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An analysis of national research systems (III): towards a composite indicator measuring research interactions

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Highlights

Interactions in research are multifaceted and need not go in the same direction. For example, higher overall mobility of researchers in science & technology need not go hand in hand with more collaboration as measured by co-publication and co-patent data.

The research is based on a large scale data collection for 53 countries (all EU member countries; all potential, acceding, and candidate EU member countries; all non-EU OECD member countries; and all BRICS countries; spanning 12 years: 2000-2011). From this long list of variables including data on funding, co-publication and co-patenting as well as researcher mobility based on bibiliometric and survey data, we present a short list of 19 potential indicators that all have their merits by themselves but are more difficult to be summarized in a composite indicator.

Concerning public-private research interactions, we see that mobility and collaboration do go hand in hand. In other words, the extent to which different kind of interactions (mobility versus collaboration) follow the same trend seems to depend on the dimension along which such interactions take place. Here, different kinds of cross-institutional interactions follow the same pattern. Although different kinds of international research interactions present a similar picture, we need to take into account that smaller (larger) national research systems are generally more (less) internationally oriented. Overall, we conclude that for constructing a composite indicator on interactions in research and innovation it is important (i) to take the nature and direction of interactions in research and innovation duly into account and (ii) to acquire more data that is well-specified to measure research interactions.

Contents

1. Introduction

1.1. Background of the project

With the introduction of the Europe 2020 strategy and its Innovation Union flagship initiative, the European Commission has made a shift in orientation from fostering 'research in Europe' towards fostering 'European research' (Nedeva and Stampfer, 2012). Recognizing that coordinating national research efforts on a case-by-case basis is practically unfeasible, attention has shifted towards the construction of a pan-European research system called the European Research Area (ERA). Accompanying this, it is widely acknowledged that many European countries are outperformed by countries like the United States when it comes to both technological and scientific research (Pavitt, 2000, Dosi et al., 2006). To remedy this situation, the European Commission aims at stimulating research excellence by increasing competition among researchers at a European level; for example, by establishing a central research funding agency, the European Research Council (ERC). Meanwhile, the current economic crisis has increased budgetary pressures across the board. Hence, allocating scarce resources to research has become an issue to be dealt with in the context of growth promoting policies. Overall then, it is unlikely that the economic crisis has no impact on research at all (Filippetti and Archibugi, 2011).

While some take investments in research as a necessary condition to foster welfare growth (Gruss, 2012), others discuss the kind of institutional and organizational arrangements that are needed to make research most productive (Marty, 2012). This project follows the latter strand of thought and investigates these issues for research at the country level. The results reported follow from a project initiated by the Directorate-General for Research and Innovation of the European Commission (DG RTD) within the context of developing indicators for the Innovation Union. The *main objective* of the overall project is to develop indicators that are capable of measuring and monitoring patterns and trends in research across countries. As such, the focus is on measuring three dimensions to research. One is about the interactions that take place between research actors within and across Europe. The main aim here is to track patterns of mobile researchers, R&D investment flows, and collaborative research endeavors across and beyond EU member states. Another dimension is about research interactions that take place between different kind of actors, such as universities, industry and government actors. Again the main aim is to track patterns of mobile researchers, R&D investment flows, and collaborative research endeavors along these institutional lines. Finally, a third dimension is about the impact that research activities have in terms of the outcomes produced and the ease with which inputs to research are transformed into research outputs. While the latter dimension has been studied in previous reports of this project (Hardeman et al., 2013; Hardeman and Van Roy, 2013), this report will be concerned with the first two dimensions; that is, measuring and monitoring research interactions – both in general and in geographical and institutional terms.

1.2. Contribution of this report

The main aim of this report is to explore the possibility of a composite indicator measuring research interactions at the country level. As such, this report is a follow up of and yet somewhat different from previous studies in which we developed a composite indicator measuring research excellence (Hardeman et al., 2013) and assessed the efficiency of national research systems (Hardeman and Van Roy, 2013). It builds upon the previous studies in that it takes the same conceptual framework as its starting point. In other words, this report uses the notion of national research systems as its main conceptual starting point and focuses on the role of research interactions therein. Yet it is different from these two previous studies in that it is more explorative in orientation. Hence the approach taken will be more data-driven and less theory-driven. Overall, the main contribution of this report lies in its assessment of the prospects of a (or more) composite indicator(s) measuring research interactions at the country level. The report proceeds as follows. The next section presents the conceptual framework for the analysis. Section 3 presents the data and discusses measurement issues. Section 4 presents the main outcomes of the analysis. Section 5 concludes.

2. Theoretical framework

2.1. Background: from research in Europe towards European research

With the introduction of the Europe 2020 strategy and its Innovation Union flagship initiative, the European Commission has made a shift in orientation from fostering 'research in Europe' towards fostering 'European research' (Nedeva and Stampfer, 2012). This shift has at least two backgrounds. One is that, recognizing that coordinating national research efforts on a case-by-case basis is practically unfeasible, attention has shifted towards the construction of a pan-European research system called the European Research Area (ERA). This was accompanied by the recognition that Europe is outperformed by countries like the United States when it comes to both technological and scientific research (Pavitt, 2000, Dosi et al., 2006). Both accounts take issue with the systemic nature of research as an interactive process (Lundvall, 1988, Gibbons et al., 1994, Aghion et al., 2009). This systemicness, however, is not just to be thought of in geographical terms (i.e. spanning national boundaries) but also in terms of research combining university and industry interests and crossing disciplinary boundaries. Overall, the main idea that has often been put forward holds that the more integrated a research system is (not just in geographical terms!), the better it is likely to perform (Nauwelaers and Wintjes, 2008).

2.2. A characterization of national research systems

Following the OECD (2002, p. 30) we define research (including experimental development) as "creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications." As such, we attribute a number of characteristics to research (see also Hardeman et al., 2013).

One is that research is about a particular kind of activity, namely, creative work that is undertaken in a systematic way. As argued by Godin (2001) there are at least three interpretations of research as systematic . One focuses on the idea of research as an activity that follows inductive, logical steps. In other words, research starts with particular observations and ends with general rules and laws. Another, though similar interpretation of research stresses that research follows the scientific method. Here, an important characteristic of research as systematic is that it produces outcomes that are reproducible and measurable. Contrary to the first two (epistemological) interpretations of research as systematic, a final interpretation of research focuses more on the institutional aspects of it. It holds that research is of an enduring, programmatic, organized nature. Here, we do not favour one interpretation of research as systematic over another. In our understanding, the production of (new) knowledge follows from research once these activities are non-serendipitous. We consider research as non-serendipitous because resources are explicitly devoted to it and that the search for new results is structured.

Another characteristic of research is that it has a particular goal orientation, namely, increasing the stock of knowledge. As such, research is primarily about producing new knowledge rather than using existing knowledge. This also implies the exclusion of education activities as these are primarily concerned with the dissemination of existing knowledge stock. A final characteristic of research is that its goal orientation is expressed in various types of outcomes (as diverse and diffuse as knowledge about man, culture, and society) with equally different kind of uses. Thus defined, research is a particular kind of activity that in principle can be performed within various domains (going from the sciences to markets to also possibly including the state, the media, and the arts).

As other systems, national research systems contain four core elements (Carlsson et al., 2002, Edquist, 2005): components, relationships, and attributes. First, components are about “the operating parts of a system” (Carlsson et al., 2002, p. 234). In other words, the people doing research, the organizations providing the environments for doing research, the instruments that are needed to perform research, and the institutions (i.e. norms, rules, and policies) operating in a country that facilitate doing research. In what follows we refer to the components of national research systems as the research capabilities of a country (Van Looy et al., 2006, Cimoli et al., 2009).

Research assets. Along the lines of Castellacci and Archibugi (2008) and Castellacci and Natera (2011), we distinguish among two main dimensions of a country’s research capabilities. First, research assets of a country refer to the set of research agents available in a country. Research assets can be further divided into physical (machines, instruments, and laboratories), human (skilled labor) and intellectual assets (knowledge and ideas). Countries that do not reach a certain threshold level of research assets available are less likely to contribute to or catch up with the technological frontier (Perez and Soete, 1988).

Structural capabilities. Another type of research capabilities concerns the structural capabilities of a country. These involve the sectorial and disciplinary composition of a country, as well as its institutional and geographical make up. Given that the evolution of a country’s economic and scientific activities follows a path dependent process (Neffke et al., 2011, Heimeriks and Boschma, 2013), both the sectorial and disciplinary composition of a country determine the extent to which and in which specific research fields a country can perform. In addition, institutions shape the behavior of research agents. In other words, institutions both enable and constrain the behavior of research agents in directing their research activities into certain directions and not others.

Interactions. Relationships concern the connections among the components. Relationships among researchers, the organizations they work in, and the institutions that shape their behavior, bind the research capabilities of country to make it an actual system. In other words, relationships are about the interactions among the components of a system. Hence, following Lundvall (1988) in his description of innovation as an interactive process, we refer to the relationships among the components of national research systems as research interactions.

Dimensions to capabilities and interactions. Both the components and relationships that constitute a system have certain attributes or properties. In the context of national research systems, these attributes characterize the nature of the capabilities. For example, when we discuss the norms and rules that operate in a national research system or the organizations, we are dealing with two completely different kinds of capabilities. Likewise, research interactions have different properties. While some interactions concern competitive pressures among researchers, others are about collaborative efforts (Carlsson et al., 2002). At a different level still, interactions in research can be about the transfer of knowledge or the sharing of research facilities. Note that these can be both of a collaborative and a competitive nature. Taken together, both research capabilities and research interactions have various – what we call – dimensions to them.

Research excellence. Apart from the components, relationships, and attributes; national research systems have a particular goal or orientation (Carlsson et al., 2002). From the definition of research provided above, it follows that national research systems are oriented at the provision of new knowledge. Notwithstanding the difficulties in defining what is new (Witt, 2009), here we take new knowledge to refer to the outcomes of national research systems as excellent. That is, new knowledge is not about the obvious, the straightforward or the usual. Rather, new knowledge is about the remarkable, the original, the striking. In other words, and as first approximation, the prime objective of national research systems is to produce what we call research excellence.

Figure 2.2.1 Conceptual building blocks of national research systems

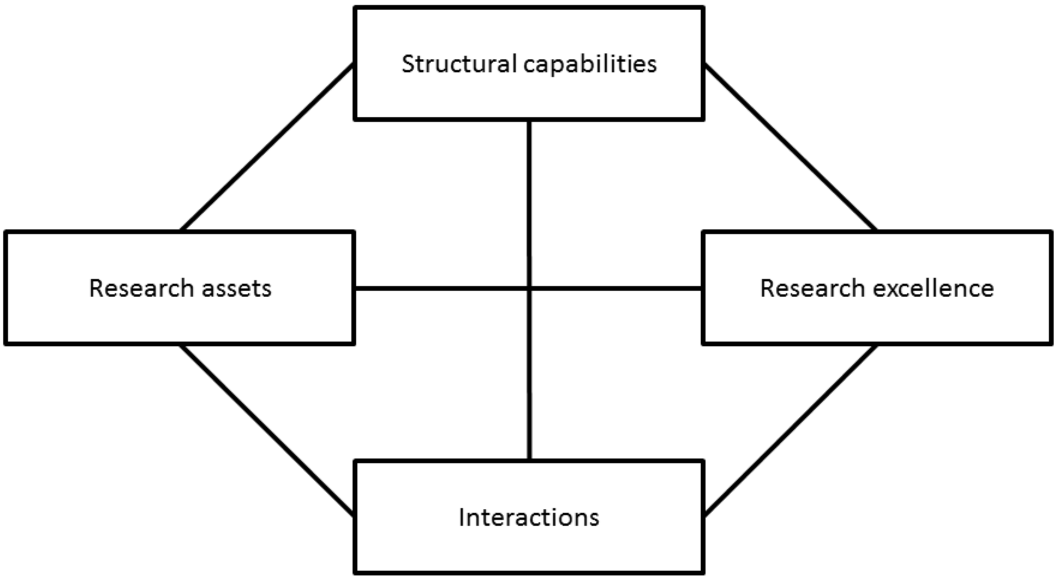


Figure 2.2.1 pictures the conceptual building blocks of a national research system. Note that, apart from singling out the different components of national research systems, these are in turn interlinked with each other. These inter-linkages, however, should not be understood in causal terms going in one direction. The fact that there is a relation between the components of national research systems need not imply causality between them. Going from the literature on national innovation systems as complex evolving systems, these linkages are to be interpreted in terms of the influence different components of national research systems have on one another. As such, research excellence feeds back into structural capabilities, research assets, and research interactions just as the latter three building blocks of national research systems shape research excellence.

2.3. Zooming in on research interactions

Not only is research to be characterized increasingly as a joint enterprise (Wuchty et al., 2007), so does joint research lead to higher impact (Jones et al., 2008). In order to characterize research as a joint enterprise (i.e. research interactions) we focus on three aspects: (i) the mode or carrier of research interactions, (ii) the dimension along which research interactions take place, and (iii) the direction of research interaction.[1] First, the mode or carrier of research interaction characterizes research interactions by the object along which research interactions take place. Among others, such modes can take the form of resources (e.g. money flowing from one place to another), people (e.g. researchers moving from one place to another) or products (e.g. knowledge flowing from one place to another). Somewhat independent from what research interactions are about, the mode or carrier makes clear the object in which such research interactions are expressed.

Second, research interactions can cross different kind of boundaries. Somewhat following the different dimensions of proximity in innovation (Rallet, 1993, Boschma, 2005, Frenken et al., 2009), we distinguish among two such dimensions. The geographical dimension distinguishes interactions that take place within countries from interactions that take place between countries (i.e. intra-national versus inter-national interactions). The institutional dimension, as in a Triple Helix of university-industry-government relations (Etzkowitz and Leydesdorff, 2000, Leydesdorff and Etzkowitz, 1996), distinguishes between interactions that take place between actors of the same institutional type and those that cross institutional boundaries. From a distinction between geographical and institutional research interactions we can describe national research systems' interactions in three ways. One focusing on research interactions in general (i.e. answering the question to what extent national research systems are indeed to be characterized as joint enterprises); another by zooming in on research interactions crossing geographical boundaries (i.e. answering the question to what extent national research systems are characterized by either intra-or international research interactions); and yet another by zooming in on research interactions crossing institutional boundaries (i.e. answering the question to what extent national research systems are characterized by either intra-or inter-institutional research interactions).

Finally, research interactions can be described in terms of their direction. In network analytic terms a distinction is often made between directed and undirected links (Wasserman and Faust, 1994). Directed links are about links that go into one direction only, as for instance when one paper is cited by another one. Undirected links are about links that go in both directions, as for instance when two research actors collaborate. What is important to note here is that, in focusing on research interactions, interest of course primarily resides in interactions that characterize a focal national research system. That is, we are primarily interested in money, knowledge, and people getting into a country, not out. In the case of undirected links, in which research interactions say as much about the partner country as it does about the focal country, this is not a problem. For example, a co-publication characterizes any two countries involved alike. This is because an undirected link can be said to be made up of two directed links; one going from the focal country to a partner country, the other going from the partner country to the focal country. In the case of directed links, though, the meaning of a link for a focal country depends crucially upon the understanding of the direction of

[1] A fourth aspect often discussed is about the kind of research interactions taking place. Here, a distinction is sometimes made among competitive, transaction, and networking kind of research interactions (Edquist, 2005). In practice, however, any two actors interacting in research compete, exchange instruments (i.e. are involved in transactions), and collaborate (i.e. network) at the same time. What is more, and anticipating on data quality issues, often we cannot know what kind of interaction is actually measured by a particular variable. For example, in using co-publication data for measuring research interactions we cannot be entirely sure about the exact kind of research interaction having taken place. That is, research actors can co-publish for various reasons that need not necessarily all be of a networking kind (Katz and Martin, 1997). For these reasons we do not consider the kind of interaction as a third aspect. The other aspect of research interactions is about the direction of the interaction.

flows. For example, if one takes patent citation (a directional link) as an indicator of knowledge flows (see e.g. Jaffe and Trajtenberg, 1998), in the context of measuring research interactions it says more about the citing country than that it does about the cited country.

3. Measuring research interactions

We use three types of data to address interactions in research and innovation. First, we collected data on **investments in research and development** (R&D). Investments in R&D can be sub-divided into (i) general investments in R&D, (ii) investments in R&D directed at a particular sector (i.e. business, government, higher education, and non-profit), (iii) investments in R&D financed by a particular sector (e.g. investments in business R&D financed by government), and (iv) investments in R&D financed from abroad (as opposed to being financed domestically). We choose to group these four types of data on investments in R&D under three headings. General investments in R&D are about the overall involvement of actors in R&D activities; investments in R&D directed at or financed by a particular sector of the economy reflect on the institutional origin respectively orientation of R&D activities; and investments in R&D financed from abroad represents the geographical origin of R&D activities. Note however that, although general investments in R&D reflect on the overall involvement of economic actors in R&D, it does not say much about interactions in a strict sense.

Second, we use publication and patent data to measure interactions in research and innovation. Here, we collected **co-publication and co-patent data** as indicators of research collaboration. As with the data on investments in R&D we distinguish among (i) general co-publication/patent data measuring the overall extent of interactions taking place, (ii) cross-institutional co-publication data measuring the extent to which interaction crosses institutional boundaries such as those between universities and industry, and (iii) international co-publication/patent data measuring the extent to which interactions span geographical (i.e. national) boundaries.

Finally, we use all kind of data measuring **mobility flows of researchers**. Again we distinguish among (i) overall mobility flows, (ii) mobility flows between different institutional sectors of the economy, and (iii) mobility flows that cross geographical (i.e. national) boundaries. Note that although in principle investments in R&D, co-publications/patents and mobility reflect on respectively financial flows, knowledge transfers, and movements of skilled labor; in practice all kind of objects might be involved in these different interactions. For example, as an indicator of research collaboration, co-publications are not uncontested as it not completely clear what is meant by research collaboration in the first place (Katz and Martin, 1997). What holds is that we can make a threefold distinction among (i) general interactions in research and innovation, (ii) interactions in research and innovation that cross institutional boundaries, and (iii) interactions in research and innovation that cross geographical (i.e. national) boundaries.

We collected data on all variables for 53 countries (all EU member countries; all potential, acceding, and candidate EU member countries; all non-EU OECD member countries; and all BRICS countries; see appendix A for a complete list of countries and country codes included in the analysis) spanning 12 years (2000-2011).[2]Table 3.1 provides the definitions of the variables that we collected. In what follows we present a descriptive analysis of these three groups of variables in turn.

[2] Not all variables included are available across all 53 countries and all 12 years. As a general rule we only considered those variables for which data is available for at least 25 countries and at least 2 years. A full list of variables considered can be provided.

Table 3.1Overview of data measuring interactions in research and innovation

Variable name	Definition	Source	Observations
General interactions in research and innovation			
gerd_gdp	Gross expenditures in research and development (GERD) as a share of gross domestic product (GDP; both in constant 2000 euros)	Eurostat; using own calculations	358
copubs_pubs	Share of co-publications in the total number of publications	ScienceMetrix (Scopus Elsevier); using own calculations	410
copat_pat	Share of co-patents in the total number of patents	Eurostat; using own calculations	450
jobmob	Percentage of job-to-job mobile human resources in science and technology (HRST) (employed, 25-64 years)	Eurostat	310
Cross-institutional (public-private) interactions in research and innovation			
berd_gerd	Business expenditures in research and development (BERD) as a share of gross expenditures in research and development (GERD)	Eurostat; own calculations	385
goverdherd_gerd	Government and higher education expenditures in research and development (GOVERD+HERD) as a share of gross expenditures in research and development (GERD)	Eurostat; own calculations	385
goverdherd_fbusiness_goverdherd	Government and higher education expenditures in research and development (GOVERD+HERD) financed by the private sector as a share of government and higher education expenditures in research and development (GOVERD+HERD)	Eurostat; own calculations	335
berd_fgoverdherd_herd	Business expenditures in research and development (BERD) financed by the government and higher education sector as a share of business expenditures in research and development (BERD)	Eurostat; own calculations	243
pubpriv_copub_researcherfte	The number of public-private co-publications per researcher (fte)	CWTS; Eurostat; own calculations	228
All_acad_industry_mob	The number of researchers who moved from an academic institution to a corporate organization of any country, per researcher in higher education (hc)	ScivalAnalytics; Eurostat; own calculations	320
International interactions in research and innovation			
gerd_fabroad	Gross expenditures in research and development (GERD) financed from abroad as a share of gross expenditures in research and development (GERD)	Eurostat; own calculations	334
international_copubs_pubs	Share of international co-publications in total number of publications	ScienceMetrix (Scopus Elsevier); using own calculations	410
international_copat_pat	Share of international co-patents in total number of patents	Eurostat; own calculations	527
foreign_own_dom_pat	Share of domestic inventions that are foreign owned in the total number of patents	Eurostat; own calculations	527

dom_own_foreign_pat	Share of foreign inventions that are domestically owned in the total number of patents	Eurostat; own calculations	527
non_citizen_advanced_students	Share of non-citizen students that attend advanced research programs as a share of the total number of students that attend advanced research programs	Eurostat; own calculations	136
FP67_coll_per_res	FP6 & FP7 collaborative links per researcher, fte	Webcorda (DG-RTD), Eurostat; own calc.	90
FP67_collab_bias	FP6 & FP7 collaborative links measured according to Frenken (2002)	Webcorda (DG-RTD), Eurostat; own calc.	275
MC_incoming	Incoming Marie Curie fellows per thousand researchers	Webcorda (DG-RTD), Eurostat; own calc.	243

Overall, the data used stem from four different kinds of sources (see Table 3.1). Data from national statistical offices and international sources were used to measure the various financial flows in research; that is, gross expenditures in R&D (GERD), business expenditures in R&D (BERD), and government and higher education expenditures in R&D (GOVERD+HERD), as well as on non-citizen advanced students.

The second types of source we investigated were survey and census data. Here, the two most important surveys with information on researcher mobility are the Careers of Doctorate Holders study (CDH)(Auriol, 2010)[3] and Career Paths of EU Researchers (MORE).[4] The *Careers of Doctorate Holders (CDH)* project was launched in 2004 in order to better understand the labour market, career path and mobility of doctorate holders, a population seen as being key to the production and diffusion of knowledge and innovation. A pilot study on 7 countries of 2005 was followed by larger scale data collections in 2007 (with data for some 20 countries) and in 2010 (offering data on some 25 countries). While relevant data on intra-EU mobility and extra-EU mobility from these surveys are gap filling and very welcome for research purposes, they are still excessively limited in geographical and temporal dimensions to make cross-European comparison possible and to qualify as inputs for composite indicators (11 and 15 EU27 member states included in 2005 and in 2009 respectively). Results of the *MORE survey* offer new relevant data on (a) researchers who have worked for at least 3 months in a country other than the country where they attained their highest educational degree after (highest-degree) graduation and (b) on researchers who have worked in the last three years for at least 3 months in a country other than the country where they attained their highest educational degree after (highest-degree) graduation. Here, it is also worth mentioning the *EUMIDA* project in this respect, which is a feasibility study for a European university data collection, based on a census of higher education institutes from around Europe (a project commissioned by the European Commission, DG-RTD as a follow-up to the AQUAMETH project). The first round of data collection resulted in a core dataset of nearly 2,500 universities from 27 European countries (all EU MSs

[3] The Careers of Doctorate Holders study (CDH) is jointly conducted by the OECD, Unesco and the European Commission For detailed information, please refer to www.oecd.org/sti/cdh.

[4] The Career Paths of EU Researchers (MORE) study is conducted by a consortium led by IDEA Consult, Belgium, involving NIFU STEP of Norway, LOGOTECH of Greece, the University of Manchester, UK, WIFO of Austria, and financed by the European Commission as a follow-up to the previous "Integrated Information System on European Researchers" (IISER) project. The IISER project was conceived with the purpose of creating an EU-wide system of indicators that capture researchers' stocks, flows, career, and mobility events using existing sources of data. For more information on MORE, please refer to: http://www.researchersmobility.eu/. For more information on IISER see: http://ipts.jrc.ec.europa.eu/activities/research-and-innovation/iiser.cfm.

excluding FR, DK, but including CH and NO), for the year 2008. Institute-level data was made available for international students at ISCED 5 and ISCED 6 levels(Daraio et al., 2011). This data could thus be complementary to official national statistics on inward mobility of PhD students, with the limitation that PhD students working outside universities (i.e. at research institutes or with industry) are not measured. Furthermore, the data is limited to the year 2008, thus further updates would be needed to identify trends over time.

Third, we use data as can be retrieved from international research grants. From among the various national and international research grants, most relevant may be those with a European (or global) reach, such as on early stage and experienced researchers supported by Marie Curie Actions (MCA)[5] or by the European Research Council (ERC)[6]. Additionally, data on cross-border collaboration can be compiled based on data on FP supported projects, although less focused on researchers. Marie Curie fellowships have been granted under the 6th and 7th Framework Programmes, thus have a wider scope (European Research Area countries are effectively comparable from 2004 onwards, although the instruments and the funding has changed with the FP7, resulting in a significant growth over time). ERC grants are available as of the introduction of FP7, thus after 2007.

Finally, as mentioned, bibliometric (scientific publication and patent) information is used to measure research interactions. Drawing networks on the basis of any two organizations or countries co-occurring on a publication or patent, research interactions taking place between them can be measured relatively straightforward (Breschi and Lissoni, 2004, Frenken et al., 2009).[7] Here we use scientific publication data from ScienceMetrix and the Centre of Science and Technology Studies (CWTS) and patent data from Eurostat to measure research interactions on the basis of bibliometric information.

[5] For an overview of grant profiles, please refer to: http://ec.europa.eu/research/mariecurieactions/about-mca/actions/index_en.htm. Data can be extracted from the European Commission's *Corda database* on Framework Programmes (FP).

[6] For further information see the following http://erc.europa.eu

[7] In addition, if individual researchers can be properly identified based on their affiliation data of publication records in bibliometric databases, their cross-border movement can be measured in a new way: by identifying not only their physical mobility, but also the effective academic mobility, that they moved and already published papers. However, this kind of data should be used with caution. First, one should not underestimate the technical complexity of the task of identifying and tracking individuals based on bibliometric records. Second, results will be biased if visiting researchers fail to mention properly all their affiliations or mention it strategically. As of now, however, such data are not available to us.

4. Results

4.1. General research interactions

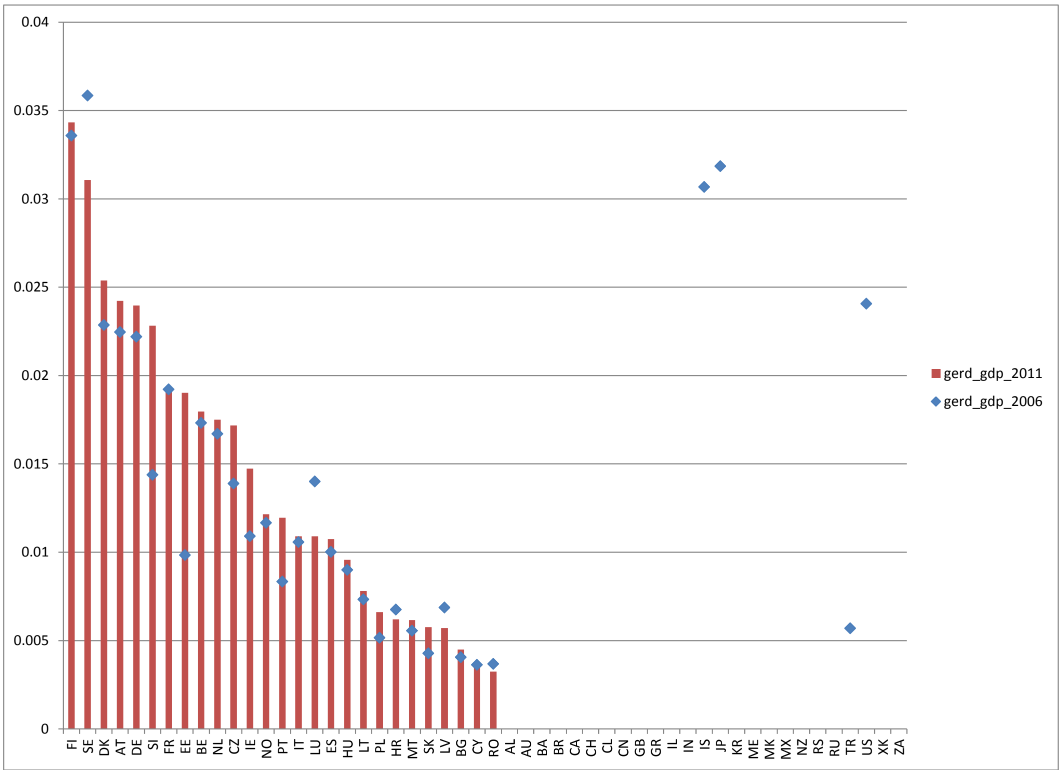
Table 4.1 presents the descriptive statistics for the variables measuring interactions in research and innovation in general. Except for the share of co-publications in the total number of publications (ranging between .78 and .96), all variables measuring general interactions show considerable variation across countries. In line with previous findings (Wuchty et al., 2007), co-publication is more widespread than co-patenting. In addition, countries differ less in terms of co-publication than they do in terms of co-patenting.

Table 4.1 Descriptive statistics of general interactions in research and innovation

Variable	Obs	Mean	Std. Dev.	Min	Max
gerd_gdp	358	0.014	0.009	0.002	0.042
copubs_pubs	410	0.880	0.042	0.692	0.958
copat_pat	450	0.623	0.139	0.000	0.955
jobmob	310	0.062	0.023	0.018	0.141

Figure 4.1.1 to Figure 4.1.4 provides an overview for all four variables measuring general interactions in research and innovation in turn. For each variable we included the latest year available and the pre-crisis year (2006) in the analysis. Note then that the latest year available is not the same for all variables. For GERD per GDP the 'usual suspects' rank first (Finland, Sweden, Denmark) and new EU member countries rank at the bottom (Romania, Cyprus, Bulgaria). With some exceptions (e.g. Estonia, Slovenia) GERD per GDP seems to be relatively stable over time.

Figure 4.1.1 **Gross expenditures in R&D (GERD) as a percentage of gross domestic product (GDP) (2006 versus 2011)**



Surprisingly, the number of co-publications per publication (Figure 4.1.2) shows that Asian (Korea) and some BRICS countries (Brazil, China) are most collaborative.Again, new EU member states can be found at the bottom of this ranking (Malta, Romania, and Poland). Note however that another BRICS country (Russia) is also ranked at the bottom. However, as mentioned before, variation across countries is fairly for this variable. Also note that the share of co-publications in the total number of publications is relatively stable over time (2006-2009).

Figure 4.1.2Total number of co-publications as a share of total number of publications of a country (2006 versus 2009)

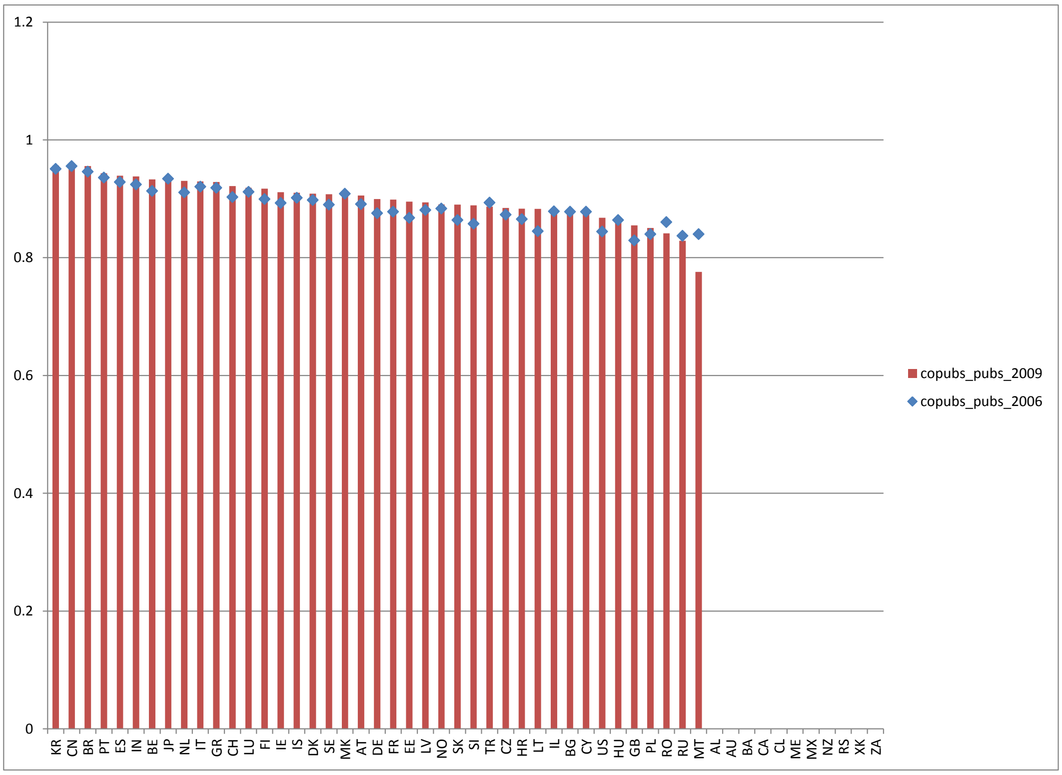


Figure 4.1.3Total number of co-patents as a share of total number of patents of a country (2006 versus 2009)

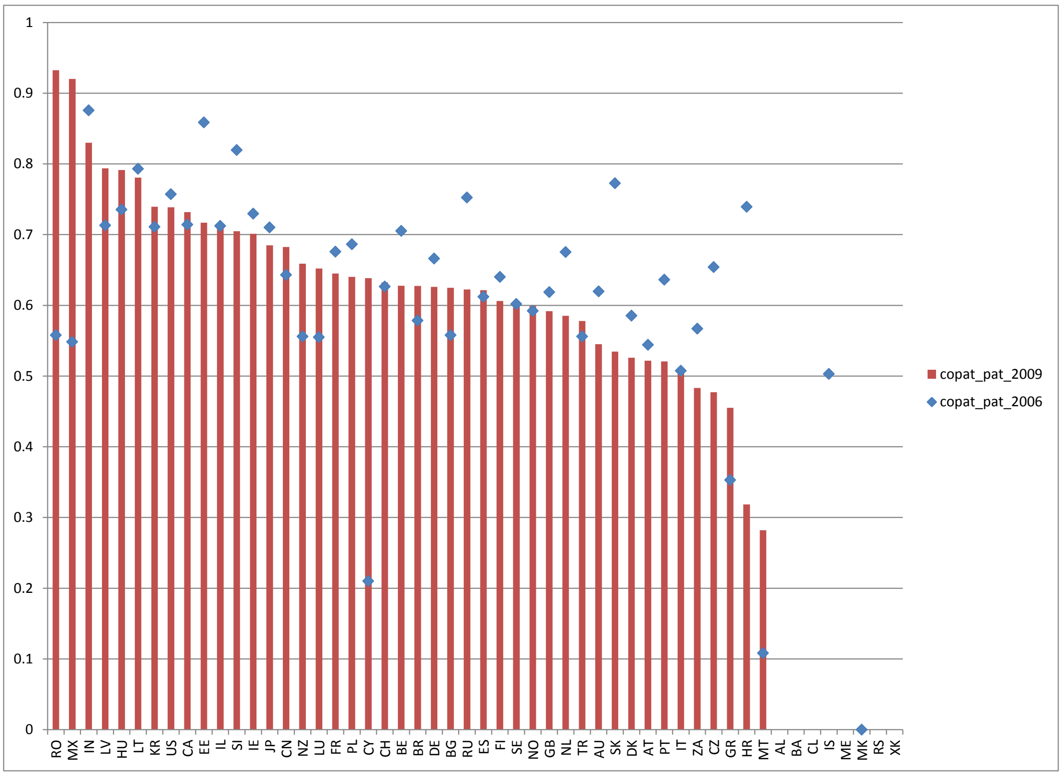


Figure 4.1.3shows that, as opposed to the number of co-publications per publication, there is much more variation across countries in the share of co-patents per patent. Also note that there are many more changes over time. Some unexpected countries top the league here (Romania, Mexico, and India). At the bottom of this ranking we find Malta, Croatia, and Greece.

For mobile human resources in science & technology (Figure 4.1.4) we find Norway, Switzerland, and Denmark on top of the ranking. At the bottom we find Romania, Hungary, and Greece. As with co-patenting, these figures seem to fluctuate from year-to-year.

Figure 4.1.4 Job-to-job mobile human resources in science & technology as a share of total human resources in science & technology activities (2006 versus 2011)

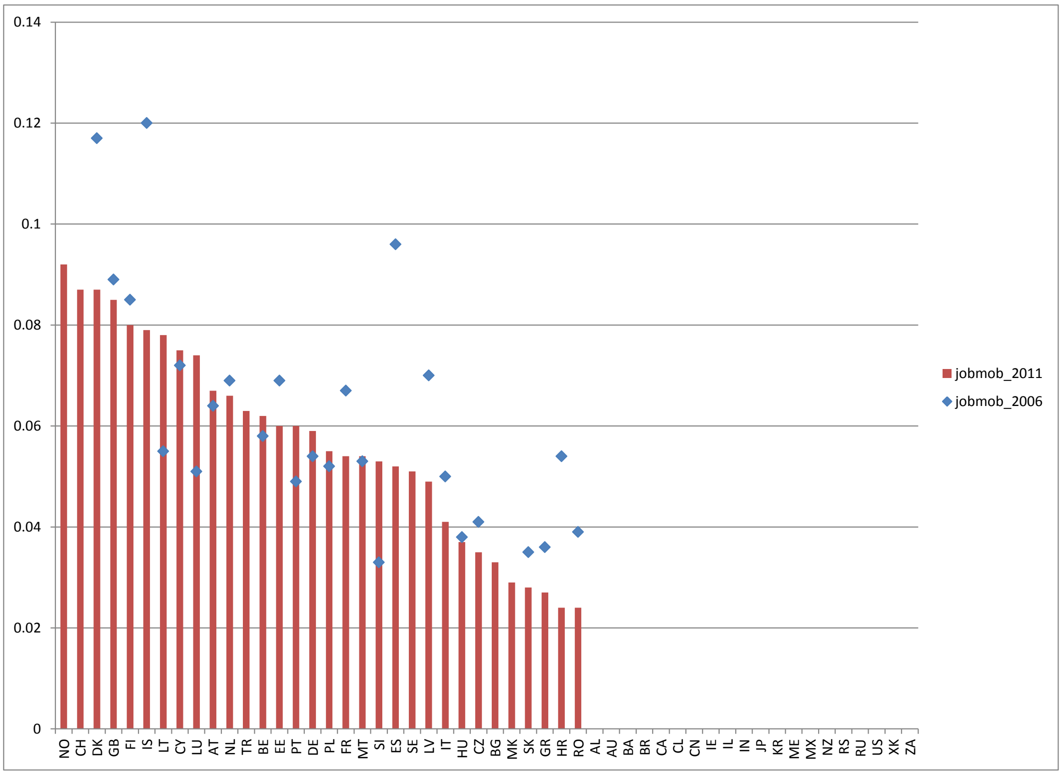


Table 4.2presents the correlations among the variables measuring interactions in research and innovation in general. Correlations show that GERD per GDP correlates positively and significantly with all other variables measuring general research interactions. For the rest, only co-publication as a share of total publications and co-patents as a share of total patents correlate significantly; though not very strong and only significant at the 5% significance level. We interpret these correlations as indicating that (i) investments in research go hand in hand with interactions in research and (ii) different kind of interactions need not strengthen one another.

Table 4.2 Correlation matrix of variables measuring interactions in research and innovation in general

	gerd_gdp	**copubs_pubs**	**copat_pat**	**jobmob**
gerd_gdp	1.000			
copubs_pubs	0.323***	1.000		
copat_pat	0.170***	0.118**	1.000	
jobmob	0.445***	0.041	0.020	1.000

Note: *** significant at 1% level; ** significant at 5% level

4.2. Public-private research interactions

Table 4.3shows the descriptive statistics on cross-institutional (public-private) interactions in research and innovation. All variables measuring cross-institutional interactions show considerable variation across countries.

Table 4.3 Descriptive statistics of cross-institutional (public-private) interactions in research and innovation

Variable	Obs	Mean	Std. Dev.	Min	Max
berd_gerd	385	0.548	0.171	0.159	0.926
goverdherd_gerd	385	0.438	0.165	0.074	0.831
goverdherd_fbusiness_goverdherd	335	0.078	0.048	0.000	0.241
berd_fgoverdherd_herd	243	0.111	0.117	0.001	0.574
pubpriv_copub_researcherfte	228	0.020	0.020	0.000	0.107
all_acad_industry_mob	320	7.950	9.517	0.000	61.087

Figure 4.2.1shows that BERD per GERD in 2011 is relatively high in countries such as Slovenia, Finland, and Sweden and relatively low in countries such as Cyprus, Latvia, and Lithuania. With a few exceptions (Luxemburg, Estonia), BERD per GERD is relatively stable over time. Alternatively, GOVERD+HERD per GERD (Figure 4.2.2) in 2009 is relatively high in countries such as Lithuania, Poland and Bulgaria and relatively low in countries such as Japan, Korea, and Luxemburg. Note that as BERD and GOVERD+HERD make up the larger part of GERD, an absolute increase in one of the two decreases the other in relative terms ceteris paribus. Like BERD per GERD, GOVERD+HERD per GERD is relatively stable over time.

As BERD per GERD and GOVERD+HERD per GERD in itself do not represent interactions in research and innovation, it is more interesting to look at data that does. Figure 4.2.3shows data on GOVERD+HERD financed by the private sector as a share of GOVERD+HERD . This variable measures the extent to which businesses invest in R&D activities performed in the public sector. Here, Lithuania, the Netherlands, and Hungary rank first; while Portugal, Cyprus, and Malta can be found at the bottom of the ranking for 2009. Again, with some exceptions (Lithuania, Turkey), GOVERD+HERD financed by the private sector as a share of GOVERD+HERD is relatively stable over time.

Figure 4.2.1 BERD as a share of GERD (2006 versus 2011)

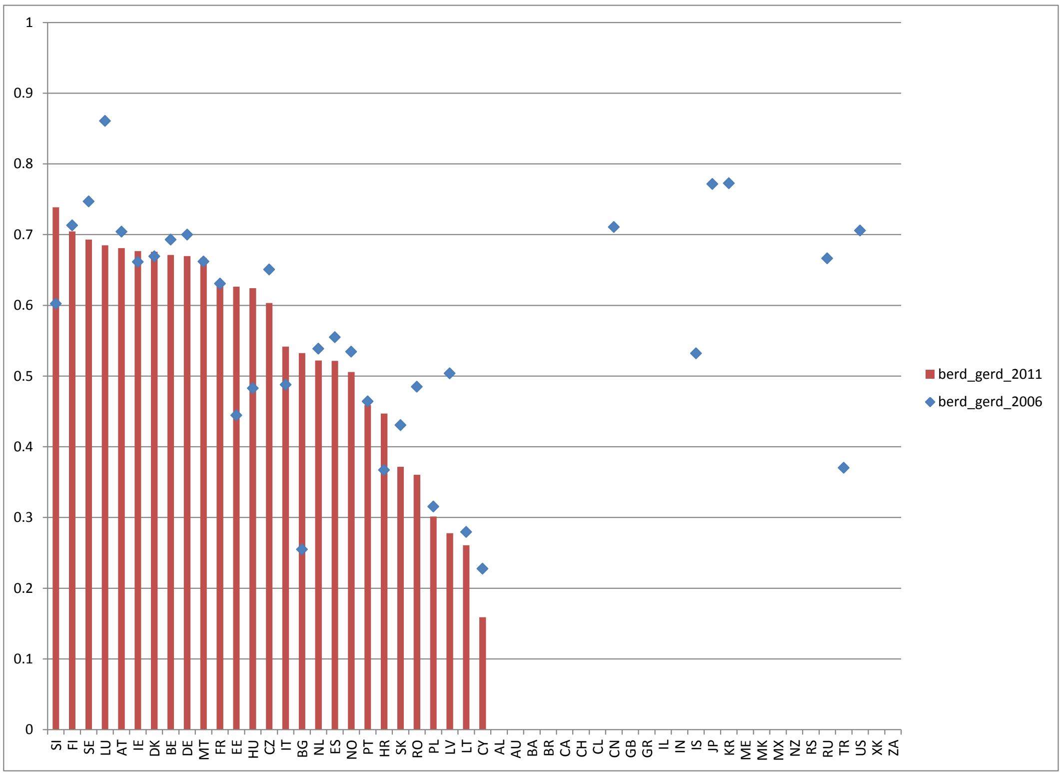


Figure 4.2.2GOVERD+HERD as a share of GERD (2006 versus 2009)

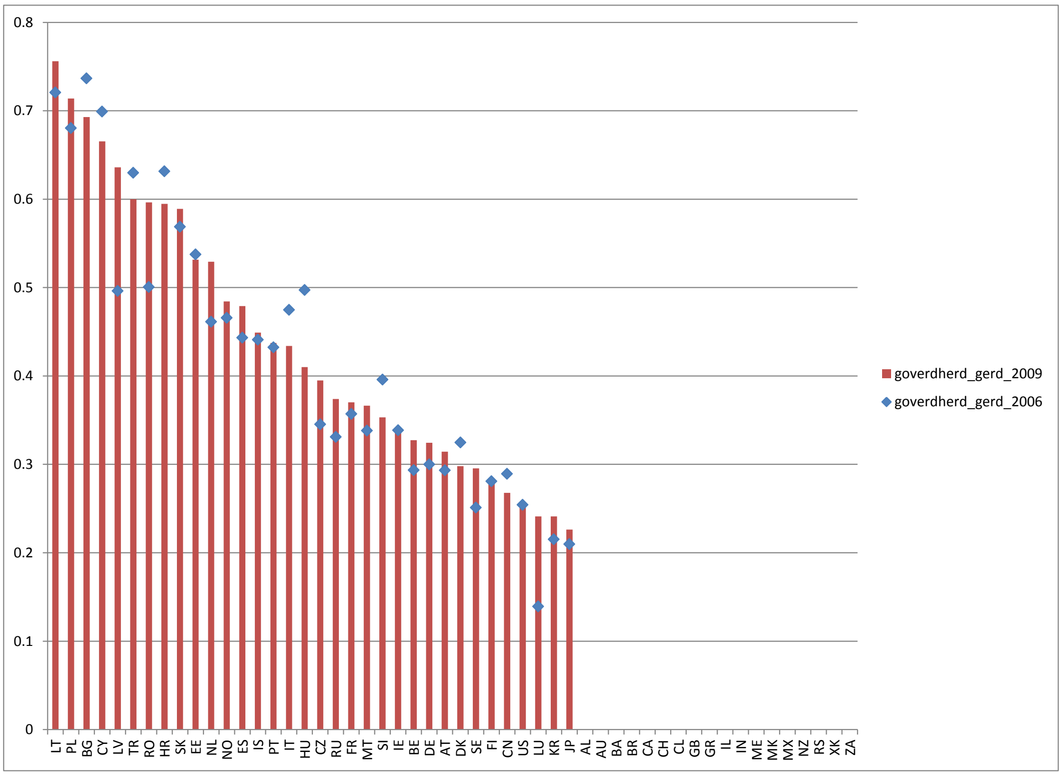


Figure 4.2.3 GOVERD+HERD financed by the private sector as a share of GOVERD+HERD (2006 versus 2009)

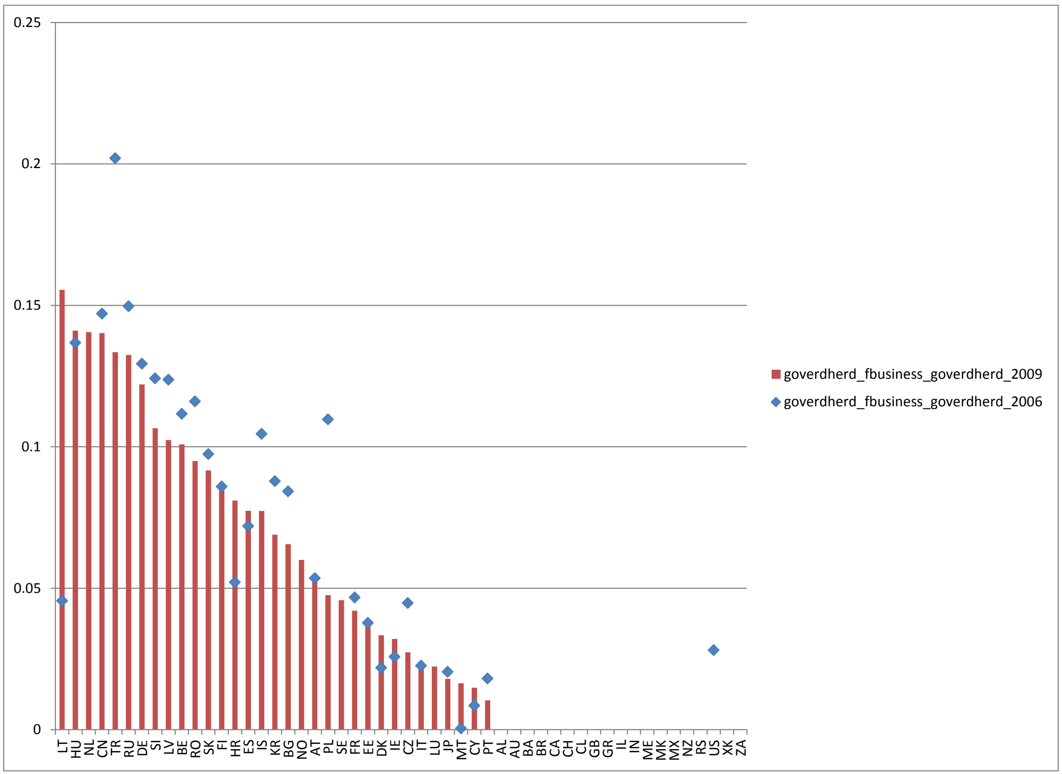
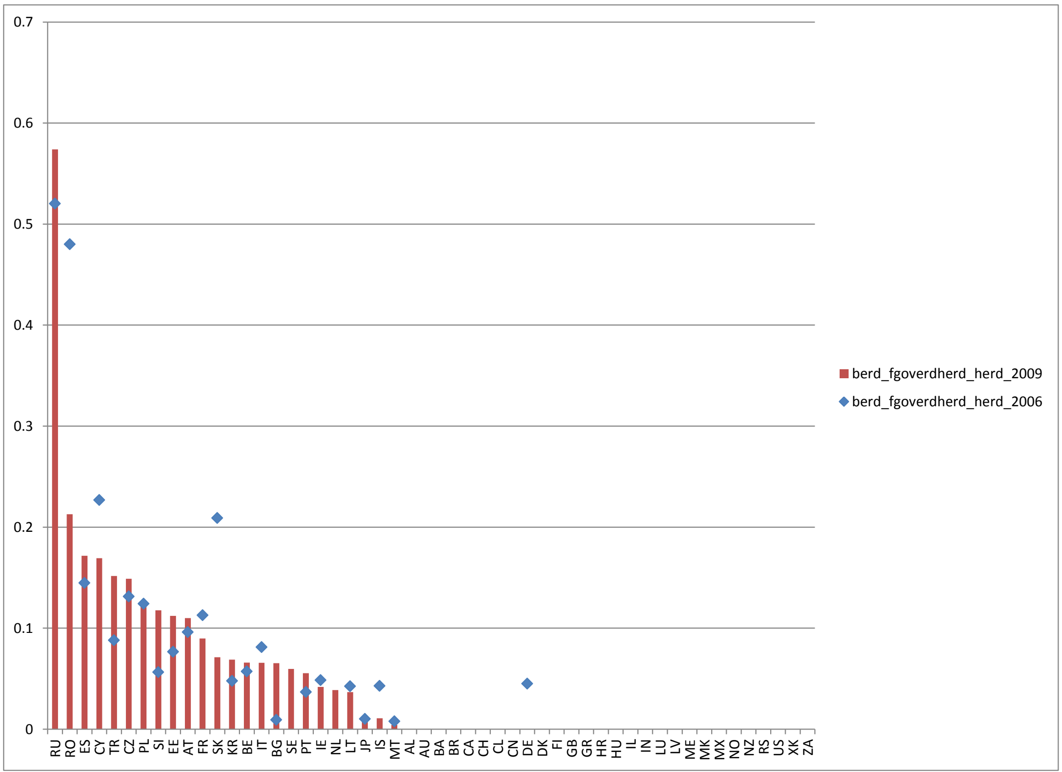


Figure 4.2.4 BERD financed by government and higher education as a share of BERD (2006 versus 2009)



Alternatively, BERD financed by the government and higher education sector as a share of BERD measures the extent to which the public sector invests in R&D activities performed by businesses

(Figure 4.2.4). Russia, Romania, and Spain rank on top, while Malta, Iceland, and Japan rank at the bottom. Note however that Russia and Malta can be considered outliers here.

Figure 4.2.5shows the number of public-private co-publications per researcher (fte). This number is relatively high in Croatia, the Netherlands, and Iceland and relatively low in Malta, Turkey, and Lithuania. However, both Croatia and Malta can be considered outliers. Over time the numbers of public-private co-publications per researcher (fte) are relatively stable.

Figure 4.2.5 The number of public-private co-publications per researcher (Fte) in a country (2006 versus 2007)

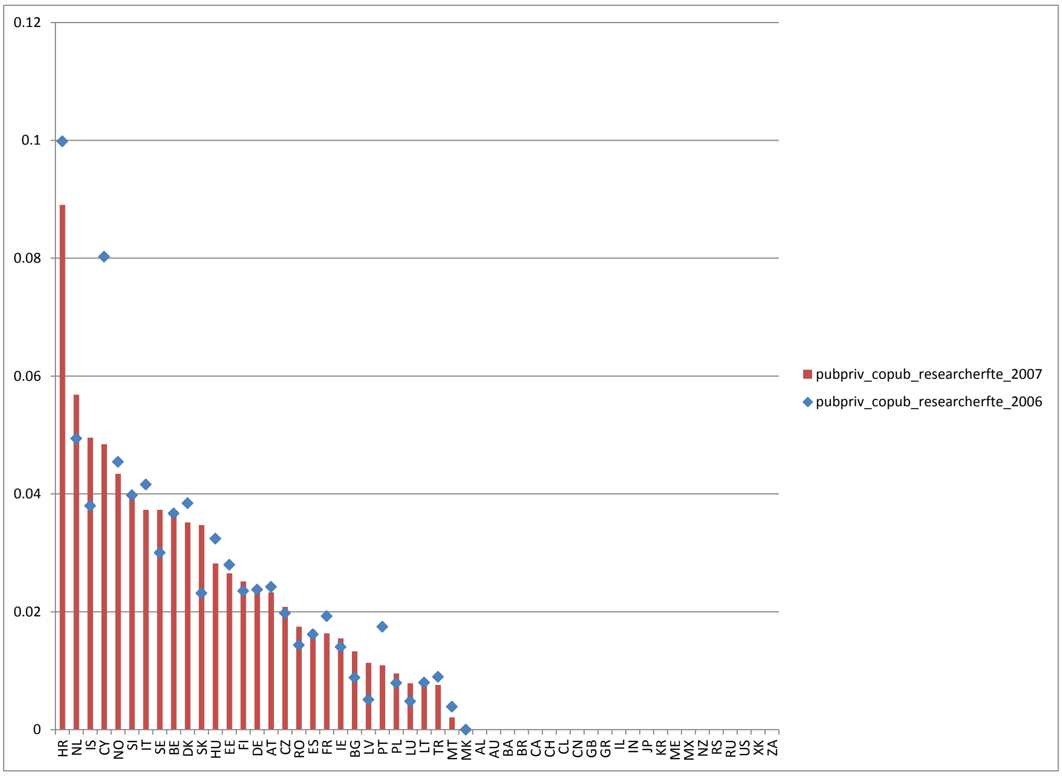


Figure 4.2.6 Share of the number of researchers who moved from an academic to a corporate organization in the total number of researchers in higher education (2006 versus 2009)

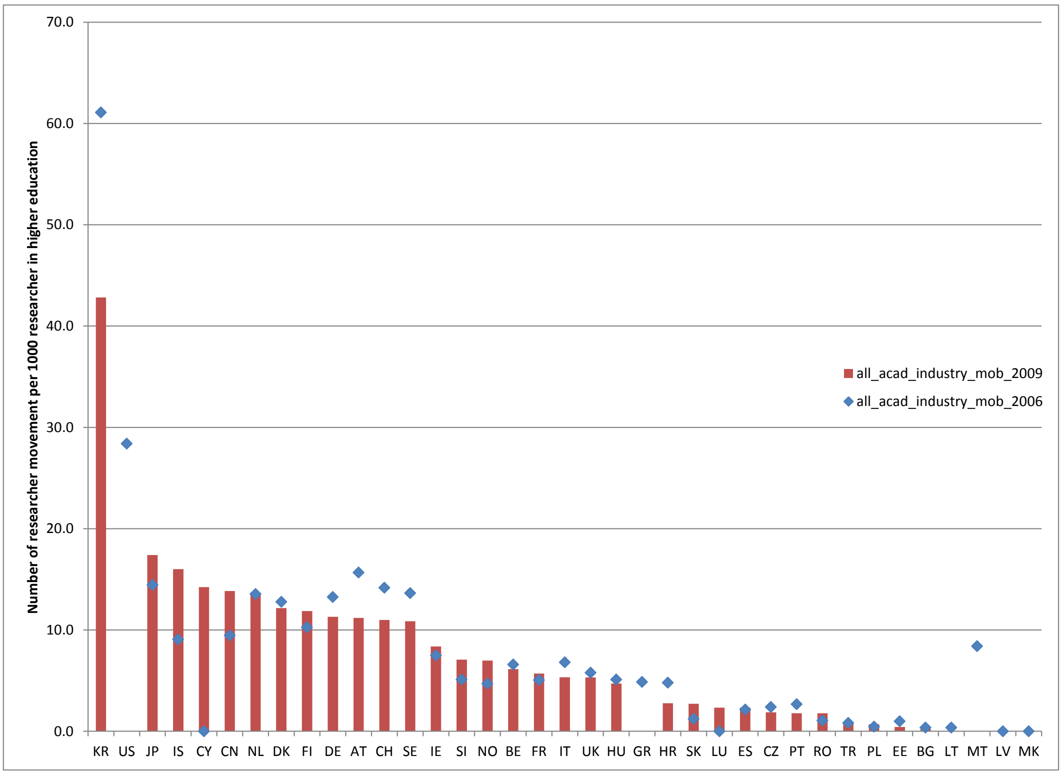


Table 4.4 Correlation matrix cross-institutional research and innovation interactions

	1	2	3	4	5	6
1. berd_gerd	1.000***					
2. goverdherd_gerd	-0.989***	1.000***				
3. goverdherd_fbusiness_goverdherd	-0.123**	0.187***	1.000***			
4. berd_fgoverdherd_herd	-0.002	0.023	0.445***	1.000***		
5. pubpriv_copub_researcherfte	-0.006	-0.012	-0.109	-0.080	1.000***	
6. all_acad_industry_mob	0.503 ***	-0.526 ***	-0.078	-0.260 ***	0.307 ***	1.000 ***

Note: *** significant at 1% level; ** significant at 5% level

Correlations show a mixed picture (Table 4.4). First, business expenditures in R&D as a share of gross expenditures in R&D correlate positively and significantly only with academic-industry mobility. It is tempting to conclude that investments in R&D made by the business sector trigger researchers to move from academia to firms. Note, however, that such inferences cannot be made from correlations alone. Second, government and higher education expenditures in R&D financed by the private sector go hand in hand with business expenditures in R&D financed by the government and higher education sector. As such it seems that public-private interactions are reciprocal as it comes to financial flows in R&D. Finally, mobility from academia to industry goes hand in hand with co-publication between the public and private sector. Hence, although mobility patterns do not go hand in hand with co-publication in general, it does when it comes to public (academic)-private (corporate) research interactions.

4.3. International research interactions

As with variables measuring general research interactions and cross-institutional research interactions, variables measuring international research interactions show considerable variation across countries (Table 4.5). What is more, correlations in Table 4.6show that almost all variables relate positively and significantly. However, what is striking from these correlations is that (overall) especially smaller countries have a larger international orientation in their interactions. The correlation between the log of the number of researchers (fte) in a country and each individual variable measuring international research interactions is positive and significant for all variables measuring international interactions in research and innovation except for non-citizen students attending advanced research programs as a share of all students attending advanced research programs. Following Frenken (2002) this observation can be explained by the fact that research actors of large (small) research countries have relatively less (more) opportunity to interact with research actors abroad. Hence, an indicator of internationalization in research has to take into account the (research) size of national research and innovation systems; rendering simple fractions an unlikely candidate for measuring international research interactions. Unfortunately, such alternative indicators are not available to us as of now.

Table 4.5 Descriptive statistics on international interactions in research and innovation

Variable	Obs	Mean	Std. Dev.	Min	Max
gerd_fabroad	334	0.090	0.070	0.001	0.510
international_copubs_pubs	410	0.386	0.133	0.108	0.779
international_copat_pat	527	0.260	0.146	0.000	0.833
foreign_own_dom_pat	527	0.310	0.160	0.000	0.933
dom_own_foreign_pat	527	0.228	0.216	0.000	1.000
non_citizen_advanced_students	136	0.199	0.157	0.007	0.807
FP67_coll_per_res	93	1.703	3.611	0.138	25.912
FP67_collab_bias	283	0.731	1.467	-0.523	9.247
MC_incoming	251	0.551	0.831	0.000	6.354
log_researchers_fte	382	3.958	0.986	1.672	6.063

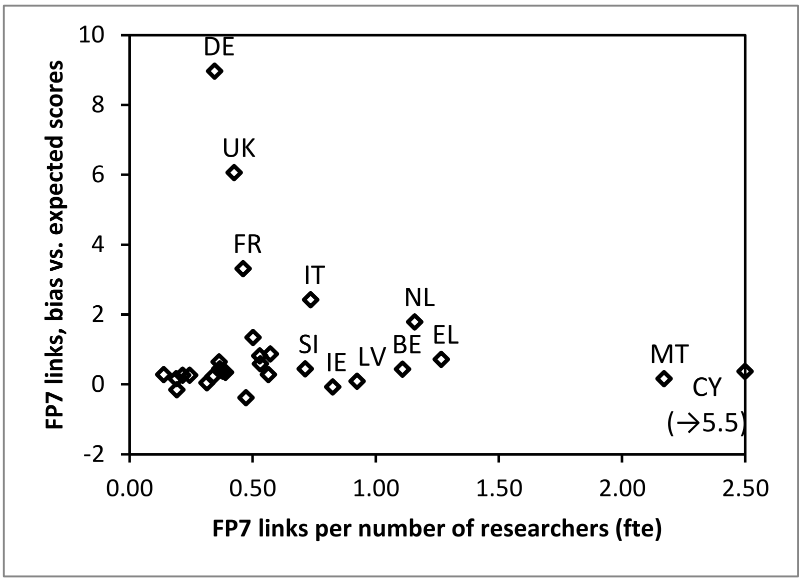
Table 4.6 Correlation matrix international research and innovation interactions

	1	2	3	4	5	6	7	8	9	10
1. gerd_fabroad	1.000 ***									
2. international_copubs_pubs	0.532 ***	1.000 ***								
3. international_copat_pat	0.462 ***	0.517 ***	1.000 ***							
4. foreign_own_dom_pat	0.497 ***	0.348 ***	0.821 ***	1.000 ***						
5. dom_own_foreign_pat	0.400 ***	0.640 ***	0.608 ***	0.366 ***	1.000 ***					
6. non_citizen_advanced_students	0.361 ***	0.455 ***	0.205 **	0.064	0.457 ***	1.000 ***				
7. log_researchers_fte	-0.475 ***	-0.541 ***	-0.552 ***	-0.516 ***	-0.432 ***	0.210 **	1.000 ***			
8. FP67_coll_per_res	0.287 **	0.326 **	0.135	0.284 ***	0.475 ***	-0.084	-0.407 ***	1.000 ***		
9. FP67_collab_bias	-0.161 **	-0.106	-0.206 ***	-0.186 ***	-0.110 *	0.179 *	0.416 ***	-0.066	1.000 ***	
10. MC_incoming	0.070	0.326 ***	0.081	0.123 *	0.475 ***	0.500 ***	-0.281 ***	0.408 ***	-0.026	1.000 ***

Note: *** significant at 1% level; ** significant at 5% level; ** significant at 10% level;

Figure 4.3.1confirms this claim graphically as it shows the correlation between international FP6 and 7 collaborations as a share of total FP6 and 7 collaborations vis-à-vis international FP6 and 7 collaborations measured in terms of the deviation from randomness. It is shown that taking either one of these two variables matters a great deal in measuring international research interactions. To our opinion, the methodology proposed by Frenken (2002) better captures the phenomenon of interest. Unfortunately, however, this methodology is more demanding in terms of data requirements. That is, measuring international research interactions properly requires pair wise data for each country's interactions with all other countries. As of now, however, such data is not available for most variables.

Figure 4.3.1 FP7 collaborative links indicator, computed according to different methodologies, 2010



5. Conclusion

The main aim of this report has been to explore the possibility of a composite indicator measuring research interactions at the country level. To fulfill this aim, we followed three steps. First, we conceptualized research interactions within the broader framework of national research systems. From the notion of national research systems, research interactions are important as they involve the relationships research actors have among each other. Research interactions have different properties. In characterizing research interactions this report focuses on three such properties: (i) the mode or carrier of research interactions, (ii) the dimension along which research interactions take place, and (iii) the direction of research interaction.

The mode or carrier of research interaction characterizes research interactions by the object along which research interactions take place. Among others, such modes can take the form of resources (e.g. money flowing from one place to another), people (e.g. researchers moving from one place to another) or products (e.g. knowledge flowing from one place to another).Research interactions can cross different kind of boundaries. Somewhat following the different dimensions of proximity in innovation, we distinguish among two such dimensions. The geographical dimension distinguishes interactions that take place within countries from interactions that take place between countries and the institutional dimension distinguishes between interactions that take place between actors of the same institutional type (i.e. university or industry) and those that cross institutional boundaries. Research interactions can be described in terms of their direction. In network analytic terms a distinction is often made between directed and undirected links. Directed links are about links that go into one direction only, as for instance when one paper is cited by another one. Undirected links are about links that go in both directions, as for instance when two research actors collaborate.

Second, in order to measure research interactions we use four types of data sources: (i) data from surveys, (ii) data from bibliometric information, (iii) data from international grants, and (iv) data from national statistical offices. Using these data we respectively measure mobility in research (survey data), research collaboration (bibliometric data and grants data), and financial flows in R&D (national statistical offices' data). Using these data, we measure research interactions in general, public-private research interactions, and international research interactions; all at the country level.

Finally, after analyzing the data, the results show that constructing a composite indicator measuring research interactions is currently not feasible. First, as to research interactions in general, only a limited number of variables are available and those available correlate poorly. Second, the same issues hold for measuring public-private research interactions. Again, data are limited and those variables available correlate poorly. Third, again, the same issues hold for measuring international research interactions. However, in addition, there is an issue of specifying the variables correctly here. In order to control for the opportunity of researchers to interact with research actors abroad it is better to measure the deviation from randomness instead of measuring international interactions as a share of total interactions. The former, however, is more demanding in terms of data requirements than the latter. Overall, we conclude that for constructing a composite indicator on interactions in research and innovation it is important (i) to take the nature and direction of interactions in research and innovation duly into account and (ii) to acquire more data that is well-specified to measure research interactions (such as systematically collected data on mobile researchers at various levels; detailed data on publications; more reliable affiliation data for researchers in bibliometric sources; data on cross-border collaboration in funding joint research infrastructures, to mention but a few possible directions of improvement).

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Abstract
Interactions in research are multifaceted and need not go in the same direction. For example, higher overall mobility of researchers in science & technology need not go hand in hand with more collaboration as measured by co-publication and co-patent data. Concerning public-private research interactions, we see that mobility and collaboration do go hand in hand. In other words, the extent to which different kind of interactions (mobility versus collaboration) follow the same trend seems to depend on the dimension along which such interactions take place. Here, different kinds of cross-institutional interactions follow the same pattern. Although different kinds of international research interactions present a similar picture, we need to take into account that smaller (larger) national research systems are generally more (less) internationally oriented. Overall, we conclude that for constructing a composite indicator on interactions in research and innovation it is important (i) to take the nature and direction of interactions in research and innovation duly into account and (ii) to acquire more data that is well-specified to measure research interactions
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