The R&D composition of European countries: concentrated versus dispersed profiles

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Introduction

In the European Union, Research & Development (R&D) expenditure as a percentage of GDP has increased from 1.76 per cent in 2006 to 2.03 per cent in 2016, where the EU members roughly spent €300 billion on R&D (Eurostat, 2017). Overall in the EU, it is the business sector that accounts for the highest share of R&D expenditure, with Slovenia (76 per cent), Hungary (74) and Bulgaria (73) having the highest shares of total R&D within this sector. The higher education sector, is the dominant R&D sector in only three countries (Cyprus, Latvia and Lithuania). The third sector, the government sector, is not the dominant sector in any EU countries, but has traditionally been a more important sector in Eastern European countries with more research being performed in academies and institutes, and less in universities (Solberg et al., 2012). On average in 2016, the business sector stood for 65 per cent of R&D expenditure in the European Union, the higher education sector for 23 per cent and the government sector for 11 per cent.

An interesting empirical question is *who* accounts for the R&D expenditures of the European countries. To our knowledge, there is no available database where one can decompose the national numbers below the sector grouping. That is, to study the R&D expenditures per higher education (HE) institution, government sector research institution (REC) or private company (PRC). Such a decomposition of R&D shares is arguably possible to conduct within the HE sector (HES), e.g. by use of The European Tertiary Education Register (ETER), but the register is not complete. Most notably, the university hospitals are severely lacking in ETER. It is nevertheless not possible to find similar numbers for the REC or PRC sectors across Europe.

In this study, we use a unique dataset covering all HES, REC and PRC institutions that have applied for funding to the European Framework Programs for Research and Innovation (EU FPs) in the period 2007-2017. *The first aim* of this study is to show the composition of R&D performing actors per country, which to the best of our knowledge has never been done before. *The second aim* of this study is to compare country profiles in R&D composition, so that we may analyse whether the countries differ in concentration of R&D performing institutions. We postulate that some countries' R&D systems are highly dominated by a very few number of institutions, while in other countries the R&D systems are more dispersed without or with very few dominant R&D institutions. *The third aim* of this study is to investigate whether different R&D country profiles are associated with how the R&D systems perform, i.e. whether the profiles are associated with Research and Innovation performance indicators.

Background: Knowledge production as driven by several sectors

Here, we define an R&D performing unit as an administrative unit that has applied the European Union for R&D funding. We do not claim to make a 'complete list' of all R&D performing units per country. Rather, we believe that the contributing units from each country in sum will provide national profiles of the general magnitude and dispersion of the R&D performing units.

Our general impression of the literature that deals with R&D actors, is that is clearly divided in two camps: the research-oriented literature, often aimed at the HE sector, and the innovation-oriented literature, often aimed at the PRC sector, and foremost small and medium-sized enterprises (SMEs). Performance indicators in the HE sector is typically centred around bibliometric indicators, where the scientific publication is the focal point, while studies of PRCs focus on economic performance or contribution to innovation measures (e.g. patents). We believe that data on participation in EU FPs is suitable for studying the composition of national R&D actors. The pillars of the FPs follow a reverse u-shape in its design: from research excellence and basic research on the one side, to programs for SMEs where market orientation is at the centre, on the other side. In between, we find the large bulk of collaboration programs where we empirically know that all three sectors are rather equally involved in proposals and projects. Hence, EU FPs combine elements from both sets of literature described above.

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In its most simple form, any theory about knowledge production begins with the HE sector, with its role sometimes described as providing research-based training of undergraduates and advanced level students (Solberg et al., 2012), to being source of external knowledge, whose publicly available results may help industry in fulfilling their goals (Falk, 2006). One general claim is that research in this sector has become more multidisciplinary over time. With research problems becoming ever more complex, and with the emergence of new specialized research fields, multidisciplinarity is seen as increasingly necessary, thus promoting collaboration (Melin, 2000), typically applied in explanations of the increased numbers of co-authors to scientific papers (e.g. Parish, Boyack & Ioannidis, 2018) thereby also mostly a matter of the HE and REC sectors. It may also lead to sharing of ideas and data, and cooperating about equipment and resources (Wagner, 2005).

Such mechanisms also involve the PRC sector, which is in line with the basis assumption of the Triple Helix literature, i.e. the HE, REC and PRC sectors are collaborating in the production of knowledge and have become increasingly interdependent (Etzkowitz & Leydesdorff, 2000), with claims that different knowledge bases (as opposed to high density in e.g. the HE sector, stemming from the largest universities), from many and weakly tied institutions will be beneficial for a country's ability to innovate, as there is a positive effect for firms from engaging in "more radical, exploratory alliances than in more exploitative alliances" (Nooteboom et al., 2007). Based on this we may outline a hypothesis that it is favourable for a country's ability to be successful in their R&D mission to have dispersed R&D systems with many actors collaborating across different sectors. A more traditional approach is e.g. Acosta et al. (2012) who argue that university scientific knowledge may have a direct influence on a region's innovation ability when a university produces useful new scientific knowledge with applications to the industry, in addition to more indirect contributions from a general flow of knowledge. As such, there is a vast body of literature studying the added value of the HE institutions for the PRC sector. Cardamone, Pupo & Ricotta (2016) studied the effect of university research on total factor productivity in Italy and concluded that there were positive externalities from universities in the productivity of local firms. The mechanisms were "informal information transmission via the local personal networks of university and industry professionals, participation in conferences and presentations, or other kinds of knowledge transmissions from academia to industry". Mowery & Sampat (2006) describe universities as no longer being 'ivory towers' that are "devoted to the pursuit of knowledge for its own sake", and that "a growing number of industrial-economy and developing-economy governments seek to use universities as instruments for knowledge-based economic development and change". Again, the perspective is that the universities serve as a supplier to industry, in line with literature that typically ask the question: "How does university research affect industrial innovation?". Mowery & Sampat (2006) argue that increased cooperation between HE and PRC units is due to slower growth in overall public funding and increased competition for research funding, which has brought universities to seek closer links with industry "as means of expanding research support". It has been suggested that universities promote partnerships with firms in order to ease their budget constraints and to improve their own efficiency in research (Fantino, Mori & Scalise, 2015), and have become increasingly 'enterprising' in terms of research commercialisation, technology licensing and transfer, and other ways of engaging with the business enterprises and industry (Tijssen, Lamers & Yegros, 2017).

There is a vast literature on how industry benefit from cooperation with HE and REC institutions (see e.g. Anic, 2017; Ankrah & Al-Tabbaa, 2015). In general, private companies engage in collaboration with HE and REC institutions motivated by the possibility to enhance their knowledge base and thus improve their production processes and develop new products (Caloghirou, Tsakanikas & Vonortas, 2001). Several studies have brought knowledge about positive outcomes of HE collaboration with the PRC sector, but the gains are usually analysed from the PRCs point of view, e.g. in Jong and Slavova (2014) where 160 British therapeutic biotechnology firms' involvement in academic communities enhanced their innovative performance in terms of new products, or in Cunningham & Link (2015) where companies gained from such collaborations through increased commercialisation probabilities and economies of technological scope. Further, sectorial mobility, i.e. PRCs hiring researchers from universities have been shown to impact firms' patenting activities (Ejsing et al. 2013). Hence, the literature seems to focus on knowledge flow as a one-way route from universities to companies, typically focusing on knowledge spillovers from basic academic research to firms (Fantino, Mori & Scalise,

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2015). It is difficult to find studies that see the collaboration from the other side, i.e. how universities may benefit from collaboration with PRCs. Anic' (2017) review of literature studying motives and benefits from industry-academia cooperation is thus highly skewed towards the papers observing the results from the companies' points of view. Even in the odd case where the 'opposite route' is explored, it is not necessarily to the benefit of the universities. Simeth & Raffo (2013) studied the 'opposite' of universities engagement in commercial activities: companies disseminating scientific knowledge, finding that French firms had a very instrumental approach to necessity of adopting academic principles; collaboration with academic institutions was only considered if it added scientific knowledge needed for their innovation development. It seems plausible to suggest that PRCs inclined to collaborate with the HE sector constitute a selected group, cf. Fernandez Lopez et al.'s (2015) sample of 375 firms in France, Spain and Portugal, where it was the most innovative firms who tended to be most interested in collaborating with universities, or in Giuliani & Araz (2009), where it was companies engaged in basic exploratory research and working on advanced innovations.

Breznitz & Feldman (2012) offer a different theory on universities' societal role outside campus. They claim that in their activities offering advice and assistance to the community (be it firms, policymakers), they may use the local community as a lab to test new ideas and perform other types of explorative actions. Hence, their arguments introduce the possibility that the HE sector may *benefit* from such cooperation since they may not only serve the local communities but may *use* them for its own R&D purposes.

One main motivation for us to make the current study, was the many stories (that are, of course, not representative to the entire sector) that we were told from Norwegian university professors about their motivation for engaging themselves as supervisors to PhD students under the Norwegian industrial PhD scheme, where the doctoral students undertake their PhD project as full-time employees at their companies with supervisors from both their current workplace and from the university. From the university supervisors we learned many stories about how such cooperation would enhance their own publication possibilities/careers due to access to advanced testing equipment and highly specialized knowledge not available at the university (Piro et al., 2013). Hottenrott & Lawson (2012) claim that few studies have taken the perspective that academic researchers may actively source ideas from industry, thus getting their research agendas shaped by industry. They argue that (pp. 6-7) "industry as a source of ideas can provide a new and fresh perspective and thus improve academic research performance resulting in more and better publications", as well as having positive effect on HES' patenting activity. In a German study of engineering departments, a clear association was found between the share of a departments' funding from industry and sourcing of ideas from industrial partners, especially from large firms. In this study, collaboration with large firms versus SMEs had very different outcomes in the HE institutions. Ideas sourced from large firms led to both fewer publications and citations, and patents as well (ideas from SMEs on the other resulted in more patents) (Hottenrott & Thorwath, 2011). Anic (2017, p.20) lists the following factors as motives for scientists to cooperate with companies: representing an opportunity to obtain government support and additional funding for their research, purchase new equipment, hire new researchers, test practical applications of their theories and to translate them into specific outcomes. In sum (Anic, 2017, p.21): "collaborative projects often yield new, academically valuable insights and ideas even if they have limited application and do not directly result in publishable results or lead to commercialization of research results, and as such are valuable for scientists".

In the Norwegian study referred to above, the 'desired' PRCs were both very large industry corporations and small start-up firms (e.g. biotechnology companies). The SMEs are generally considered to be the carriers of more radical innovations in the literature, but small and large firms are unequally innovative in different sectors. Larger firms have been shown to be more innovative in the aircraft and pharmaceutical industries, while the opposite is the case in e.g. computers and process control instruments, electronics and medical equipment where small firms contributions to innovation is strong (Braunerhjelm, Ding & Thulin, 2018). SMEs' relation to larger firms are often dependency-based (Yang, Zheng & Zhao, 2013), but at the same time many SMEs are developed based on larger firms, i.e. spin-offs (Eriksson & Moritz Kuhn, 2006). Therefore, it is argued that the benefit of academic research is particularly strong in start-up firms (Fontana, Geune & Matt, 2016); due to need of short-

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term/immediate technology assistance related to specific problems/projects (McKelvey, Zaring & Ljungberg, 2015).

In studying the relationship between the ‘academic sectors’ (HE/REC) and PRC, much emphasis is on physical proximity (e.g. D’Este, Guy & Iammarino, 2013; Fantino, Mori & Scalise, 2015; Maietta, 2015; Steinmo & Rasmussen, 2016), with different understanding of the necessities of larger and smaller PRCs (Bjerke & Johansson, 2015). Steinmo & Rasmussen (2016) found that engineering-based firms tend to rely on geographical and social proximity to public research organizations, while science-based firms rely more heavily on cognitive and organizational proximity. This in particularly holds for large firms with strong absorption capacity, thus stimulating collaboration with academic research partners (Boschma, 2005). Fantino, Mori & Scalise (2015) found that proximity is more important for SMEs (larger firms’ collaboration with universities are less bounded by geography), but only proximity to a high-quality university, not to any generic university. The studies in favour of geographical proximity shows that companies located near universities frequently collaborate with them and benefit from spillovers (Anic, 2017), although there are studies indicating that companies give more preference to the research quality of a university partner than to its geographical closeness (Laursen, Reichstein & Salter, 2011).

Size and diversity

Several studies have shown that company size is positively related to science-industry cooperation (Anic, 2017). It is argued that especially SMEs are inclined to substitute internal R&D with university research, foremost in highly specialized technologies (Hottenrott & Lawson, 2012). Larger companies, on the other hand, possess several layers of resources enabling them to fully exploit collaborative links with academic research institutions (Anic, 2017).

The importance of firm size to absorption capacity (Boschma, 2005) is somewhat contradictory to the claim that radical innovations (only) take place in small firms. Bjerke & Johansson (2015) argue that “Large firms appear to be more innovative than small firms as they have both the financial muscles to take larger risks and an internal knowledge pool of sufficient size and scope to develop new ideas”. Add to that, large national and multinational firms often play the critical role of competent customers in the innovation process (Bjerke & Johansson, 2015). Our purpose here is not to conclude in any debate about what levels of firm size that are beneficial to academic collaboration or innovation. Large firms carry out more innovations in absolute numbers (Ebersberger & Herstad, 2012), while small firms are more dependent on external participation in their innovation (Bjerke & Johansson, 2015). Related to this, Both Kaiser, Kongsted & Rønde (2015) and Braunerhjelm, Ding & Thulin (2014) found a positive association between labour mobility and innovation (measured as patent applications). Multinational firms, however, serve as examples where the transfer of technology takes place within the institution (Keller & Yeaple, 2009), and it has been shown that such firms are more innovative than independent corporations (Ebersberger & Lööf, 2005). However, recent UK surveys indicate that the contributions from UK university researchers to problem solving and socioeconomic impact are significant (Tijssen, Lamers & Yegros, 2017).

Our main interest here is the presence of strong actors from both academic sectors and the private sector, but most research on leading R&D actors are performed within *one* sector only. From the HE sector, looking at *size* and performance indicators, Frenken, Heimeriks & Hoekman (2017), using bibliometric data from the Leiden ranking, find that research performance differences among universities mainly stem from size (in addition to disciplinary orientation and country location). Moed et al. (2011) found the same at both national and institutional level: in a study of 40 countries there was an association between publication production and citation impact, but it was not beneficial for a country to have a high concentration of the research within certain institutions or fields.

In the PRC sector, regions with a high degree of variety among firms in related industries have been shown to achieve strong economic performance (Frenken, van Oort & Verburg, 2007), and regions where several small and large firms coexist have been shown to be more productive in terms of innovation (Agrawal et al., 2014). Braunerhjelm, Ding & Thulin (2018) ask: for a region with a given number of inventors, does the way in which

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those inventors are organized (e.g. all in one large firm, spread out across many small firms, distributed across a mix of large and small firms) influence their productivity? They argue that innovation productivity is greater in 'diverse' regions, i.e. those where large and small labs coexist. Their argument is that such coexistence reduces the costs of spin-out formation. Here, we approach a theory of *diversification driven by a few large actors* as an important factor for innovation push. According to Falk (2006), high R&D intensity may either be the result of a R&D intensive industry or an industry with a high share of R&D intensive actors. Similarly, the equivalent at national level would be high R&D intensity across all R&D performing actors, or a skewed landscape of R&D actors, with a low number being extremely R&D intensive (at the expense, or in addition to the rest). In any case, the promotion of a diverse set of R&D participants from various sectors appear fruitful. They serve different roles: academic research, innovation, and building bridge between the two; they account for different types of innovation; and they complement each other by transfer of knowledge and personnel. Thus, we outline the following hypothesis to be tested:

The performance indicator scores of national R&D systems, will increase by:

a) *a skewed distribution of R&D actors,*
b) *in both the academic sectors and in the PRC sector,*
c) *in combination with the presence of R&D intensive locomotives in both sets of sectors*

We know from the vast literature on participation in EU FP projects, that the research networks of Europe are characterized by a stable set of core actors, particularly large universities (Lepori et al. 2015), but also in REC institutions with a solid experience from former EU FP projects (European Commission, 2015; Piro, Scordato & Aksnes, 2016). In the funding of EU FP projects, there is roughly a 30-30-30 divide in grant recipients between the three sectors HE, REC and PRC. The remaining 10 per cent is for non-R&D performing public sector institutions and for other organizations (typically NGOs). The latter two sectors are increasingly involved in the EU FPs, mostly due to their role as representing stakeholders/users – not as knowledge producers.

In this study, we present the composition of R&D performing units in 40 European countries based on their participation in proposals submitted to the EU FPs. We show how the composition vary by sector involvement, and how dispersed the composition of R&D institutions is for each country. We then show whether the countries' total R&D activities are driven by a few 'national locomotives', i.e. very large universities, research institutes or private corporations. The main distinction is between a country's degree of dispersion and a country's degree of R&D intensity. Based on such profiling, we finally study whether these profiles are associated with R&D performance indicators at the national level.

The European Framework Programs for Research and Innovation

The history of the European Framework programs for Research and Innovation (EU FPs) shows a development from industrial and technological focus towards tackling economic problems of Europe and job creation (FP7) and addressing societal challenges (H2020). With the creation of the European Research Council in 2007, the EU FPs covered the whole span from market to basic research. In H2020, the pillar *Excellent Science* accounts for 32 per cent of the overall budget, and the pillar *Industrial Leadership* 22 per cent. Simplified, these two pillars point towards different sectors (HE/REC and PRC), while the third main pillar of the H2020, *Societal Challenges*, builds bridge between all sectors through its multidisciplinary and multi-sectorial approach, and is the largest pillar of the overall budget with 39 per cent. The EU FPs thus make a very good case for a study of the total set of R&D actors of a country, as for example bibliometric studies do not capture the private sector which is almost a non-publishing sector (cf. Leydesdorff & Wagner, 2009).

The large funding that is available through the EU FPs, and the seemingly favourable opportunity for participating with other actors at the front internationally in EU funded projects, have made most countries that fully participates in the EU FPs oriented towards increased national mobilization for EU FP participations. Several countries have introduced national level support schemes to help/support their R&D performing actors to get involved in EU projects, where the first step is to participate as either partner or coordinator in a project proposal. In the present study, our focus is on *proposal participations* – not project participations in funded

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projects. The reason for this choice is that the *success rates* vary across countries, sectors and institutions. When we aim at describing the composition of R&D systems across European countries, we do not want to limit the analysis to those actors who have succeeded in getting their projects funded, as this would remove too many of the (often smaller) R&D involving actors in Europe. Our aim is not to identify successful R&D institutions of Europe, but to identify all R&D performing institutions.

Methods

This is an exploratory study with the aim of characterizing European R&D systems and see whether their profiles differ by R&D performance indicators. We do not claim to make any inferences about causality. Our analyses are thus based on simple descriptive statistics. The novelty of our study is in the creation of the indicators to describe the R&D systems.

The R&D systems are characterized by two indicators. First, a measure of a country's R&D dispersion which we label the 'R&D Gini coefficient'. Second, a well-established indicator: Gross Domestic Expenditure on R&D (GERD) as percentage of GDP. The R&D systems are thereby characterized by their 1) dispersion, and 2) intensity. These indicators are compared with the respective countries' scores on the most frequently used *research* indicator, which is the citation index of the countries' scientific publications, and with indicators for innovation output, where we have used a sub-sample from the European Innovation Scoreboard: applications in patents, trademarks and design. Combined they provide output measures of both research and innovation.

Data from ECORDA

This study draws upon proposal (not project) data from the European Commission's data warehouse ECORDA, covering the European Union's Seventh Framework Programme for Research and Technological Development (FP7, 2007-2013) and Horizon 2020 (H2020, 2014-2017). Our data thus covers FP7 in its entirety but is restricted to the early results of H2020.

At the Nordic Institute for Studies in Innovation, Research and Education (NIFU), all institutional addresses in EU's application and project databases of FP7 and H2020 have been standardized (approximately 1.4 million institution names). To the best of our knowledge, such a standardized data file including both applicants and grant recipients does not exist anywhere else. The project database of ECORDA *is* standardized (i.e. all institutions operate with one standardized name, and one sectorial belonging), but is not updated as mergers or change of institutional names occur. The proposal database on the other hand is unstandardized, meaning that if one wants to find out how many proposals a given institution has participated on, it requires a full check of the entire database as (similar to publications in Web of Science) e.g. large universities (in particular) may be listed with several hundred different names (For example University of Oxford; Univ Oxford; Dept. Psychology, U Oxford; Univ Oxxford, etc.). Then there is a problem of sectorial belonging, with challenges within each institution and across countries. Many applicants have two or more sectorial belongings listed to their names in the application database. A very large number of the applicants also have assigned themselves the wrong sector (e.g. small firms or think-tanks listing themselves as REC, public secondary schools listing themselves as HES, university hospitals listing themselves as PUB, etc.). A substantial amount of work has been put into making a correct sectorial classification of all applying institutions to the EU FPs, after their institutional standardization has been performed. Our distribution of proposal participations across sectors will thus deviate quite much from the official numbers provided at the sector level by the European Commission.

Several delimitations and methodological considerations have been decisive to the final selection of EU FP applicants. *First,* because our study spans a 11-year time-period, we have faced the many cases of *mergers*. This is relevant in all sectors. The units in our sample are treated as they are in 2017, i.e. separate units in earlier years are collapsed into their status as of 2017. Mergers in the HE sector are relatively easy to deal with. Mergers in the PRC sector is, on the other hand, very difficult to deal with since they are less known and often result in new companies with a completely different name. We have to the best of our knowledge classified the PRC contributions to their formal belonging in 2017.

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Second, and related to the issue above, there are many applicants in our sample that *no longer exists*. HE and PRC institutions that have disappeared do appear in our analysis, which add to a higher number of units than what is the case in 2017.

Third, there is a challenge with large research associations and large corporations split into different institutes or divisions. It is not always clear-cut which units that belong to large national academies of science, or under some of the many national research councils that in some countries are R&D performing actors (in other countries the research councils are simply funding agencies and are thus classified as PUB in our database, not REC). The problem with many of these very large research associations is that roughly half of the submitted proposals have no more information than the overall institution name, whereas the other half contains information about which institute the applicant belongs to. Further, we do not have enough knowledge about all countries with such research associations to enable us to decide exactly which institutes that are integral part of the main association and which institutes that are only loosely affiliated, and hence should be treated as separate units. Because of this, very large institutions such as INSERM and CNRS in France, Fraunhofer in Germany, CNR in Italy, CSIC in Spain, and all national academies of sciences in Eastern Europe, are analysed at the overall level - not split into subunits. In the private sector, the problem is much the same for very large corporations such as Phillips B.V., Siemens A.G., Volvo A.B., and they are also treated at the overall organizational level.

Fourth, the ECORDA categories PUB (public sector units, not research performing) and OTH (other institutions, foremost NGOs) are excluded from this study. Pragmatically because it is not possible for us to standardize them due to lack of knowledge about each country's (or region's or city's) internal organisation[1]. Methodologically because the sectors PUB and OTH are mostly involved in EU FP proposals as stakeholders/end-users, not as R&D performing actors themselves.

As this is an exploratory study, and because our data are analysed at the national level, we have kept the level of detail in the EU FPs also at the overall level. It is fully possible that dispersion and intensity of the European R&D systems may mean different things to different programs in the EU FPs (e.g. ERC vs. programs for SMEs) or in different fields of research (e.g. clinical medicine vs. social sciences), but for reasons of simplicity, the only stratification we do in our sample, is to split the results by *sector* (HES, REC, PRC) in addition to provide total numbers at the national level.

The R&D Gini coefficient

The main indicator of this study is the *R&D Gini Coefficient*. The name of the indicator must not be confused with the well-known Gini Coefficient, which is a statistical measure of the income distribution of a country. Here, we use the calculation method of the Gini coefficient to calculate the *R&D distribution among a country's R&D performing institutions.* We do so in total and for the three sectors HES, REC and PRC individually. The coefficient varies from 0 (maximal equality) to 1 (maximal inequality). The coefficient will be 0 in the odd case where a country has, say, two R&D performing institutions, and both have five EU FP participations. The coefficient will be 1 in the similarly odd case where this country experience that one of the institutions do not have any EU FP participations, while the other has ten.

Gross Domestic Expenditure on R&D (GERD) as percentage of GDP

Data on GERD as percentage of GDP is taken from OECD's Main Science and Technology Indicators (Volume 2017/2). For each country we use an average of available years in the period 2005-2016. For non-OECD members where OECD do not provide numbers, other data sources have been used. For seven countries (Serbia, Montenegro, Bulgaria, Croatia, Cyprus, Lithuania and Macedonia), we have used data from Eurostat (average of the years 2006 and 2016), and for Albania and Bosnia and Herzegovina data is taken from UNESCO (2017-numbers).

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[1] For example; a public nursing home: should it be treated as an individual unit, or is it part of a municipality? If it is not public, is it a private corporate that has the ownership (PRC) or is it voluntary organizations which runs the nursing home (OTH)?

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OECD does not split data by sector. We have used Eurostat's sector numbers, where each country is assigned an average of the years 2006 and 2016. As our analysis covers the years 2007-2017, it is important to level out year-to-year fluctuations as well as long-time trends of significance. For example, the PRC sector in Poland saw its GERD share of GDP rise from 32 per cent in 2006 to 66 per cent in 2016, and in Latvia the share declined from 50 to 24 per cent in the same period.

Citation indicator

For each country we use its national average field normalized citation index (MNCS) throughout the period 2007-2016 (see Waltman et al., 2012, for more detailed information). An MNCS value of one represents the world citation average (adjusted for each publication's scientific field). A country MNCS below 1 implies that its publications are cited less than the world average for all publications in Web of Science within the same fields (for example: 0.86 means that the publications are cited 14 per cent less than for similar publications worldwide; 1.25 means the country's publications are cited 25 per cent more compared to the world average). All 40 countries in this study (see Table 1) have been split into five citation categories by citation values (the highest citation indexes are found in category A, the lowest scores in category E).

Innovation indicators

As a research performance indicator, the MNCS (and similar/related bibliometric indicators) has become standard in comparing the *research performance* of countries and institutions. There is no equivalent indicator for *innovation.* At policy level, a country's ability to (successfully) innovate is often interpreted by its rank in the *European Innovation Scoreboard* (EIS). We agree with the recent criticism raised towards EIS by Edquist et al. (2018), pointing out that the composite nature of the EIS has many flaws. Their main criticism is that a country's EIS score is based on an arithmetic average of 27 indicators, where no distinction is made between input and output types, leading to a substantial and spurious double counting, i.e. countries with high innovation input will undoubtedly also have a high innovation output (cf. Aksnes et al. 2017 on the challenges of using R&D statistics as an input variable and publications as an output variable to draw conclusions about the productivity or efficiency of national research and innovation systems). Here, we have chosen to use three output variables from EIS to provide a proxy for a country's innovation ability (European Commission, 2018). We use the EIS scores from the category *Intellectual assets,* which is made up of three variables: PCT patent applications, trademark applications and design applications.

We have weighted the three EIS categories discretionary, as we believe the patent indicator should be given more weight (as trademarks are less R&D intensive). This choice has great influence on how a country ends up on the innovation indicator. Poland makes a good example. Its patent score is just 19.6 in EIS, but 128.7 on design. Our weighting gives Poland a much lower total score than if an arithmetic average was used. The same is the case for Portugal (26.7 on patents and 102.5 on trademark). We create a new indicator for Intellectual assets, where the value of PCT is weighted 0.5; the value of trademark 0.25 and the value of design 0.25[2]. Further, we use indexes relative to the EU average – not raw numbers. As for the citation indicator, the countries are split in five categories (1 equals the highest scores, 5 equals the lowest scores), with an additional category (value 9) representing countries where data was not available (Albania, Bosnia and Herzegovina, Moldova and Montenegro).

Results

Table 1 gives an overview of the contribution of 40 European countries to FP7 and H2020 proposals. In absolute numbers, Germany and the UK form a top-tier, both with approximately 134 thousand proposal participations. Italy and Spain (118 and 107 thousand) form the second most active group, followed by France with 89 thousand participations. Obviously, large countries have contributed to most proposals.

[2] For Serbia, data on PCT patent applications is not available. We have thus calculated Serbia's Intellectual assets score based on design and trademark applications only.

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When adjusting the numbers for population size, it is the Netherlands and Spain that have been the most active countries, with almost 3 percentage points higher participation activity than their shares of the European population (the countries are listed in Table 1 by their over- or underrepresentation of participations compared to country size, "% Dif.").

Table 1: Number of participations/contributions by country and sector (EU FPs 2007-2017)

Country	HES	PRC	REC	Total	% Partic.	% Pop.	% Dif.	% HES	% PRC	% REC
Netherlands	29047	20613	9789	59449	5.66	2.69	+2.97	48.9	34.7	16.5
Spain	30219	43199	34349	107767	10.26	7.32	+2.95	28.0	40.1	31.9
UK	85739	39115	9055	133909	12.75	10.27	+2.49	64.0	29.2	6.8
Greece	12912	13493	11881	38286	3.65	1.76	+1.89	33.7	35.2	31.0
Italy	43077	47857	27872	118806	11.31	9.54	+1.78	36.3	40.3	23.5
Sweden	19673	10139	3671	33483	3.19	1.60	+1.59	58.8	30.3	11.0
Belgium	14751	12307	7488	34546	3.29	1.81	+1.48	42.7	35.6	21.7
Switzerland	15880	8567	4245	28692	2.73	1.35	+1.39	55.3	29.9	14.8
Finland	10856	7128	5135	23119	2.20	0.86	+1.34	47.0	30.8	22.2
Austria	11435	9464	6875	27774	2.65	1.38	+1.27	41.2	34.1	24.8
Denmark	12676	7456	1752	21884	2.08	0.91	+1.18	57.9	34.1	8.0
Ireland	10528	5989	801	17318	1.65	0.73	+0.92	60.8	34.6	4.6
Norway	6323	5112	5173	16608	1.58	0.82	+0.76	38.1	30.8	31.1
Slovenia	3123	4518	3029	10670	1.02	0.33	+0.69	29.3	42.3	28.4
Portugal	7827	8745	7360	23932	2.28	1.62	+0.66	32.7	36.5	30.8
Cyprus	2637	2782	213	5632	0.54	0.14	+0.40	46.8	49.4	3.8
Estonia	2041	2001	480	4522	0.43	0.21	+0.22	45.1	44.3	10.6
Israel	8655	6129	946	15730	1.50	1.29	+0.21	55.0	39.0	6.0
Iceland	752	819	363	1934	0.18	0.05	+0.13	38.9	42.3	18.8
Luxembourg	541	1241	543	2325	0.22	0.09	+0.13	23.3	53.4	23.4
Malta	538	879	42	1459	0.14	0.07	+0.07	36.9	60.2	2.9
Latvia	1216	1054	595	2865	0.27	0.31	-0.04	42.4	36.8	20.8
Montenegro	153	60	43	256	0.02	0.10	-0.07	59.8	23.4	16.8
Lithuania	1932	1226	630	3788	0.36	0.44	-0.08	51.0	32.4	16.6
Germany	50385	46033	38109	134527	12.81	13.01	-0.20	37.5	34.2	28.3
Croatia	1943	1648	946	4537	0.43	0.67	-0.23	42.8	36.3	20.9
Macedonia	447	353	133	933	0.09	0.33	-0.24	47.9	37.8	14.3
Kosovo	42	20	15	77	0.01	0.29	-0.29	54.5	26.0	19.5
Hungary	4274	5661	3033	12968	1.24	1.53	-0.29	33.0	43.7	23.4
Slovakia	1773	2032	1142	4947	0.47	0.86	-0.38	35.8	41.1	23.1
Albania	242	73	101	416	0.04	0.46	-0.42	58.2	17.5	24.3
Czech Rep.	5230	4392	2868	12490	1.19	1.68	-0.49	41.9	35.2	23.0
Bulgaria	1583	2752	2192	6527	0.62	1.11	-0.49	24.3	42.2	33.6
Moldova	140	120	219	479	0.05	0.56	-0.52	29.2	25.1	45.7
Bosnia Herz.	353	140	60	553	0.05	0.59	-0.54	63.8	25.3	10.8

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Serbia	1681	1282	905	3868	0.37	1.11	-0.74	43.5	33.1	23.4
France	21276	32219	35501	88996	8.48	10.29	-1.81	23.9	36.2	39.9
Romania	4229	4095	2927	11251	1.07	3.09	-2.02	37.6	36.4	26.0
Poland	8482	7054	5667	21203	2.02	6.01	-3.99	40.0	33.3	26.7
Turkey	6061	4453	886	11400	1.09	12.74	-11.66	53.2	39.1	7.8
Total	**440672**	**372220**	**237034**	**1049926**	**100**	**100**		**42.0**	**35.5**	**22.5**

Even after adjustment for population size, we see that with a few noticeable exceptions, it is till the large nations of Europe that has been the most active in the EU FPs. Both the UK and Italy have much higher shares of EU FP proposal participations compared to their country size. A common feature of the countries that have participation patterns most in line with their size, is that they are all small countries (Iceland, Luxembourg, Malta, Latvia, Montenegro and Lithuania). Two of Europe's largest nations stand out with lower participation levels compared to country size – Germany and France – but Germany's lower share compared to size is just 0.2 percentage points. France, however, has a much lower share of the proposal participations: 1.8 percentage points lower than what its size should indicate. Europe's largest country by population size, Turkey, stands out with an extreme disproportionality between its share of the European population and its share of participations: 11.7 percentage points. Another main feature of Table 1 is the fact that all Eastern European countries except Slovenia, are found among the countries with a negative difference between population and participation, most notably Eastern Europe's largest country Poland[3].

By sector, 42 per cent of the proposal participations are from the HE sector, 35.5 per cent from the PRC sectors and 22.5 per cent from the REC sector. The sector percentages in Table 1 adds to 100, because our study does not include participations from the two remaining sectors in ECORDA – Public Sector and Other – who account for some 7.1 per cent of the total (3.9 OTH and 3.2 PUB). The highest share of HES contribution is found in the UK (64 per cent) where the REC sector's share is very low. In many countries there is a trade-off between these two sectors. Large shares in the REC sector is at the expense of the HE sector, foremost in countries with a dominating research performing national research council (e.g. France and Spain) or with a national academy of science (e.g. Moldova and Bulgaria). A third option is to have a strong governmental research institute sector such as Norway (REC accounts for 31 per cent), unlike Denmark where most research institutes are now integrated in the universities, so that the REC sector here only accounts for eight per cent. The countries where the PRC sector is the most dominating sector are all very small, thus with a low number of HES and REC institutions (Malta, Luxembourg, Cyprus).

Among Europe's largest countries, Italy, Spain, France and Turkey have PRC shares above the European average. Innovation leaders in the European Innovation Scoreboard (EIS, 2018) such as the UK, Sweden, Finland, Denmark and the Netherlands (in addition to Switzerland) have all PRC contributions below the European average. The lowest PRC involvements are geographically located at the Balkan Peninsula: Kosovo, Bosnia and Herzegovina, Moldova, Montenegro and Albania.

In Table 2 vi study the dispersion of R&D performing units at country and sector levels. We use two indicators, first, the R&D Gini Coefficient, and then, the percentage of institutions who account for 50 per cent of all contributions. Greece is the country with the highest R&D Gini Coefficient, indicating a very unevenly distribution of proposal activity among the 2,779 Greek institutions that contributed to EU FP proposals. A total of 0.7 per cent of all Greek institutions accounted for more than 50 per cent of the proposal volume. The Greek dispersion was particularly evident in the REC sector where just 2.5 per cent of the Greek REC institutions accounted for more than 50 per cent.

The Greek standing on top of the list in Table 2 as Europe's most skewed R&D country may very well be more due to Greece's financial situation than to the R&D system itself. It is well-known that from FP7 to H2020, the

[3] Russia and Ukraine are not included in this study.

Greek proposal volume increased excessively, arguably due to few funding sources available domestically. Greece should thus be considered an outlier, and a removal of Greece from Table 2 would have made the numbers more consistent.

The highest R&D Gini Coefficients are found in 'successful' countries, such as Switzerland and the innovation leaders of the European Innovation Scoreboard. The general trend is in line with country differences by expected proposal activity, i.e. there are clear geographical differences, with the states from the Balkan displaying the lowest R&D Gini Coefficients. These coefficients are, however, more meaningful when studied in relation to the percentages of institutions that account for 50 per cent of the contributions. Our interpretation of the latter numbers is that they indicate whether a country/sector is dominated by one or a few 'locomotives'.

Table 2: R&D Gini coefficients and concentration of R&D, by country and sectors

		R&D Gini coefficients				% of participants behind 50%			
Country	**R&D units (N)**	**Total**	**HES**	**REC**	**PRC**	**Total**	**HES**	**REC**	**PRC**
Greece	2779	0.865	0.788	0.901	0.689	0.7	8.6	2.5	5.1
Switzerland	2495	0.863	0.829	0.866	0.612	0.4	7.3	3.9	7.6
UK	12400	0.859	0.789	0.804	0.573	0.3	6.6	4.1	9.3
Sweden	3267	0.851	0.743	0.857	0.559	0.3	11.9	3.3	10.6
Netherlands	5702	0.845	0.770	0.841	0.610	0.3	12.3	2.8	8.0
Belgium	3149	0.843	0.869	0.817	0.639	0.4	7.5	3.0	6.8
France	8485	0.841	0.763	0.936	0.651	0.7	6.6	0.6	5.5
Germany	13652	0.837	0.805	0.884	0.611	0.5	6.8	0.5	7.4
Denmark	2331	0.836	0.835	0.775	0.562	0.2	10.0	7.8	10.4
Ireland	1805	0.836	0.799	0.741	0.578	0.3	10.8	3.8	9.4
Finland	2541	0.831	0.790	0.885	0.512	0.3	10.9	1.6	13.4
Portugal	2319	0.826	0.835	0.746	0.741	1.5	7.7	9.8	6.4
Austria	2837	0.824	0.822	0.787	0.609	0.9	6.3	4.4	7.7
Spain	11233	0.822	0.768	0.828	0.632	0.8	9.0	3.4	6.8
Italy	13404	0.820	0.976	0.862	0.618	0.6	8.4	1.5	7.1
Norway	1911	0.815	0.830	0.751	0.516	0.9	7.1	8.1	13.0
Cyprus	581	0.813	0.795	0.573	0.692	1.5	10.5	15.0	5.0
Czech Republic	1576	0.808	0.800	0.870	0.558	0.6	8.0	1.0	10.0
Israel	1766	0.800	0.852	0.741	0.593	0.4	8.5	9.0	8.7
Luxembourg	310	0.785		0.734	0.674	1.9		7.7	4.9
Serbia	576	0.785	0.882	0.737	0.560	1.2	5.7	7.2	8.5
Poland	3179	0.782	0.785	0.548	0.509	1.4	6.8	2.1	11.8
Croatia	744	0.774	0.900	0.732	0.532	1.1	2.9	6.0	10.5
Slovenia	1451	0.772	0.882	0.835	0.566	1.0	3.2	2.5	10.8
Malta	227	0.771		0.417	0.661	1.8	33.3	20.0	4.2
Estonia	687	0.767	0.763	0.631	0.549	1.3	16.7	14.7	10.9
Romania	1704	0.767	0.738	0.731	0.569	2.5	9.5	6.7	8.1
Hungary	2088	0.765	0.759	0.792	0.540	0.9	12.2	0.7	11.2
Lithuania	617	0.765	0.786	0.705	0.484	1.5	12.1	8.2	13.7
Turkey	1824	0.764	0.774	0.864	0.540	1.6	5.6	1.3	10.6

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Iceland	288	0.758	0.684	0.942	0.538	1.7	14.3	9.5	11.9
Slovakia	874	0.755	0.759	0.861	0.509	1.4	12.1	2.0	11.9
Latvia	499	0.729	0.765	0.578	0.475	3.0	11.1	18.6	14.9
Bulgaria	1325	0.724	0.707	0.849	0.485	2.3	9.6	0.9	13.1
Macedonia	192	0.711	0.821	0.680	0.463	2.6	5.9	7.7	16.1
Moldova	109	0.711	0.658	0.843	0.322	2.8	12.5	5.0	24.7
Montenegro	55	0.706	0.676	0.383	0.302	3.6	20.0	36.4	25.6
Bosnia Herz.	131	0.685	0.696	0.499	0.298	3.8	15.0	19.0	25.6
Albania	125	0.611	0.752	0.470	0.215	7.2	14.3	16.7	34.5

The most extreme case is Denmark with 0.2 per cent of the applying institutions accounting for 50 per cent of the proposal contributions. The explanation of this is probably the Danish mergers in the HE sector including the gradual absorption of state research enterprises. Furthermore, there are relatively few very large Danish private companies, i.e. a very low number of universities become highly dominating. In the Danish PRC sector, 10 per cent of the companies account for 50 per cent of this sector's total activity. This is a high number compared to e.g. Switzerland, France, Belgium and Germany with much higher concentration around a few companies.

After Denmark, the R&D Gini Coefficients are the highest in the EIS innovation leaders: the UK, Sweden, Netherlands and Finland – all of which are dominated by 0.3 per cent of their participants (as in Ireland). In Switzerland and Israel 0.4 per cent of the participants make up 50 per cent of the proposal volume. Two countries stand out being in the top-10 list of countries that are most dominated by a few actors across all three sectors: France and Germany. Italy have the single highest R&D Gini Coefficient in Table 2, displayed for its HES sector, but it is the Italian REC sector, that by far is most dominated by a few actors (just 1.5 per cent make up 50 per cent of the contributions).

A few countries have a very high dominance of key actors in the REC sector only: Czech Republic, Hungary, Slovakia and Bulgaria due the strong standings of their national scientific academies, but also Turkey and Finland have REC sectors dominated by few actors. Very high concentration in the PRC sector is found in Southern European countries such as Italy, Spain, Portugal, Greece, Cyprus and Malta, in addition to the Benelux countries and Austria/Switzerland.

The results so far show country differences in sector composition of R&D systems, and by large a pattern of more unequal distributions of R&D activities in 'successful' countries. A unique feature of some of Europe's largest countries, is that all three sectors of the R&D system are highly concentrated, while countries like Switzerland, UK and Sweden are highly skewed overall, but are not among the most skewed countries in any specific sector (Table 2). Overall, the bivariate correlations between the R&D Gini Coefficients and the percentages of institutions accounting for 50 per cent of the contributions are strong: -,903 for Total, -,678 for HES, -,839 for REC and -,971 for PRC (all significant at the ,000 level). Still, just considering the shares of R&D performing institutions that account for more than 50 per cent of the total proposal volume is insufficient, as we do not know whether the concentration is made up by few or many institutions, and we do not know how many proposals that they have contributed to.

Therefore, in Table 3, we study the prevalence of large actors, i.e. R&D 'locomotives'. The cut-off for inclusion has been set at 50/500 proposal participations or more. There is a clear divide between Europe's five largest countries and the rest: Germany, Spain, Italy, France and the UK all have more than 200 50+ locomotives. The rest of Europe falls beneath the 100-mark. Of course, adjusting these numbers for population size would give a very different rank order: Iceland would top the list, both in total and in each sector. Norway, Luxembourg and Slovenia would all come up high in the total numbers, foremost due to these countries' relative large shares of large REC locomotives. Cyprus and Malta would also have high shares of R&D locomotives, due to relative high number of PRC locomotives. The UK stands out with the highest number of 50+ university locomotives (108), Spain the largest number of research institutes (128) and Italy, the largest number of private companies

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(86). When we study the 500+ locomotives, the numbers obviously drop substantially. UK, Germany and Italy now stand out with 49 to 39 locomotives, and with Netherlands (24 in total) exceeding France (Spain has 26). The dominance of the universities now become clear. 77 per cent of the 500+ locomotives are universities (21 per cent are RECs) and just 2 per cent PRCs, with only Italy and Spain having to such PRCs.

In the main analysis of this study, we investigate the association between the R&D Gini Coefficients (Table 2) and outcome indicators of the R&D systems: Intellectual assets and the citation index of scientific papers. Table 3 provides the country scores on these variables (countries are listed by GERD shares of GDP). Here, the outcome indicators are significantly associated with GERD as percentage of GDP: ,762 for EIS and ,701 the citation indicator (both significant at the ,000-level). The correlation between the outcome indicators is ,693. There are some noticeable exceptions to this general pattern. Neither France or Slovenia are among the ten highest ranked countries by performance outcome, despite being among then ten countries with highest GERD shares.

Table 3: Main indicators by country (countries listed by GERD as % of GDP)

					50+ locomotives			500+ locomotives		
Country	**GERD as % of GDP**	**Intell. assets (EIS)**	**Citation Index**	**Classification**	**HES**	**REC**	**PRC**	**HES**	**REC**	**PRC**
Israel (IL)	4.2	136.7	124.2	C1	10	7	5	6	0	1
Sweden (SE)	3.3	176.5	144.6	A1	23	10	10	11	1	0
Switzerland (CH)	3.3	169.2	168.1	A1	22	12	12	7	4	1
Finland (FI)	3.2	163.5	138.1	B1	15	12	3	7	1	0
Austria (AT)	2.9	142.7	137.8	B1	20	31	14	8	3	0
Denmark (DK)	2.9	166.7	163.4	A1	11	10	10	5	0	0
Germany (DE)	2.8	153.4	130.7	B1	96	98	71	34	8	1
Belgium (BE)	2.3	85.7	147.8	A3	12	27	30	7	4	0
France (FR)	2.2	93.0	127.1	B2	96	49	73	9	9	0
Iceland (IS)	2.2	66.8	175.5	A3	3	2	2	1	0	0
Slovenia (SI)	2.2	72.7	96.0	D3	5	9	2	2	1	0
Netherlands (NL)	1.9	136.6	159.3	A2	24	30	28	18	5	1
Czech Rep. (CZ)	1.7	53.2	99.5	D4	17	5	3	4	1	0
Norway (NO)	1.7	53.2	140.6	B4	13	27	4	3	1	0
Estonia (EE)	1.6	90.5	141.5	A2	4	2	1	2	0	0
UK (UK)	1.6	83.2	144.3	A3	108	39	55	46	3	0
Ireland (IE)	1.4	48.6	140.8	B4	13	3	9	6	0	0
Italy (IT)	1.3	92.2	125.2	C2	71	77	86	28	9	2
Luxembourg (LU)	1.3	128.2	133.1	B2	1	3	1	1	0	0
Portugal (PT)	1.3	61.8	117.5	C3	17	41	21	6	1	0
Hungary (HU)	1.2	39.3	104.5	C4	15	6	7	1	1	0
Spain (ES)	1.2	65.1	120.5	C3	57	128	77	18	6	2
Serbia (RS)	0.9	24.2	74.8	E5	4	4	2	2	0	0
Croatia (HR)	0.8	27.0	79.7	D5	4	3	4	1	0	0
Greece (GR)	0.8	30.3	116.6	C5	25	22	36	7	5	0
Lithuania (LT)	0.8	44.8	76.8	E4	9	3	0	1	0	0
Poland (PL)	0.8	59.8	77.1	D4	38	15	8	3	1	0
Slovakia (SK)	0.8	30.4	81.7	D5	7	1	1	0	1	0

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Turkey (TR)	0.8	11.9	65.8	E5	26	1	6	1	1	0
Bulgaria (BG)	0.6	68.5	87.1	D3	8	3	3	0	1	0
Latvia (LV)	0.6	43.2	86.8	D4	4	3	1	0	0	0
Malta (MT)	0.6	134.6	103.0	C2	1	0	4	1	0	0
Romania (RO)	0.5	18.2	69.7	E5	20	14	5	1	0	0
Cyprus (CY)	0.4	94.0	138.7	B2	7	0	10	2	0	0
Macedonia (MK)	0.4	11.8	81.7	D5	1	1	0	0	0	0
Montenegro (ME)	0.4	N/A	63.8	E9	1	0	0	0	0	0
Bosnia & H. (BA)	0.3	N/A	56.0	E9	2	0	0	0	0	0
Albania (AL)	0.2	N/A	47.7	E9	2	0	0	0	0	0
Moldova (MD)	N/A	N/A	75.9	E9	0	1	0	0	0	0

Some countries combine large GERD shares with high EIS scores (but not citation scores), e.g. Finland, Austria, Germany and Israel, while Iceland and Belgium combine relative high GERD shares with high citation scores (and not EIS scores). Four countries with GERD shares below two per cent, are among the most cited countries: UK, Estonia, Ireland and Norway. The most remarkable finding in Table 3 is nevertheless that the Netherlands is the only country with less than two per cent of GDP spent on GERD, that is both in the top-ten rank for EIS and citation indicators. Switzerland, Denmark and Sweden are the other countries that feature in both top-10 EIS and citation scores (and with some of the highest GERD shares of GDP

In Fig.1 we show the association between R&D performance indicators and the country composition of R&D participants. On the y axes the countries are located by GERD as percentage of GDP shares (compared to the mean in the sample). On the x axes, the countries are located by their R&D Gini Coefficients (compared to the mean in the sample). In the diagram, the countries are marked by their performance output classification in Table 3, where they are split in five groups by citation indicators (A to E, where A represents the highest score) and EIS scores (1 to 5, where 1 represent the highest scores). Four countries are assigned the EIS score 9, since they are not included in the EIS.

In Fig.1, there are two groups of countries (with R&D Gini coefficients below and above the mean), which ensures that the visual outlook is mainly linear, rather than loglinear. On the left side, Iceland (IS) and Slovenia (SI) have high GERD shares in combination with a relative low R&D Gini coefficient. On the right side, Cyprus (CY) and Greece (GR) combine low GERD shares with very high R&D Gini coefficients. These four countries may be considered as outliers due to either small size (Iceland), economic difficulties (Cyprus and Greece) and more complex explanations for Slovenia, being the only Eastern European country with over 2 per cent GERD of GDP. The most striking finding of Fig.1 is that high GERD shares in combination with high R&D Gini coefficients is associated with high R&D performance indicator scores. At least three factors contradict claims that the observations are simply a matter of correlation between R&D investments and performance indicators.

First, any causal mechanism from high R&D investments to high performance indicator values, must be transferred through a set of R&D performing actors. What Fig.1 reveals, is that that the transition of funding to R&D output goes through highly dispersed R&D systems in a large bulk of the most successful R&D nations. *Second*, all six countries with R&D investments above 2.5 per cent except Israel, have either top scores on both EIS and citations (Denmark, Sweden and Switzerland) or second highest score on citations and highest on EIS (Finland, Austria and Germany). The R&D Gini coefficients in these countries are high, clearly indicating that the most successful R&D countries of Europe do so with a work-force of R&D institutions that are log-tailed, i.e. the efforts are pulled by a relatively small group of leading actors, not by a generally high activity level across all R&D actors. The latter is more typical in countries with low R&D investments. *Third*, when we study the countries with low GERD shares (below 1.5), there is a clear tendency that there are higher citation scores in countries with high R&D Gini Coefficients compared to countries with low coefficients, across the same GERD levels. In countries with medium high GERD shares, it is difficult to see how R&D performance indicators vary

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by R&D Gini Coefficients as high citation scores are found in countries with both low coefficients (Iceland and Estonia), and in countries with high coefficients (Belgium, France, Netherlands and the UK), with rather similar GERD shares. The difference of course between these two sets of countries is that former are very small nations, with Iceland having a disproportionally extreme high level of national locomotives from all sectors, while Estonia has one of the highest population-adjusted numbers of HES locomotives.

In the introduction of this article, we outlined the following hypothesis: The performance indicator scores of national R&D systems, will increase by a) a skewed distribution or R&D actors, b) in both the academic sectors and in the PRC sector, c) in combination with the presence of R&D intensive locomotives in both sets of sectors. In Table 4 we summarize the findings so far, to test whether there is consistency in the countries' citation indicators and their scores on R&D Coefficients in total (cf. point a above), their R&D Coefficients in each sector (cf. point b above), and the presence of locomotives (cf. point c above). The countries are listed in Table 4 by their citation indicator. Many cells in the table are left empty, as we decided on a lower threshold of minimum 20 per cent of the proposal volume in order to be included, so that sectors that constitute a very low share of a nation's total R&D do not override the conclusions that would otherwise be made on the basis of the most important R&D sectors of the respective countries.

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Fig.1: R&D performance indicators, by GERD (as percentage of GDP) and R&D Gini Coefficients (all institutions, 2007-2017)

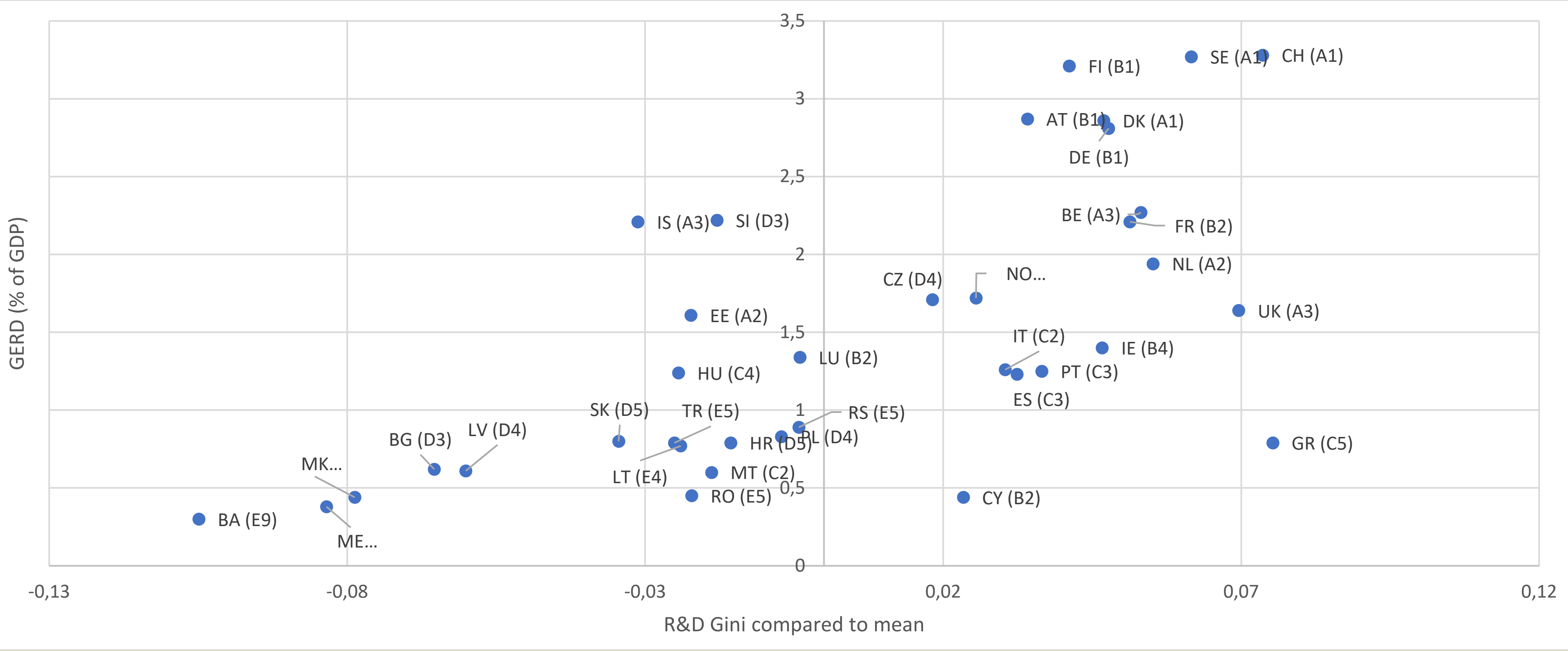

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Table 4: Citation indicators, R&D Gini Coefficients and presence of large locomotives.

	R&D Gini Coefficients				50 + units			500+ units		
	Total	HES	REC	PRC	HES	REC	PRC	HES	REC	PRC
Iceland	0.878	0.701		0.726	1.000		1.000	1.000		
Switzerland	1	0.849		0.826	0.802		0.537	0.539		0.959
Denmark	0.969	0.856		0.758	0.596		0.665	0.572		
Netherlands	0.979	0.789		0.823	0.437		0.627	0.693		0.479
Belgium	0.977	0.89	0.873	0.862	0.326	0.453	1.000	0.401	0.720	
Sweden	0.986	0.761		0.754	0.707		0.377	0.713		
UK	0.995	0.808		0.773	0.516		0.323	0.464		
Estonia	0.889	0.782		0.741	0.947		0.291	1.000		
Ireland	0.969	0.819		0.78	0.874		0.743	0.852		
Norway	0.944	0.85	0.802	0.696	0.779	1.000	0.294	0.380	0.398	
Cyprus	0.942	0.815		0.934	1.000		1.000	1.000		
Finland	0.963	0.809	0.946	0.691	0.853	0.422	0.209	0.840	0.377	
Austria	0.955	0.842	0.841	0.822	0.712	0.681	0.612	0.601	0.708	
Luxembourg	0.91			0.91			0.635			
Germany	0.97	0.825	0.944	0.825	0.362	0.228	0.329	0.271	0.200	0.099
France	0.975	0.782	1	0.879	0.458	0.145	0.428	0.091	0.285	
Italy	0.95	1	0.921	0.834	0.365	0.245	0.543	0.304	0.307	0.271
Israel	0.927	0.873		0.8	0.380		0.233	0.481		1.000
Spain	0.952	0.787	0.885	0.853	0.382	0.531	0.634	0.255	0.267	0.353
Portugal	0.957	0.856	0.797	1	0.514	0.766	0.780	0.383	0.201	
Greece	1	0.807	0.963	0.93	0.699	0.380	1.000	0.413	0.927	
Hungary	0.886	0.778	0.846	0.729	0.481	0.119	0.276	0.068	0.213	
Malta	0.893			0.892			1.000			
Czech Rep.	0.936	0.82	0.929	0.753	0.498	0.091	0.108	0.247	0.194	
Slovenia	0.895	0.904	0.892	0.764	0.754	0.838	0.370	0.637	1.000	
Bulgaria	0.839	0.724	0.907	0.655	0.354	0.082	0.163		0.293	
Latvia	0.845	0.784	0.618	0.641	0.638	0.296	0.196			
Slovakia	0.875	0.778	0.92	0.687	0.402	0.035	0.070		0.381	
Macedonia	0.824	0.841		0.625	0.150					
Croatia	0.897	0.922	0.782	0.718	0.294	0.136	0.361	0.155		
Poland	0.906	0.804	0.585	0.687	0.310	0.076	0.080	0.052	0.054	
Lithuania	0.886	0.805		0.653	1.000			0.235		
Moldova	0.824	0.674	0.901	0.435		0.054				
Serbia	0.91	0.904	0.787	0.756	0.177	0.109	0.109	0.187		
Romania	0.889	0.756	0.781	0.768	0.317	0.137	0.097	0.034		
Turkey	0.885	0.793		0.729	0.100		0.028	0.008		
Montenegro	0.818	0.693		0.408	0.502					
Bosnia/Herz	0.794	0.713		0.402	0.166					
Albania	0.708	0.77	0.502		0.216					

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The numbers in Table 4 are standardized by the best-performing country[4] (value set to 1.0). We show locomotive numbers for institutions with more than 50 proposal participations (cf. Table 3), adjusted for country size, but also for institutions with more than 500 proposal participations, which is a threshold level that limits the analysis to a very small group of the very largest R&D units of Europe.

Do highly cited R&D systems have a more skewed distribution of R&D actors? Yes, the pattern in Table 4, with Iceland and Greece representing outliers, clearly indicates a moderate decline in R&D Gini Coefficients as the citation index drops (R^2=0,654). *Are the systems skewed in both academic sectors and in the PRC sector?* The evidence for this in Table 4 is mixed. On the one side, all countries on the top of the table (except Iceland) have relative high sector R&D Gini Coefficients, but we find the most skewed systems among the large countries that are not among the most cited countries. The general finding of the sector results is that is not so much a matter of a gradient, but of a divide between Western and Eastern European countries. *What is the extent of R&D intensive locomotives?* To this question, the results in Table 4 are undoubtedly associated to citation scores. Although large countries like Germany, France, Italy and Spain for obvious reasons have much higher numbers of R&D locomotives, the per capita numbers are lower than in smaller, yet higher cited countries. We find it interesting that the number of relative large PRC locomotives (50+) are much higher among the most highly cited countries, while the extremely large PRC locomotives (500+), are almost non-existing in these countries, but do appear in large countries with lower citation indicators. Switzerland and Netherlands are exceptions to this. Large countries such as Germany, France, Italy and Spain seem unable to combine high R&D Gini Coefficients with a relative high level of R&D locomotives, while the highest cited countries combine these two aspects.

Conclusion

In this study we have provided descriptive data on the number of R&D performing institutions in 40 European countries, in total and across sectors. Using proposal participation in the EU FPs, we have described the participation patterns of the three main R&D sectors and of the institutions within these. Our study shows that the concentration of R&D actors at country-level and within the sectors differ across European countries, with the general conclusion being that countries that can be characterized as well-performing on citation and innovation indicators seem to combine a) high shares of Gross Domestic Expenditure on R&D (GERD) as percentage of GDP with b) a highly skewed R&D system, where a small part of the R&D performing actors account for a very high share of the national R&D performance. This indicates a dual R&D system which combines a few large R&D performing institutions with a very large number of small actors.

Interpreting this conclusion in light of the theoretical discussion about science-industry cooperation and sector benefits from this is not straight-forward. An interesting question, however, is a) whether a skewed set of PRC actors is consistent with strong innovation output, while skewed sets of HE and REC actors is consistent with strong citation scores, or b) whether skewed sets of actors in all three sectors are consistent with strong performance output indicators overall. In the first case (a), one may claim that industry 'innovates' and research performing sectors 'publish', providing support to theories about universities as suppliers of knowledge to the private sector. In the other case (b), strong presence of both types of actors may benefit a country's capability of both innovation and research, as the science-industry cooperation may be based on a more mutual set of benefits than what is the focal point in innovation studies that mostly describe the knowledge transfer from universities to private companies only. The empirical evidence related to case a) above, is that the countries with the most skewed sets of PRC actors are not the best performers on innovation output (Portugal, Cyprus, Greece, Luxembourg, Malta, France, Belgium, Spain and Italy). In the second case, skewed sets of HE institutions (Italy, Croatia, Slovenia, Serbia, Belgium, Israel, Portugal, Denmark and Norway) or skewed sets of REC actors (Iceland, France, Greece, Finland, Germany, Czech Republic, Switzerland, Turkey, Italy and Slovenia) are also only weakly associated with good citation scores.

[4] Greece, Cyprus, Malta and Iceland have not been chosen as reference values and are given the score 1.00 equal to the second-highest performing country.

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By contrast, three out of four countries (Iceland is the exception) with the highest citation indicators (Switzerland, Denmark and the Netherlands) combine the following elements: very high overall R&D Gini coefficient values, strong scores on Intellectual assets and no particular dominance of any sector. Switzerland stand out as the most consistently skewed R&D nation, with very high R&D Gini coefficients observed across all three sectors. Countries where the HE sector accounts for more than 50 per cent of the contribution to EU FP proposals, even when citation scores are high (such as Sweden and the UK), fail to perform equally well at the Intellectual asset indicator. In fact, among the 13 European countries with a citation score 20 per cent above the European average, there are only five countries where the HE sector accounts for more than 50 per cent. Some of these countries (e.g. UK, Estonia and Ireland) are characterized by relatively weak EIS scores, while Finland and Sweden have been able to combine a strong HE sector with a strong innovation ability. At the other end of the spectrum, we find countries that combine low citation and innovation scores with low R&D Gini coefficients, and in most cases R&D systems dominated by the HE sector. As such, our results are more useful when describing the R&D systems of the most – and of the least successful R&D systems, than on scaling all countries. We believe our study actualise future studies that investigate how locomotives from all three sectors may be catalysts for R&D processes both leading to strong research and innovation output and which mechanisms of skewed R&D systems that are beneficial compared to more egalitarian systems.

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