and globalization definitely are a reality (Florida, 2005).

The PPC/UIC model and performance indicators presented in this exploratory paper critically hinge on the assumption that the underlying empirical data are valid proxies of public-private research cooperation linkages. Even though these data may provide a somewhat restricted and biased view of reality, they nonetheless define a unique and useful international frame of reference to gauge worldwide patterns and aggregate-level trends. In the absence of counter evidence, one may assume that country-level PPC/UIC statistics reflect joint knowledge production and, by association, cross-sectoral knowledge flows between industrial R&D and scientific research done within public sector organizations and universities. PPC and UIC data can therefore be used as a macro-level performance indicator of these linkages and flows - and have been used as such for the *European Innovation Scoreboard* (European Commission, 2008; 2009) and its successor report series under the heading of the *Innovation Union Scoreboard* (European Commission, 2011a, 2011b). However, countries are often too heterogeneous for policy relevant analysis, as they comprise of areas and regions with distinctly different R&D landscapes and PPC/UIC patterns. Hence, macro-level statistics provide little insight into the R&D environments and

economic frameworks affecting collaborative activities. We need more nuance and fine-tuning to understand and explain what is happening and why it does happen the way we observe it. Disaggregated data at the micro-level are required.

Obviously, PPC and UIC magnitudes and intensities may vary significantly within and across R&D-intensive industrial sectors and large R&D-active technology companies. Only in those cases where sufficiently large numbers occur, may one expect a reasonable degree of validity and a meaningful statistics. Further research is needed into the nature of PPC and UIC indicators as quantitative proxies to support and advance empirical studies of globalization processes and strategic analysis of corporate R&D trends. Enhancing the robustness of these indicators will lend further credibility to the usage of PPC and UIC statistics as performance indicators within evidence-based policy reports on research and innovation (Tijssen, 2004b). Additional data gathering of macro and micro level information is therefore essential to enhance the quality and scope of these quantitative indicators. Such information sources may gradually become available through case studies and dedicated surveys amongst business enterprises, universities and public research organizations worldwide. The outcomes should not only help assess the relevance of public science for external industrial R&D and innovation, but also the potential of universities and other public research organizations to engage in industrial relevant basic science, knowledge transfer, the commercialization of their assets and related entrepreneurial activities.

Acknowledgement

I am grateful to my CWTS colleagues Ludo Waltman and Nees Jan van Eck for their valuable research assistance.

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