Accounting for Science-Industry Collaboration in Innovation: Existing Metrics and Related Challenges

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The theme of this year's Global Innovation Index (GII) report underlines the importance of linkages among innovation actors in modern innovation ecosystems.

Innovation is increasingly understood as an interactive learning process that embraces the integration of knowledge from external sources. Innovation processes have become more fragmented and 'open'.[1] Markets for technologies allow for the exchange of technologies more and more frequently.

In this arrangement, universities and public research organizations (PROs) are a fundamental pillar of the innovation ecosystem. On the one hand, they provide human capital and training. On the other hand, they advance knowledge through public science and diffuse that knowledge through tacit or tangible technology transfer activities. Accordingly, in high- and middle-income countries alike, strategies have aimed to improve linkages among public research and firms.

Although there is now consensus that these linkages among innovation actors are crucial, measuring their existence and impact remains daunting. As outlined in the Preface to this report, this difficulty has an effect on our ability to judge existing policies. This is unfortunate because the creation of linkages is likely one of the most complex innovation policy areas, with no easy recipes and few countries or regions with notable successes.

With a view to improving the availability of the indicators that could be useful in the GII, this chapter discusses the metrics that are currently available to measure public-sector research and science-industry collaboration.

Putting a figure on public-sector research

Although our main interest here is related to metrics for science-industry linkages, often data on the size of public-sector research are used to assess its role in the broader innovation ecosystem. A number of first-class variables with wide country coverage for recent years exist today to assess the size of public-sector research (see Table 1).

These metrics show that universities and PROs account for a substantial share of both total research and development (R&D) and the number of researchers in a given country. For instance, in high-income economies, the public sector is responsible for anywhere between 20 and 45% of annual total R&D expenditure. PROs—rather than universities or firms—are often the main R&D actors in low- and middle-income economies.

On the one hand, these data are part and parcel of a complete analysis of innovation potential. They help to identify where limited public research—and hence a lack of knowledge creation—is holding back a country's innovation ecosystem. Public research itself does not guarantee a proficient business R&D and innovation. Yet public research efforts trigger firms to perform more R&D themselves as these efforts raise the returns on firms' innovation expenditure. Indeed, almost no country has—in absolute terms—large private R&D expenditures but meaningless public R&D.

On the other hand, these metrics alone do not contribute to assessing the linkages between the public and the private sector or any resulting impacts. Worse, in many non-OECD countries the problem is in fact that the majority of R&D projects and researchers are concentrated in universities or PROs, often without diffusion to the private sector. In middle- and low-income countries, firms often contribute little to scientific research. Absent its own R&D capacity, the private sector cannot 'absorb' what is done in public research. Public actors are also unable to identify the correct research priorities and methods. Researchers have little incentive to transfer their technologies.

Another interesting set of variables used to assess the contribution of the public sector is the level and share of basic R&D conducted in universities and PROs. Basic R&D in the public sector is recognized as a necessary driver for radical innovations. On their own, businesses

Table 1: Selected measures of the size of public research

Metric	Availability of data and country coverage
Public-sector R&D expenditures (including as a share of total R&D)	Available for a wide range of countries, based on the Science and Technology Statistics of the UNESCO Institute for Statistics (UIS) and the Science, Technology and R&D Statistics of the Organisation for Economic Co-Operation and Development (OECD)
Basic research performed in the public sector as a percent of national basic research	Available only for a limited number of countries, based on OECD Research and Development Statistics and national sources
Number of researchers or R&D personnel in the public sector	Available for a wide range of countries, based on the UIS and OECD statistics mentioned above

do not conduct blue-skies research with no expectation of some financial returns. Given the increasingly science-based nature of technological advances, publicly financed science is said to be increasingly crucial to innovation.[2]

Accordingly, governments usually provide the majority of the funding for basic research—more than three-quarters of all basic research in high-income economies. In low- and middle-income countries for which data are available, public research is also responsible for the majority of basic research—close to 100% in China, close to 90% in Mexico, about 80% in Chile and the Russian Federation, and about 75% in South Africa.

Again, the metrics currently available for measuring the level and share of public-sector basic R&D are only a useful starting point.

First, basic research conducted in the public sector will have an economically 'useful' role to play only if it is eventually transformed into innovations by innovation actors. Other innovation actors will require a large internal absorptive capacity to make use of public investments in the field. In the United States of America (USA), businesses devoted US$16.5 billion to basic research in 2009. This is small compared with the country's total R&D spending (US$247.4 billion in 2009), but it still accounted for about 22% of the overall funding for basic research in the USA.[3]

Second, the correct level of basic research investment versus more applied R&D in the public sector or the economy as a whole is subject to a passionate discussion.

On one side, it is argued that basic research is a central driver of scientific breakthroughs and follow-on radical innovation.[4] In this view, it is critically important that the 'blue sky nature' of basic research is untainted by short-term and/or commercial interests. In the case of advanced countries, the worry is that both public institutions and firms will do less and less basic research, which will have an impact on the potential of future innovation. Public research institutions are also subject to budget cuts that constrain their ability to fund expensive research infrastructures. In the case of firms in high-income countries, the focus on shorter product cycles and the pressures of financial markets are said to have reduced basic R&D.

On the other side, there are worries that public research is too focused on research without any tangible economic or social repercussions. Policies to stimulate technology transfer are out to maximize the return on investment in public R&D. Universities and PROs ought to undertake more development to produce useful inventions that can be readily transferred to firms.

The following questions will occupy innovation economists and policy makers for some time to come: What is the optimal level of basic research versus more applied R&D, both in the public and the private sector? How does it vary between different technical fields and for different levels of national development? What are the implications for funding agencies?

Third, and for reasons outlined earlier, lower-middle- or low-income countries in particular would be ill-advised to concentrate all their efforts on basic research rather than more development-oriented, more 'practical' research activities. As outlined before, in developing countries the problem is often an excessive focus on basic research without diffusion to innovation actors in the private sector.

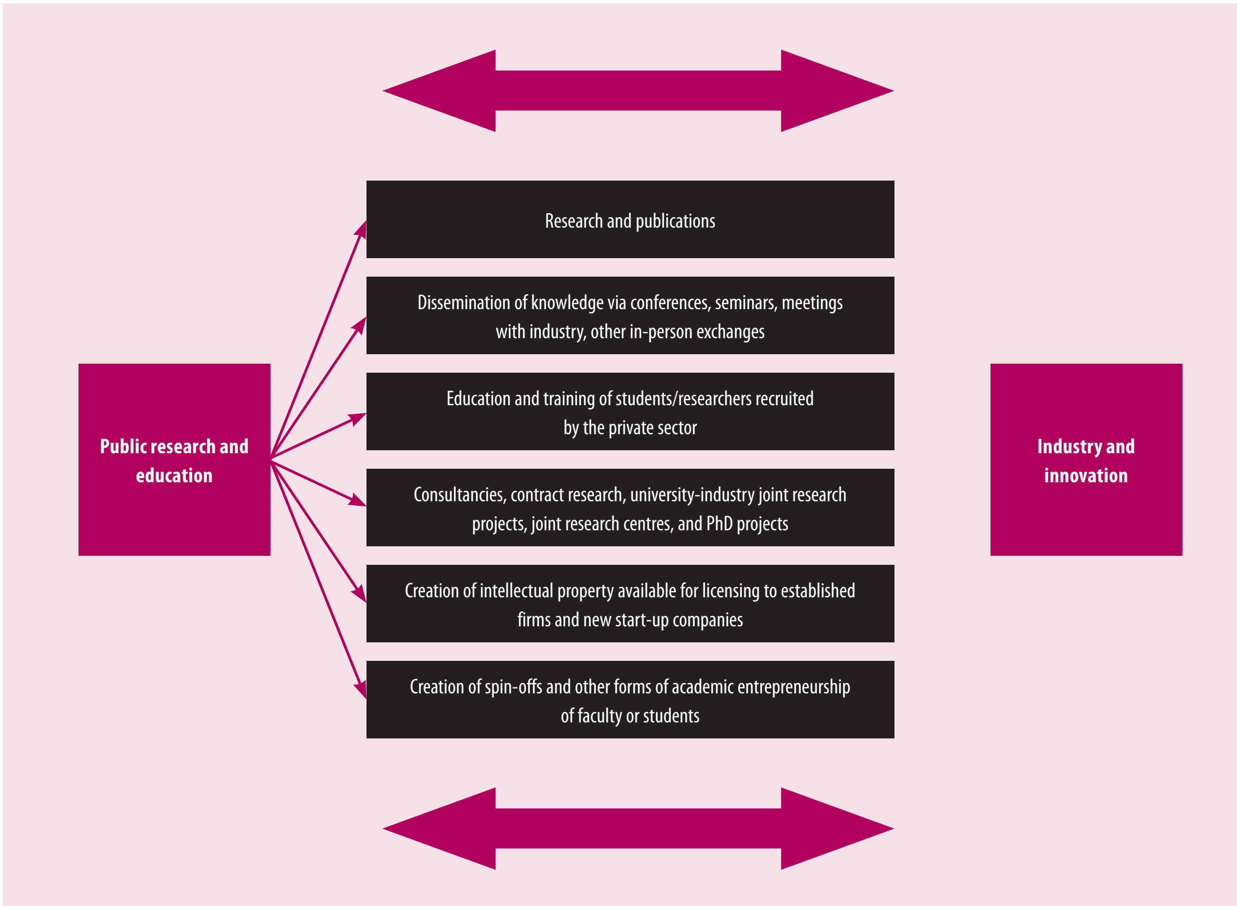
In sum, the use of data to measure public R&D (basic or more applied) or the number of researchers is but a useful starting point for assessing the potential of industry-science linkages.

Measuring public-private linkages

The measurement agenda has increasingly evolved to address the *systemic dimension* of innovation—that is, the activities of multiple innovation actors and linkages among them.[5]

This ambition for measurement is also important to poorer economies because innovation linkages

Figure 1: The multiple vectors of knowledge transfer from universities and PROs to industry



Source: WIPO, 2011b.

within them are, on average, weak. Innovation indicators for less-developed economies ought to assess the extent to which connections and linkages are present in the field of innovation, define the nature of these links—including determining whether they are national or international—identify involved or excluded agents, and ascertain the efficiency of existing information channels.[6]

Channels of science-industry linkages

In a first step, it is important to showcase the different public-private linkages. This demonstration of science-industry channels also reveals the complexity of measurement and the danger of focusing excessively on single measures.

Public-private knowledge transfers occur through a large number of formal and informal and two-way channels. Figure 1 illustrates the following informal and formal channels of exchange:

- *Informal channels* include transferring knowledge through publications, conferences, and informal exchanges among scientists.
- *Formal channels* include hiring students and researchers from universities and PROs, sharing equipment and instrumentation, contracting technology services, encouraging research collaboration, creating university spin-offs or joint firms, and generating newer intellectual property (IP)-related transmission channels such as licensing inventions from universities.

A key measurement problem is that a significant share of collaborative activity remains unmeasured. Firm surveys and detailed studies, however, show that informal—and often unmeasured—contacts are most prevalent. Conventional university outputs such as numbers of graduates and publications, among

Table 2: Advanced science and technology metrics available to assess public-private collaboration

Metrics to assess linkages	Availability
Industry funding of public R&D and government-financed business R&D	Data are largely available for many high- and middle-income countries via statistics collected by the OECD and UNESCO (see Table 1). Very limited country coverage for data on cross-funding of basic R&D.
Co-publishing activities	No official data exist. Limited estimates can be produced by using private publication databases and identifying publications where co-authors are affiliated with firms and others are affiliated with public research institutions.
Researcher mobility between industry and science	No known large-scale data source is available to assess moves of researchers between industry and science at the national or international level. Some available information is based on inventor surveys or the study of academic patenting (see the section on 'inventor and innovation surveys'). For PhD holders, information is available for some mainly developed countries; see www.oecd.org/sti/cdh.
Joint research agreements or research centres	Almost no official data exist, but some information is available from company reports, annual reports of public research institutions, press announcements, and the like.
IP-BASED VARIABLES	
University and PRO patents	Estimates available for selected countries for patents filed under the Patent Cooperation Treaty (PCT), based on either the method developed at the Catholic University of Leuven (Belgium) or the method developed at WIPO.*
	Only incomplete data are available with respect to national patent filings in selected countries. In some countries, surveys are conducted by technology transfer associations, such as the US Association of University Technology Managers in the USA and ProTon Europe, the European Knowledge Transfer Association.
Co-patenting activities	WIPO estimates are available for joint filings under WIPO's PCT for selected countries.
Patent-to-patent and patent-to-non-patent citations	No across-the-board data on public-private citations are available for a large set of countries. The data that do exist are available only in selected studies based on bibliometric techniques applied to databases of the USA and European patent office, Google Patents, or commercial providers such as the 'Web of Science'. Studies are subject to potential biases, most notably those relating to problems with the identification of the applicant's affiliation.
Number of licenses and options; licensing income	Limited data are available through technology transfer offices, associations, or surveys in Europe and in North America. Very little information is available for non-OECD economies.
	No across-the-board country-level data are available. Very limited data—obtained from university technology transfer offices or associations, selected case studies, or journal articles—exist.

* Du Plessis et al., 2010; WIPO, 2011b.

others, are the most frequently cited activities contributing to innovation.

Moreover, it is important to realize that these exchanges do not take place in one direction only, from universities and PROs to firms. Rather industrial research complements and also guides more basic research. Such an exchange is also a means of equipping university scientists with new and powerful instruments. Existing metrics often underappreciate this two-way street of knowledge exchange.

The data available for assessing the frequency and type of collaboration are limited, especially in terms of public, official sources with the wide institutional and country coverage needed for the GII. Often these data points are available only for some high-income economies. Furthermore, existing data say little about the dimensions of quality and impact of cooperation, and thus the question of to what extent the collaboration may have been a key driver for different types of innovation is left unaddressed.

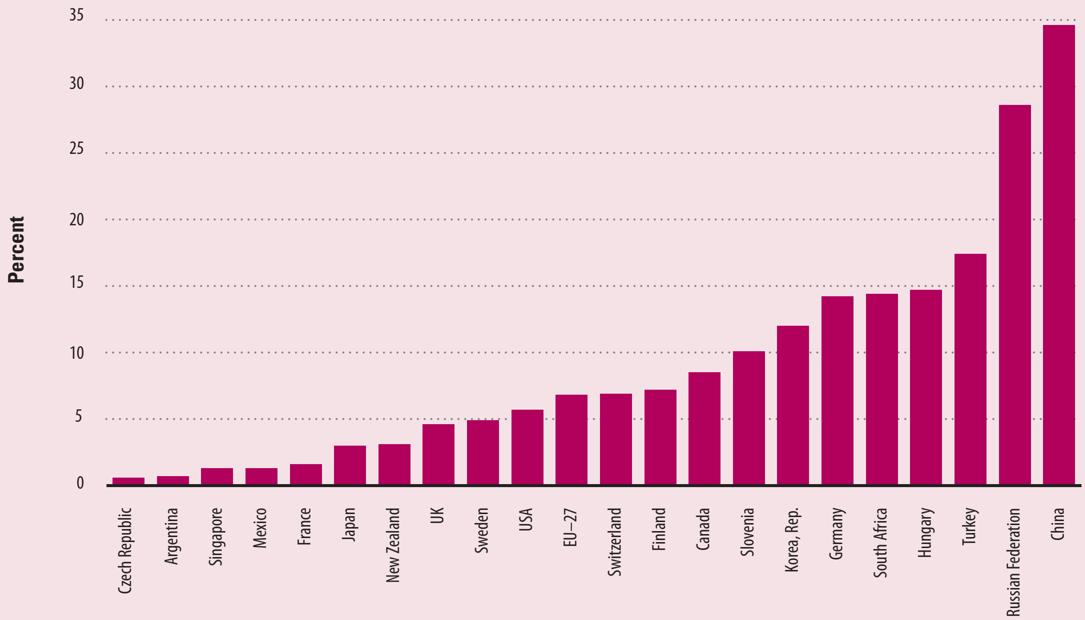
Two main categories of metrics to elaborate on these linkages can be distinguished:

1. *Advanced science and technology metrics*
2. *Inventor and innovation surveys*

Metrics of assessment: Advanced science and technology metrics

A first set of indicators focuses on the existence of networks of researchers/inventors (Table 2) and the extent to which the industrial base makes use of the results of scientific work for innovation.[7]

Figure 2: Higher education research expenditure financed by industry, selected countries (2008 or latest available year)



Souce: OECD, Science, Technology and R&D Statistics database.

The data presented in Table 2 mostly relate to R&D cross-funding and linkages, as demonstrated in data related to R&D funding, R&D cooperation, researcher mobility, publication activities, patenting and licensing, and business ventures emanating from universities and PROs, such as university spin-offs. Except for the data on cross-funding of R&D, usually these metrics are available only for a select number of high-income countries. Some metrics are not easily available at all. For instance, official statistics on joint research agreements and on cooperation between firms and the public sector, the exchange of know-how, the mobility of researchers, and even co-publication data are hardly available at all, much less for a wide range of economies.

The limited available statistics on the number of academic spin-offs are often used to evaluate technology transfer. These are mostly only available for the USA and Canada; these are based on the reporting of the technology transfer association,[8] and in a few select high-income countries.[9] Also the focus on the number of start-ups directly related to university IP can be misleading.[10]

In the following section, we focus on R&D cross-funding and IP-based variables and spin-offs.

Public-private cross-funding of R&D

Data on industry funding of R&D in higher education (primarily in universities, colleges, and laboratories affiliated with these institutions of higher education) is increasingly available for a large set of OECD and a few non-OECD economies (see Figure 2).[11]

When using these data on industry funding in any innovation ranking, it must be kept in mind that for most economies the share of higher education R&D expenditure financed by industry is relatively small. In the USA, for example—a country with arguably good science-industry links—firms finance about 6% of academic R&D. In Germany or Hungary this figure is closer to 15%, and in Turkey, the Russian Federation, and China businesses finance an even higher share of public R&D. It is, however, difficult to tell the extent and quality of linkages from these percentages alone. It must also be kept in mind that these data do not include the share of government PRO R&D expenditures financed by industry.

Metrics on the public funding of business R&D measure grants, loans, and government procurement efforts, but they exclude R&D tax credits. In the OECD region, the government funds nearly 7% of total business expenditure on R&D, down from nearly 9% in 1999.[12] More than 15% of business R&D is funded directly by government in the Russian Federation,

Table 3: Top 10 PCT applicants in 2011: Public research organizations

Rank	Applicant	Country of origin	Number of applications
1	Commissariat a L'Energie Atomique et aux Energies Alternatives	France	371
2	Fraunhofer-Gesellschaft Zur Forderung der Angewandten Forschung E.V.	Germany	294
3	Centre National de la Recherche Scientifique (CNRS)	France	196
4	Agency of Science, Technology and Research	Singapore	180
5	Consejo Superior de Investigaciones Cientificas (CSIC)	Spain	120
6	China Academy of Telecommunications Technology	China	119
7	Mimos Berhad	Malaysia	108
8	Electronics & Telecommunications Research Institute of Korea	Rep. of Korea	104
9	National Institute of Advanced Industrial Science and Technology	Japan	100
10	United States of America, Represented by the Secretary, Department of Health and Human Services	USA	98

Source: WIPO Statistics Database; WIPO, 2012.
Note: Government and research institutions include private nonprofit organizations and hospitals.

South Africa, Spain, Hungary, and Turkey. Although these metrics are an important tool for understanding the support of the public sector given to private-sector research and the ensuing potential linkages, the public funding of business R&D might, however, not systematically trigger true science-industry collaboration.

Intellectual property: Technology transfer channel

In the absence of comprehensive data on science-industry relationships, data on patents and licenses are used to gain insight into the technology transfer performance of universities and PROs.

While the use of such IP data has been influential in the policy debate, certain caveats are related to these metrics—most notably that a large share of inventions originating from public research is not patented under the institution's name, and hence is invisible as university output.[13] There is consensus in the literature and in policy circles that additional indicators need to be developed to achieve adequate monitoring that will allow a more accurate assessment.[14]

- *University and PRO patents:* Extracting the information from the patent databases requires additional manipulation and the use of search algorithms because patent documents do not easily reveal the institution of the patent applicant.

Based on available estimates, since 1979, the number of international patent applications filed under WIPO's Patent Cooperation Treaty (PCT) system by universities and PROs has been steadily increasing, except for a drop in 2009 linked to broader economic conditions.[15] The share of universities' and PROs' patents out of total patents under the PCT has been increasing since 1983, reaching 6% for universities and 3% for PROs in 2010. Most of the growth in applications is driven by high-income economies.

Among middle-income countries, China leads in terms of university applications with 2,348 PCT filings, followed by Brazil, India, and South Africa. PROs from China and India alone represent 78% of total patents by PROs originating from middle-income countries. They are followed by Malaysia, South Africa, and Brazil. The highest rates of university PCT applications as a share of total patents are reported for Singapore, Malaysia and Spain. The countries with the highest participation of PROs out of total PCT filings are Malaysia, Singapore, and India. Table 3 shows the top 10 PCT applicants among public research organizations in 2011.

Aside from a few high-income countries, statistics on national patent applications from universities and PROs are largely unavailable. The countries with the largest share of university applications are China (13.4%), Spain (13.2%), Mexico (12.6%), and Morocco (11.2%). The countries with the largest share of PRO resident applications are India (21%, based on estimates and not official data), Mexico (close to 10%), China (7%) and France (close to 4%).

In this context, co-patenting— when firms and universities / PROs decide to apply for patents jointly— is also an important indicator. After the year 2000, joint filings between firms and universities have been on the rise. In 2010, they made up about 18% of all PCT applications involving universities from high-income countries, up from almost none in 1980. On average, university-company co-ownership of PCT patents is more prevalent in middle-income than in high-income countries, even though the levels of filings are substantially lower in the former country group. Japan has the highest share of university-company partnerships at 42% of all university applications, followed by the Russian Federation (30%), China (29%), and Brazil (24%).

- *University IP licensing and commercialization:* Close to no indicators exist for assessing the scale of university commercialization and related downstream impacts. The most widely used indicators for measuring university technology transfer are the number of licenses issued and the income associated with these licenses. These data are available for only a few countries, are often based on nongovernmental surveys using varying methodologies and schedules, and are largely confined to universities without covering PROs.

Broadly speaking, the data tend to support the view that university and PRO licenses and related income are growing from low levels. Outside the USA, both are still relatively modest compared with the number of patents filed by public research institutions, or compared with income from their R&D contracts and consulting, or their R&D expenditure. Also, on average, university and PRO licensing income is still marginal compared with total university and PRO funding or research expenditure.

In middle- and low-income economies, data on technology transfer are even scarcer. Studies point to the nascent stage of IP and its commercialization, which is limited to a few patents and institutions. Other forms of IP, such as copyrighted works and know-how, are more commonly used to transfer knowledge to businesses.[16]

Metrics of assessment: Inventor and innovation surveys

In the last decade, large-scale inventor surveys and innovation surveys, which are both useful for assessing science-industry linkages, have flourished. The focus, size, and type of sampling involved in these two survey exercises are not comparable. Inventor surveys focus on specific inventors who have filed for a patent; innovation surveys address a representative sample of all firms in a given economy. Both types of surveys are the source of interesting academic follow-on papers focused on very particular researchers, institutions, or countries that provide a rich contextual background to studying science-industry collaboration.

Inventor surveys

Inventor surveys have been conducted primarily in Europe, Japan, and the USA; some of these surveys focus on large firms only. The so-called PatVal, a European-wide survey of inventors, is probably the most representative of all patent holders and covers all technical fields in six major European Union (EU) countries. The survey requests information about the sources of knowledge that were used in the research project and the assessment of the importance of the sources of knowledge leading to the patent.

PatVal's results show that coming up with technological breakthroughs worthy of a patent often involves collaboration among inventors.[17] About 20% of PatVal-EU patents are developed through collaborations among the employer organization and other partners, with variations across countries. Interestingly, 75% of these collaborations are formalized through specific contracts, and IP-based collaborations tend to be more formalized than non-IP based ones, as discussed later.

PatVal's results also show that a firm's customers are the most important source of innovation, followed by the knowledge supplied by the patent literature and the scientific literature.[18] Interaction with the firm's competitors, its participation in conferences / workshops, and its contacts with suppliers are ranked second as sources of innovation. Yet university and non-university research laboratories feature prominently for only a smaller share of firms. Specifically, 22% and 13% of the inventors in the PatVal survey rated the knowledge coming from universities and other public laboratories as important.

Although most discussions of the PatVal survey results dismiss the importance of university inputs on this basis, two arguments supporting the role of university inputs can be made. First, the aforementioned sources of innovation—such as scientific literature, conferences, and contact with suppliers—are often tightly linked to universities. Access to scientific literature and to conferences is often enabled by public researchers or the public research system. Studies that combine data on scientific co-authorship with data on patent co-invention at the level of individual researchers show that connectedness among scientists and inventors is extensive.[19] These studies also show that particular authors/inventors are fundamental to ensuring the intersection between the two worlds of science and technology.[20] Research shows that the mobility of researchers is crucial to transferring scientific knowledge with certain excludability from university to industry, and in fact, the more valuable the patent, the higher the probability of a move to a company.[21]

Second, as outlined earlier, it is not unnatural to assume that only a small share of inventors and firms actually work directly with public research institutions because only a small share of firms are involved in more radical innovations and scientific breakthroughs. In this light, the low absolute or relative numbers of innovations that are brought to market through collaboration is neither surprising nor disappointing. These figures must be seen in terms of the structure of the particular industry, the sophistication of the innovation ecosystem, and types of innovations produced—that is, radical innovations or more incremental ones.

Business innovation surveys

A second set of survey indicators concern enterprise innovation surveys that assess innovation cooperation. These address the question of whether firms have cooperated with public research institutions during the innovation process.

In the absence of results from business innovation surveys with broad country coverage or better data on industry-science linkages with broad country coverage, the GII relies on the survey results of the World Economic Forum (WEF)'s Executive Opinion Survey.[22] One question in that survey asks respondents about the intensity with which businesses and universities collaborate on R&D.[23] One advantage is that the question potentially targets formal and informal collaboration alike. The data are, however, 'soft' data—they are very qualitative. They also relate to R&D rather than to innovation more broadly. Another statistic from the WEF survey in use in the GII assesses the state of cluster development.[24]

Currently, the most pertinent and complete innovation survey is the European Community Innovation Survey (CIS), which—until recently—was conducted primarily in European high-income economies.[25] Encouragingly, since 2005 the CIS places greater emphasis on the role of linkages with other firms and institutions in the innovation process.[26] Furthermore, UNESCO's Institute for Statistics (UIS) and the Red Iberoamericana de Indicadores de Ciencia y Tecnología (RICYT, or Network of Science and Technology Indicators-Ibero American and Inter-American) are both emphasizing innovation linkages when formulating guidelines on how to implement innovation surveys in developing countries.[27]

These business innovation surveys examine which of the following modes are used to conduct innovation and which are the sources of this knowledge transfer, including public research institutions:

- *Open information sources:* These comprise openly available information that does not require the purchase of technology or IP rights and does not require interaction with the source.
- *Acquisition of knowledge and technology:* This refers to purchases of external knowledge and/or knowledge and technology embodied in capital goods and services.
- *Innovation cooperation:* This refers to active cooperation with other enterprises or public research institutions for innovation activities (including the purchase of knowledge and technology).

One advantage of the business innovation surveys is that, in principle, they address all linkages, including informal ones. Moreover, they are not limited to technological breakthroughs and patents but instead embrace innovation (including process innovation) in general. A second advantage is that these surveys contain a large number of representative responses.

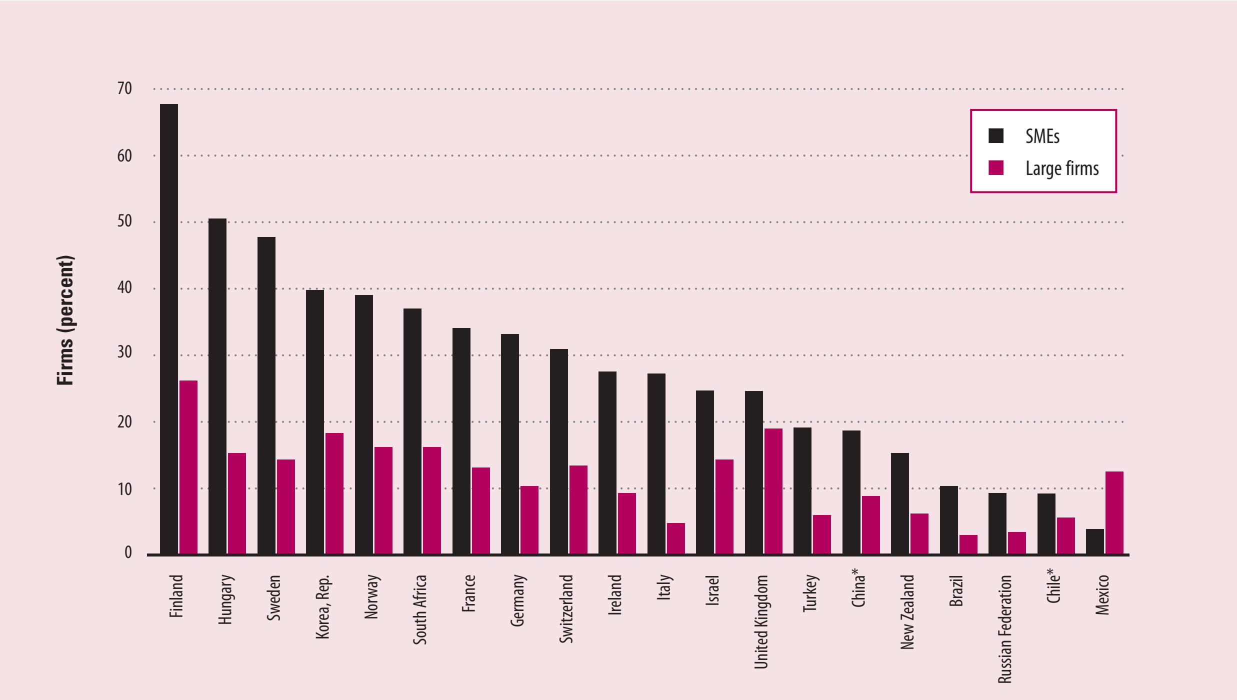
One reason for not using innovation survey data in the 2012 GII is the limited, although fast-growing, number of countries that carry them out these surveys. This will likely change because the goal of the UIS is to create an international database of innovation statistics for countries at all stages of development as of 2013.[28]

As was the case with inventor surveys, another challenge is the interpretation of related results. Firms are asked to evaluate which knowledge sources are 'highly important' to their innovation. The data produced show great variation by country, and comparability is not evident (Figure 3). A key problem with these business innovation surveys is still the cross-country comparability of results.

As expected, available data from existing innovation surveys—mostly for European, other advanced, and a few middle-income countries (e.g., China, the Russian Federation, and South Africa)—show that internal sources are often reported as the most important for innovation. Suppliers of equipment, materials, components, or software are the most likely external collaboration partner. The next likely collaborators are other enterprises within the enterprise group, often followed by customers and clients-competitors, and then, last—as seen in the inventor survey—universities and PROs. In most countries, large firms are usually two to three times more likely than small and medium-sized enterprises to engage in such collaboration.

Provisional results from the UIS show that in many surveyed countries a low percentage of firms cooperated with universities and other higher education institutions. Yet great differences across countries prevail.[29] In the Philippines, 47.1% of all innovation active manufacturing firms cooperate with universities or other higher education institutions; Malaysia shows similar levels of cooperation. This percentage

Figure 3: Firms collaborating on innovation with higher education or government research institutions by firm size, 2006–08



Source: OECD Science, Technology and R&D Statistics; OECD, 2011.
Note: See http://www.oecd-ilibrary.org/science-and-technology/data/oecd-science-technology-and-r-d-statistics_strd-data-en for detailed technical notes.
* China (2004-06); Chile (2007–08).

drops to 15–20% in Indonesia, South Africa, Colombia; it drops further, to 9% in the Russian Federation and 2% in Brazil. In some countries, other cooperation partners present even lower rates.

At face value, apart a few countries that seem to have the opposite experience, university interaction with industry appears to be a quantitatively small part of the overall pattern of knowledge flows for innovation.[30] This is not true in all countries, however. Innovating large firms in the Nordic countries, Hungary, and the Republic of Korea collaborate to a significant extent with public institutions, while few enjoy such collaboration in the Russian Federation, Chile, and Mexico. Moreover, innovation surveys cover product, process, marketing, and organizational innovation. It is not expected that connections to public research matter much to a majority of innovating firms, especially when they do not participate in research in the same way as universities.

The very sparse literature, based on innovation surveys, assessing linkages and their importance finds that incremental innovators benefit from intra-industry knowledge spillovers and close proximity to universities, but that radical innovators (those who come up with products new to the market) collaborate with universities, even with foreign universities. However, these studies also show that radical innovators source knowledge from universities but do not necessarily cooperate with them directly. In this latter case, they might not be counted in the above statistics as relying on public research institutions as external partners.[31]

Furthermore, the vehicle of technology transfer—that is, informal links, research agreements, patent licensing, and so on—between the innovating firm and the public sector is not explained. For the most part, this question is not posed. Only a few innovation surveys include such detailed information.

The relatively new US Business R&D and Innovation Survey breaks new ground in this respect.[32] It contains questions on agreements with public research institutions and other interactions with academia, such as the hiring of academic consultants for short-term projects in science and engineering, the visiting of corporate scientists at universities, and financial support to public research in order to support R&D.

In general, however, the qualitative dimension of collaboration (exactly how important such collaboration is, and via which levers it occurs) is often uncertain when looking at these survey results. An exception is seen when some more detailed industry studies have been carried out as a follow-up. More importantly, existing metrics and more detailed studies struggle to shed light on the ensuing downstream effect and impact of university and PRO outputs and the collaboration of industry with these institutions. Additional related impacts of cooperation may materialize over time, complicating the accurate measurement of impacts further.

Conclusions

This chapter shows that it is infeasible to reduce the complex web of science-industry relations and their indirect and direct effects on industrial innovation to a single-headling figure. Possible metrics are often not available for many countries, and those that are available are imperfect in their ability to encapsulate the complex set of overlapping interactions and knowledge flows. It is hoped that in the near future it will be possible to use a cluster of variables to measure the intensity and efficacy of science-industry collaboration. Certainly, an important objective of the GII exercise is to point to the current state of data in a given innovation policy field and to encourage the improvement of its metrics.

Notes

1 WIPO, 2011a.

2 NRC, 2003.

3 NSB, 2012.

4 NRC, 2003; WIPO, 2011b.

5 Freeman and Soete, 2007.

6 See Eurostat and OECD, 2005; RICYT, 2001.

7 Veugelers, 2007.

8 Statistics Access for Tech Transfer (STATT), AUTM, May 2011, available at http://www.autmsurvey.org/statt/index.cfm.

9 See WIPO 2011b for a summary of available data and a related discussion.

10 For a discussion of this point, see WIPO, 2011b.

11 Following the OECD *Frascati Manual on R&D Survey Standards*, the definition of higher education sector covers all universities, colleges of technology, and other institutions of post-secondary education, whatever their source of finance or legal status. It also includes all research institutes, experimental stations and clinics operating under the direct control of or administered by or associated with higher education institutions.

12 OECD, 2011.

13 See Box 4.3 in WIPO, 2011b; see also Khan and Wunsch-Vincent, 2011.

14 EC, 2009.

15 WIPO, 2011b.

16 WIPO, 2011b; Zuñiga, 2011.

17 Guiri et al., 2007.

18 Guiri et al., 2007.

19 See the project 'Academic Patenting in Europe (APE-INV)', steered by Francesco Lissoni at http://www.esf-ape-inv.eu/index.php, for some work in the field.

20 Breschi and Catalini, 2010.

21 Crespi et al., 2006.

22 The Executive Opinion Survey is given annually to thousands of business executives to gather their insight into their business operating environment. For further information on this survey, see Brown and Geiger, 2011.

23 The survey question asks 'To what extent do business and universities collaborate on research and development (R&D) in your country?' Possible answers: 1 = do not collaborate at all; 7 = collaborate extensively. See https://wefsurvey.org.

24 See Chapter 1 of this report.

25 In the future, another potential source of information is the World Bank Enterprise Survey, which has a large country coverage. Its Innovation and Technology Module currently has only one linkage question, which is related to the share of firms using technology licensed from foreign companies.

26 Eurostat and OECD, 2005. Questions on sources of information and cooperation (the latter focused only on R&D activities) have been in the CIS questionnaire since its first round. In 2005, the whole issue of linkages was emphasized by the *Oslo Manual* (3rd edition). The document in which UIS and RICYT are also emphasizing linkages in developing countries is an annex to the 3rd edition of manual.

27 RICYT undertook the first effort to develop guidelines for innovation surveys outside of the OECD and the European Union. This resulted in the *Bogotá Manual,* which is used in most innovation surveys conducted in Latin American countries. See http://www.ricyt.org/.

28 The UIS has developed a pilot data collection that has been conducted in 2011. The pilot was focused on the gathering of national data from the most recent national innovation surveys in 19 pre-selected countries: Brazil, China, Colombia, Egypt, Ghana, Indonesia, Israel, Malaysia, the Philippines, the Russian Federation, South Africa, and Uruguay. Thanks go to Martin Schaaper and Luciana Marins from the UIS for providing this and related information.

29 Thanks go to Martin Schaaper and Luciana Marins from UIS for providing this and related information. The data will be published in the summer of 2012 under the title 'Results of the 2011 Pilot Innovation Data Collection', conducted by the UNESCO Institute for Statistics (UIS).

30 Cosh et al., 2006.

31 Mohnen and Hoareau, 2003; Mairesse and Mohnen, 2010.

32 See the US Business R&D and Innovation Survey, available at http://www.nsf.gov/statistics/srvyindustry/about/brdis/.

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