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ZEW policy brief

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Knowledge Flows between Science and Industry and How to Measure Them

New Ways of Knowledge Exchange and Their Measurement

The exchange of knowledge between science and industry has been a focus of innovation research and policy for many decades. New developments in the way technologies are generated, shared, and transferred into new products, services, and business models are currently re-emphasising science-industry interactions. Main drivers are the emergence of open innovation models, the increased internationalisation of innovation processes, the rise of digital platforms, new modes of governance in public research, and the enlarged role of disruptive innovations. At the same time, the measurement of knowledge flows is still limited, and indicators on recent trends in science-industry interaction are lacking. This limits innovation policy in monitoring changes and addressing challenges. A conference in October 2019 in Berlin brought together industry representatives, researchers, and policy makers to discuss these developments and how the measurement of science-industry links could be improved.
This policy brief summarises key trends in science-industry collaborations, presents existing indicators and discusses ways to improve our indicator system on knowledge flows between science and industry in order to better inform policy.

KEY MESSAGES //

- Science-industry collaboration is important for innovation – this is particularly true for ambitious, risky or disruptive innovation activities.
- Firms, universities, and research institutes use a multitude of channels, with a focus on face-to-face interaction, both in formalised joint projects or through informal contacts.
- Most existing indicators – such as joint patent applications, co-publications or financial flows – focus on codified knowledge. There is a lack of indicators on people-based knowledge flows, as well as on the exchange of tacit knowledge, e.g. through personal contact.
- A broader, balanced picture is needed in order to adequately evaluate the effectiveness of knowledge transfer between the two sectors, including new indicators.
- Internationally harmonised indicators can help policy makers in assessing the state of science-industry interaction in their country, and identify potential good practices in other countries.

TRENDS IN SCIENCE-INDUSTRY COLLABORATION

Four Important Developments in Science-Industry Collaboration

The way science and industry interact and exchange knowledge is shaped by many factors. Four developments are currently changing science-industry collaboration.

- Open innovation—by sharing their own knowledge with others, firms aim to overcome firm boundaries and access external knowledge more effectively and efficiently from a more diverse knowledge input, but also input that is better linked to the specific needs of their innovation process. For higher education institutions (HEIs) and public research institutes (PRIs), open innovation calls for more direct involvement in industrial innovation and managing dynamic inter-organisational networks (Perkmann and Walsh, 2007).
- Platforms and clusters for knowledge exchange—markets for knowledge and technology have become more important with the emergence of digital platforms and open science approaches. They can facilitate knowledge flows but also require new ways of IP management both at firms and at HEIs and PRIs. Clusters are another emerging approach to ease knowledge transfer within an industry, field of technology, or region.
- Disruptive innovation—new technologies (particularly those related to digitalisation) offer a great potential for changing markets and user-producer interactions. Disruptive innovations often challenge science-industry collaboration, as the former tends to require new forms of knowledge transfer that differ from established channels, such as exchange of IP or joint research projects.
- Internationalisation—firms increasingly aim at sourcing and exploiting knowledge at a global scale. This is challenging knowledge transfer activities at science, which are often linked to the national or regional level. Internationalisation also calls for a more harmonised measurement of science-industry interactions.

In addition to these specific changes, there is a general trend of knowledge co-creation of firms and science institutions becoming more important (OECD 2019). For example, the share of HEI/PRI jointly patenting with industry is constantly increasing, as is the share of science-industry co-publication. A main driver is the increasing significance of knowledge-based capital for firms as well as the increasing complexity of technologies, particularly in areas that cross disciplinary borders. In building this capital, HEIs and PRIs become important knowledge sources and partners.

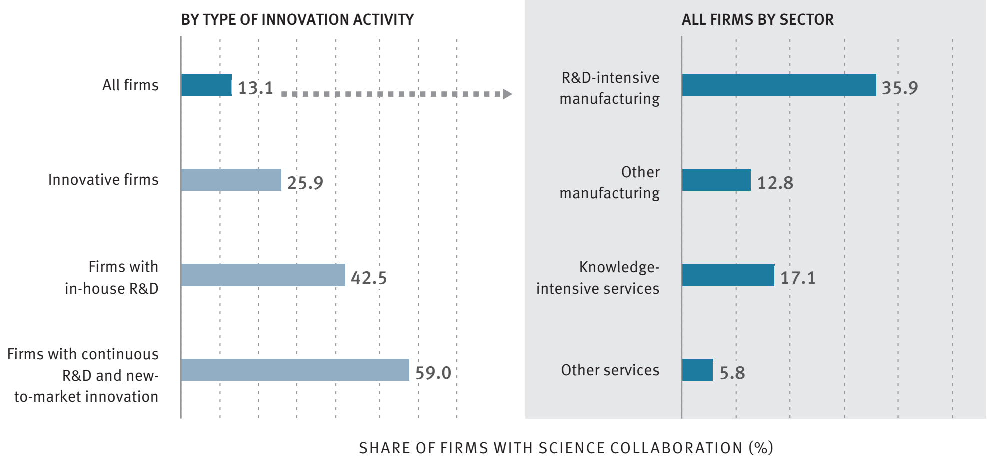
ACTORS IN SCIENCE-INDUSTRY COLLABORATION

Science Collaboration is Highest in R&D-Intensive Manufacturing

Data from the German Community Innovation Survey reveal that 13% of all firms with more than five employees collaborate with science – both on innovation and in other contexts. Figure 1 shows that the share of firms with science collaboration is the highest in R&D-intensive manufacturing (35.9%) and knowledge-intensive services (17.1%). However, a significant number of firms in non-R&D-intensive manufacturing (12.8%) and in other services (5.8%) also utilise knowledge from HEIs and PRIs. Moreover, scientific collaboration partners vary depending on their disciplines, with the highest probability of being in engineering and natural sciences (Paunov et al., 2017; Audretsch et al., 2004), though the social sciences and humanities also engage in knowledge exchange (Schartinger et al., 2002). During 2015 and 2017, firms in Germany had more than 125,000 collaboration projects with science institutions. This is about 0.8 projects per full-time researcher at German HEIs or PRIs. The vast majority of scientific partners (95%) are located in Germany (Rammer, 2019).

The more innovation-oriented a firm, the higher the probability for science collaboration. 25.9% of innovative firms – firms that introduced at least one product or process innovation –collaborate with science. Among firms with in-house R&D, this share raises to 42.5%. The highest share

FIGURE 1: SHARE OF FIRMS COLLABORATING WITH SCIENCE (GERMANY, 2015 – 2017)



Weighted results for firms with 5+ employees in manufacturing (Nace 5-39) and services (46, 49-53, 58-66, 69-74, 78-82).
Source: Mannheim Innovation Panel, 2018 survey – calculations by ZEW.

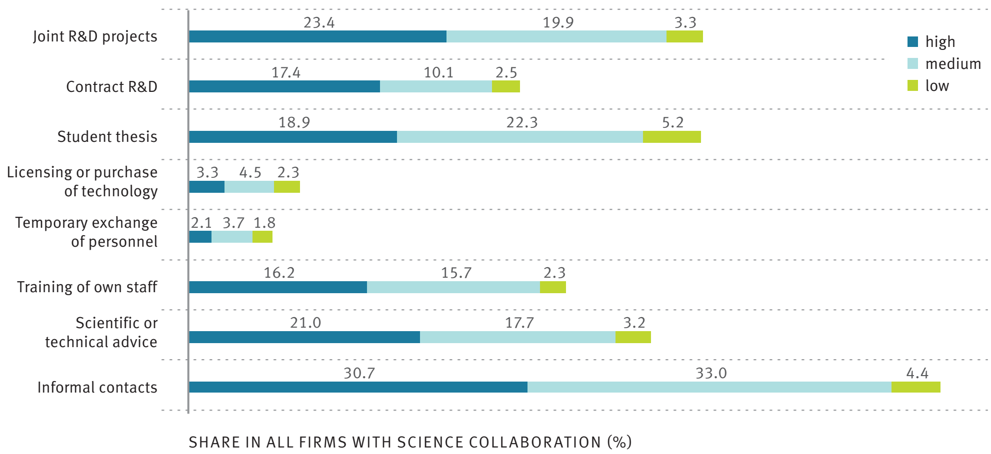
is found among firms with continuous in-house R&D and new-to-market innovations. In this group, 59.0% collaborate with HEIs or PRIs. These figures suggest that firms with more ambitious innovation (which tend to be more risky or disruptive) tend to rely more on science-industry collaborations. There firms look for new scientific breakthroughs to fuel their innovations. Consistent with this finding is that scientific excellence is a major driver for industry collaboration, at least in engineering and natural sciences (Perkmann et al., 2011).

CHANNELS OF KNOWLEDGE TRANSFER

Firms, HEIs and PRIs use a multitude of channels to exchange knowledge. The most frequently used transfer mode are informal contacts. 64% of all firms collaborating with science access scientific knowledge through personal communication with HEI and PRI researchers (Figure 2). This

Informal Contacts Most Important for Scientific Knowledge Transfer

FIGURE 2: CHANNELS OF SCIENCE COLLABORATION USED BY FIRMS IN GERMANY 2015 — 2017, BY EFFECTIVENESS FOR ACCESS TO SCIENTIFIC KNOWLEDGE



Weighted results for firms with 5+ employees in manufacturing (Nace 5-39) and services (46, 49-53, 58-66, 69-74, 78-82).
Source: Mannheim Innovation Panel, 2018 survey – calculations by ZEW.

is also the channel most often rated as highly effective. Joint R&D projects (47%) and joint supervision (46%) of student theses are other frequently used transfer modes. Many firms rely on different channels, combining both formal and informal modes of knowledge exchange. Such an approach has been found to be beneficial for firms in garnering the most innovation results (Grimpe and Hussinger, 2013).

Up to now, two transfer channels are only rarely used by firms and rated as little effective: the licensing or purchase of technology developed at science, and the temporary exchange of personnel. This hints at potential barriers. With respect to technology acquisition, the current IP management at universities has been viewed by many firms as complicating the transfer of technology by making technology acquisition more costly and time consuming. Personnel mobility between industry and science is complicated by different payment systems and employment regulations. Changing temporarily between the two sectors may also hamper personal career opportunities within a researchers' home sector instead of improving their careers. The actual relevance of these and other barriers, however, are not well understood and would require dedicated analyses.

Characteristics of Transfer Models

For measuring and evaluating science-industry links, the variety of exchange modes has to be taken into account. Figure 3 lists different types of science-industry interactions that have been used in empirical studies. Three characteristics of transfer modes are important to consider:

- direct face-to-face interaction, both in formalised joint projects and through informal contacts, has been found important for reducing barriers in science-industry interaction by building up mutual trust and finding a common language (Bruneel et al., 2010);
- the extent to which channels allow for the transfer of tacit (not codified) knowledge is relevant, as tacit knowledge tends to contain the most critical information for firms' innovation activities (Hicks, 1995; Howells, 1996; Ahrweiler et al. 2011); and
- for measurement purposes, tracing interactions is highly relevant. Transfer modes that leave a formal track (e.g. on paper or digitally) are easier to record than interactions without a formal track, which can usually only be measured by surveying individuals or organisations that have been involved in the respective transfer activity.

Only a small fraction of transfer modes share all three characteristics, including collaborative R&D projects, researcher mobility between the two sectors, and joint publications and patenting. These are also the areas for which reliable and internationally comparable data sources are best available. Nevertheless, these modes cover only a part of science-industry knowledge flows. For most transfer modes, no established data source exist.

MEASURES FOR SCIENCE-INDUSTRY KNOWLEDGE TRANSFER

Most Widespread Indicators for Science-Industry Interactions

International science and technology statistics provide some indicators for measuring science-industry interactions. The most widespread indicators include:

- financing of R&D at HEIs and PRIs by business enterprises based on R&D statistics;
- publication of scientific articles co-authored by researchers from industry and science based on bibliometric analysis;
- joint patent applications by firms and HEIs/PRIs, or patent applications with inventors from both industry and science based on patent data; and
- the number of firms collaborating with HEIs/PRIs on innovation or using HEIs/PRIs as information sources for innovation based on innovation surveys.

Analysing the indicators reveals diverging results in terms of country differences. These differences reflect the diverse types of interactions covered by each indicator. When looking at Germany, R&D financing at HEIs and PRIs by business enterprises has been increasing substantially over the past

FIGURE 3: TYPES OF INTERACTIONS FOR MEASURING SCIENCE-INDUSTRY KNOWLEDGE TRANSFER

TRANSFER MODE	Face-to-face	Tacit knowledge	Formal track	Data source
Collaborative research projects/programmes	applies fully	applies fully	applies fully	RD, IS
Mobility of researchers from science to industry and vice versa	applies fully	applies fully	applies fully	LFS
Joint publications	applies fully	applies fully	applies fully	Bibliom.
Joint patenting	applies fully	applies fully	applies fully	Patstat
Temporary exchange of researchers between industry and science	applies fully	applies fully	applies partly	Survey
Meetings, talks, personal communication	applies fully	applies fully	does not apply	Survey
Training of researchers of enterprises	applies fully	applies partly	applies fully	Survey
Conferences attended both by industry and science	applies fully	applies partly	applies partly	Survey
Contract research and consulting	applies partly	applies partly	applies fully	RD
Lectures at universities held by employees of enterprises	applies partly	applies partly	applies fully	Admin.
Joint ventures of firms and science institutions	applies partly	applies partly	applies fully	Admin.
Joint supervision of PhD and Master theses	applies partly	applies partly	applies partly	Admin.
Use of public research facilities by industry	applies partly	does not apply	applies partly	Survey
Startups by researchers from science	does not apply	applies fully	applies fully	Survey
Startups by university students/graduates	does not apply	applies partly	applies fully	Survey
Employment of university graduates or doctorate holders by firms	does not apply	applies partly	applies partly	LFS
Cooperation agreements between firms and science institutions	does not apply	does not apply	applies fully	Admin.
Firms locating at the campus of science organisations	does not apply	does not apply	applies fully	Admin.
Internships by university students in firms	does not apply	does not apply	applies fully	Survey
Startups based on science patents	does not apply	does not apply	applies fully	Admin.
Licensing/selling of science patents to enterprises	does not apply	does not apply	applies fully	Admin.
Purchase of prototypes developed at science	does not apply	does not apply	applies fully	Admin.
Material transfer agreements	does not apply	does not apply	applies fully	Admin.
Citation of science patents in firm patents	does not apply	does not apply	applies fully	Patstat
Citation of science articles in firm articles	does not apply	does not apply	applies fully	Bibliom.
Participation of firm members in boards of science institutions	does not apply	does not apply	applies fully	Admin.
Hyperlinks between firms and science institutions on websites	does not apply	does not apply	applies fully	Digital
Reference to science in firms' social media activities, and vice versa	does not apply	does not apply	applies fully	Digital
Financing of chairs or research posts in science institutions by firms	does not apply	does not apply	applies fully	Admin.
Researchers in firms reading publications, patent files etc.	does not apply	does not apply	does not apply	Survey

■ applies fully; ■ applies partly; ■ does not apply; ■ existing data sources; ■ data sources to be developed

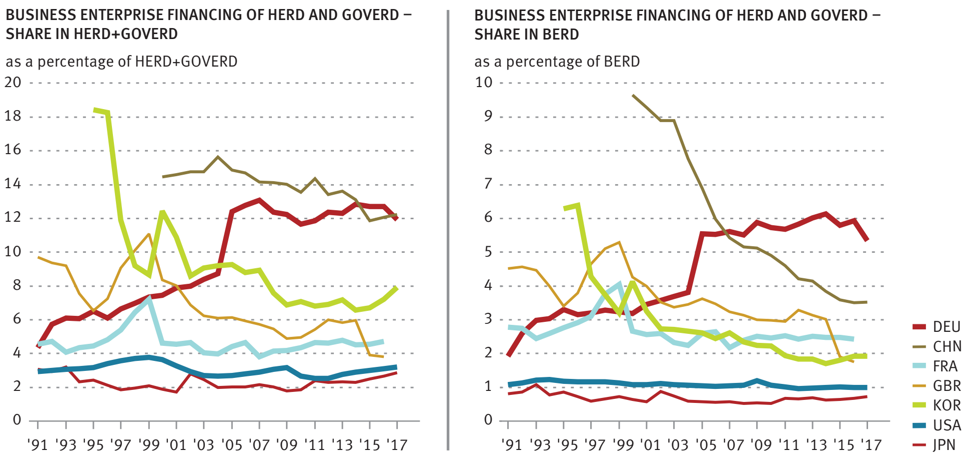
RD: R&D statistics; IS: Innovation statistics; LFS: Labour Force Survey; Bibliom.: bibliometric databases; Patstat: Patent statistics; Survey: surveys of firms of HEIs/PRIs; Admin.: administrative data at HEIs/PRIs; Digital: digital data sources
Sources: Bozeman (2000), Polt et al. (2001), Schartinger et al. (2002), Perkmann et al. (2013), Ankrah and Al-Tabbaa (2015), Schmoch (1999, 2003), Bekkers and Bodas Freitas (2008), Mansfield (1995), Mansfield and Lee (1996).

25 years (Figure 4). In most other large OECD countries, however, the indicator shows a downward trend. In 2017, Germany had the second highest indicator value among all OECD countries (marginally lower than Lithuania) with respect to the share of industry financing of R&D performed in HEIs and PRIs. Moreover, the share of expenditures on R&D performed by HEI/PRI in total intramural R&D expenditure of firms is significantly higher in Germany than in other large OECD countries.

Co-publications from Joint R&D Projects

These R&D financing indicators mainly measure interactions based on joint R&D projects and contract R&D. Indicators on co-publications, in contrast, focus on knowledge flows related to basic R&D activities. Co-publications typically emerge from joint R&D projects but can also result from joint supervision of student theses, in particularly of PhD students, or temporary exchange of personnel. In addition, science-industry co-publications may appear if researchers move from

FIGURE 4: FINANCING OF R&D IN HEIs AND PRIs BY FIRMS



Note: break in series for many countries due to changes in definitions and data collection methods. BERD: business enterprise R&D expenditure; HERD: Higher education R&D expenditure; GOVERD: R&D expenditure in government institutions. Source: OECD, MSTI 1/2019; calculations by ZEW.

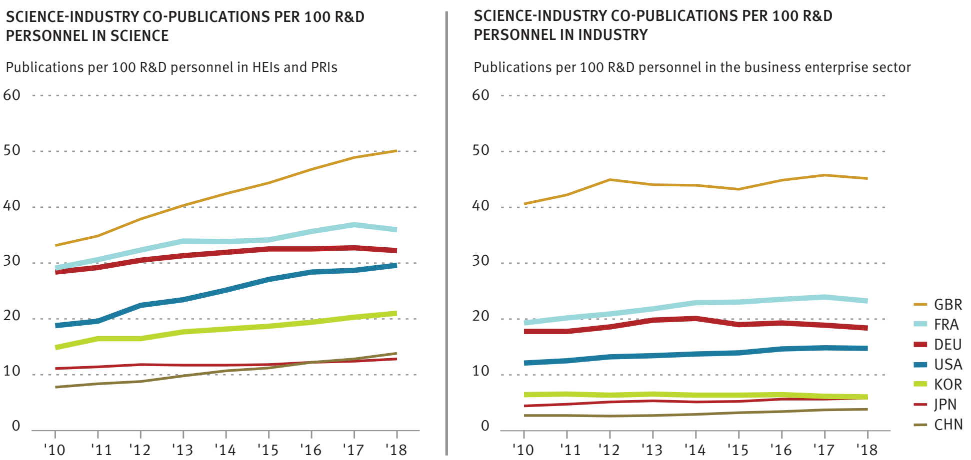
science to industry, and a research result generated jointly with other researchers at science is published only after they left science, hence showing their new industry affiliation.

Co-publications: Germany Well behind UK and France

For co-publications, Germany shows a lower indicator value than the UK and France, and a lower increase than in most of the other large OECD countries. This is particularly clear when co-publications are related to the number of R&D personnel in the science sector (Figure 5). It seems that the increase in R&D financing by businesses at HEIs and PRIs did not result in a higher joint scientific output, perhaps because most of business R&D financing is for applied R&D.

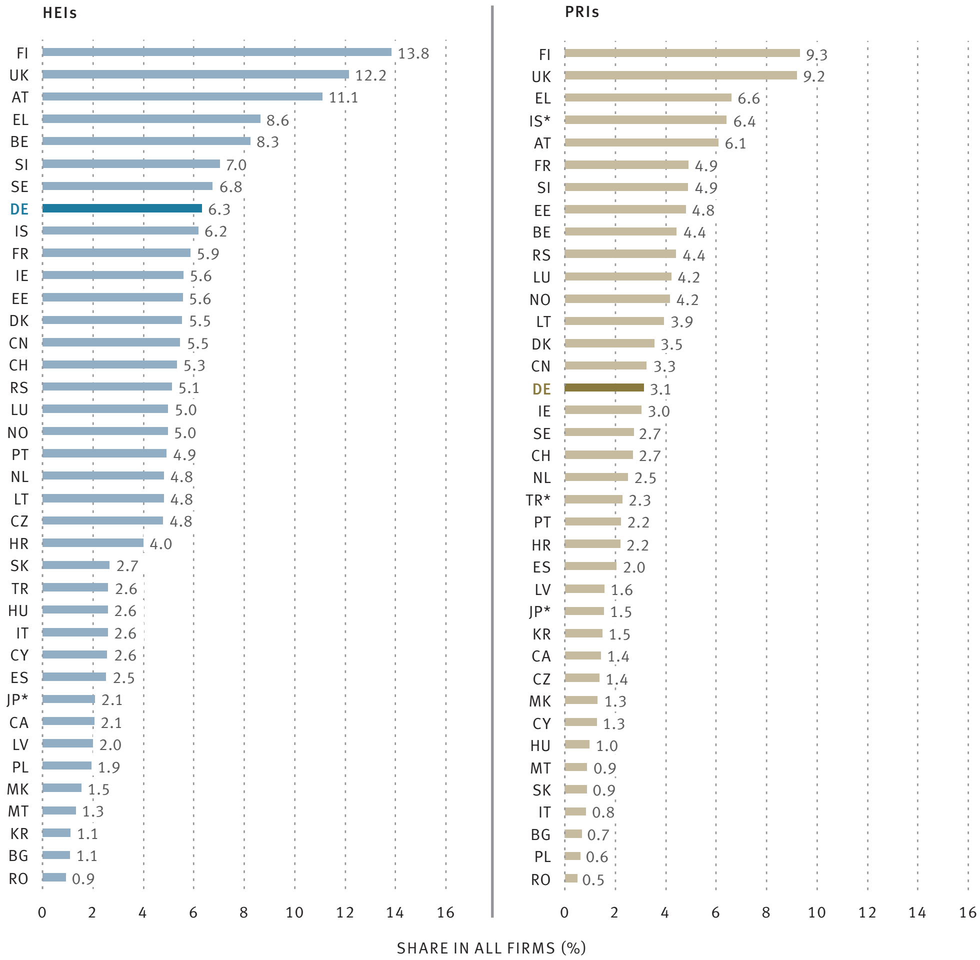
Another group of indicators is obtained from innovation surveys. The Community Innovation Survey collects data on the number of firms that co-operate on innovation activities with HEIs or PRIs (without providing information on how the co-operation actually takes place). This indicator is

FIGURE 5: SCIENCE-INDUSTRY CO-PUBLICATIONS PER R&D PERSONNEL



Note: number of R&D personnel has been estimated for some countries and years.
Source: European Innovation Scoreboard 2019/ScienceMetrics; OECD, MSTI 1/2019; calculations by ZEW.

FIGURE 6: FIRMS THAT CO-OPERATE ON INNOVATION ACTIVITIES WITH HEIs AND PRIs (2014–2016)



Firms with 10 + employees in NACE rev. 2 divisions 5-39, 46, 49-53, 58-66, 71-73; * 2012–2014.
Source: Eurostat, Community Innovation Survey 2016. NBSC, NISTEP, STATCAN, STEPI; calculations by ZEW.

conceptually close to the R&D financing indicator but focuses on interactions among small and medium-sized firms, as it is neither weighted by the number of co-operations per firm, nor by the financial flows associated with the co-operation project. In addition, the indicator also includes co-operation beyond R&D. The results show a relatively high indicator value for Germany when looking at co-operation with HEIs, and a much lower one for PRI co-operation (Figure 6).

A Comprehensive Metrics on Knowledge Exchange Is Needed

The existing indicators on knowledge flows between science and industry are certainly informative, yet still limited. They focus on a few transfer channels, particularly joint R&D projects. A large number of other widely used channels are poorly covered by existing indicators. This is particularly true for channels based on personnel mobility, and for informal contacts. In addition, there are no internationally harmonised and regularly updated data sources on interactions relating to start-ups (e.g. spin-offs from HEIs and PRIs) or joint infrastructure. For assessing the state of science-industry links, potential gaps, and the contribution of policies to reduce gaps and improve the links between both sectors, a comprehensive metrics on knowledge exchange between science-industry would be needed. This should cover:

- collaboration in R&D projects (e.g. based on financial flows from R&D statistics and projects/activities from innovation statistics);
- personnel mobility (graduates, researchers);
- industry engagement in student education;
- codified knowledge production (co-publication, co-patenting, licensing);
- transfer through start-ups and joint business activities;
- infrastructures (labs) and intermediaries devoted to knowledge exchange; and
- informal contacts (based on surveys in science and industry).

A Methodology Should Be Developed on How to Define Knowledge Flows

For establishing such an indicator system, a methodology has to be developed on how to define and measure knowledge flows. Both existing data sources (such as labour force surveys or linking administrative information on employee mobility with employer data), new data sources (particularly digital ones like websites and platforms) and dedicated surveys (especially on transfer activities at HEIs and PRIs) should be considered. For achieving internationally harmonised indicators, co-ordination with international organisations such as the OECD or UNESCO would be highly useful.

With such an extended metrics at hand, more analysis on the role of knowledge flows for different types of innovation in different market and technology environments could be facilitated, as well as reviews of policies to strengthen science-industry ties.

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FURTHER INFORMATION //

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Note on this ZEW Policy Brief

A conference entitled "How (much) knowledge flows – measurement, determinants and innovation policy relevance of knowledge flows between science and industry" was held at the Futurium in Berlin on 11 October 2019. This ZEW policy brief summarises findings from the conference and supplements the lectures and discussions held at the event by placing them in the context of the wider international academic debate.
The conference was jointly devised and organised by the research statistics arm of Stifterverband and ZEW, with support by VDI/VDE IT. The conference was part of a joint research project of Stifterverband and ZEW funded by Germany's Federal Ministry of Education and Research (BMBF).

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