Cooperation patterns in science within Europe: the standpoint of small countries

Kadri Ukrainski · Jaan Masso · Hanna Kanep

Abstract This article is concerned with the cooperation patterns of science among European countries from the viewpoint of small countries. This is an issue, which empirical literature so far has overlooked, but which is still relevant for understanding the implications of integration processes in EU. We have replicated and expanded in sample, indicator and time dimensions the empirical analysis suggested by Frenken (Economic Systems Research 14(4):345–361, 2002) for assessing the homogeneity of cooperation patterns among European countries. We find that small states are less homogenously collaborating with all countries in the European research system and their intra-national research cooperation is also more fragmented. Our analysis reveals the outcomes of cooperation processes, and also highlights the factors such as research funding and research specialisation that can impact the results of the connectivity measurement. We also show that the results are sensitive to the size and measurement of the science system.

Keywords Research collaboration · Mutual information · European integration · Small countries

JEL Classification C43 · D80 · O38

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Introduction

The integration of science systems in Europe has been discussed under the notions of European Research Area (ERA) and *Innovation Union* with concerns for enhancing innovation, competitiveness and integration in the EU. This policy drive can possibly incorporate very different interpretations as integration of science systems can have several meanings (e.g. Luukkonen et al. 1992; Frenken 2002; Frenken and Leydesdorff 2004; Luukkonen and Nedeva 2010). It seems to be an agreement that the policy is aimed at social rather than cognitive integration in science involving shared structural and organisational developments as well as shared work processes (Luukkonen and Nedeva 2010).

Empirical evidence has been provided that European science system has become more integrated (Frenken 2002), but the integration of regions within EU 15 countries has progressed more slowly than the connectivity among non-EU OECD countries (Chessa et al. 2013). However, it has been also argued that the integration processes have incorporated evermore peripheral regions if judged by the collaborations in EU Framework Programs (Scherngell and Lata 2013).

The question of empirical assessment of the integration processes in science in Europe has not received much attention, with the exception of Luukkonen et al. (1992), Frenken (2002) and Frenken and Leydesdorff (2004), who all propose different measures for assessing the collaboration patterns in science at EU level, but also the connectivity of individual countries within the EU. These measures compare the observed matrix of co-authored articles with an expected one, in which the co-publications are uniformly distributed across countries considering the size of individual countries and their tendencies to cooperate internationally. Frenken and Leydesdorff (2004) choose an approach oriented to *distribution* of the collaboration activities in research rather than collaboration *frequencies* (considered by Luukkonen et al. 1992) for building indicators for describing research networks between the countries.

Tijssen (2008) notes that the interconnectivity within the European science system can especially be attributed to the group of small member states, but the results of Frenken (2002) point to the disadvantages for smaller countries to collaborate very widely across countries in Europe. Naturally, the question arises: what does this idea of integration imply for small countries? What could be alternative strategies of internationalisation of research for small countries? This paper aims to elaborate the role of small countries in the integration of European research activities by empirically analysing the co-publication patterns. For that purpose, by using the data on scientific co-publications from the ISI database for 3 years (2000, 2005, 2009) we calculate various indicators of research collaboration based on the approach of Frenken (2002), and Frenken and Leydesdorff (2004). We highlight the main shortcomings in the methodology, especially concerning the policy implications for small countries.

"Smallness" is a definition often used context-specifically (Geser 2001). Therefore, also in the science policy literature, micro-states along with relatively larger countries are referred to as small. In this article, we refer to the following small countries in Europe: Cyprus, Estonia, Latvia, Luxembourg, Malta and Slovenia, ranging roughly between 0.4 and 2.3 million inhabitants. Although these are very small countries there are large differences in the sizes of science systems, levels of R&D expenditures, etc. (see also appendix Table 3). Still, from the perspective of our article, the potential for international cooperation in terms of the size of research systems is rather small in these countries.

The article is organised as follows: The next section discusses the factors relevant for research collaboration in small countries. Thereafter, the methodology is presented for

evaluating collaboration patterns of research systems in Europe. In fourth section, the data sources are described and the fifth section presents the results which are then critically discussed in the sixth section. The final section concludes.

Factors determining the research collaboration of small countries

Research collaboration is a means for creating and exchanging the research ideas, methodologies and results among academics, but also scientists working for industry and government. Luukkonen et al. (1992) review the literature showing that the collaborative academic linkages have increased ever since the end of the nineteenth century. More recent growth of internationalisation of research and development (R&D) activities of business enterprises has also been documented, although these globalise more slowly compared to other business activities such as FDI or trade (Carlsson 2006). This literature highlights the main reasons and benefits arising from collaborative research: exchange of both intellectual and material resources, but also increased productivity and visibility. Luukkonen et al. (1992) explain that different economic, cognitive and social factors shape the motives for research collaboration, and these vary by scientific fields and countries.

Authors and organisations researching scientific collaborations have noted that smaller countries tend to have higher levels of international collaboration (examples are earlier studies of Luukkonen et al. 1992; Narin and Whitlow 1990, and more recent reviews in Knowledge, Networks and Nations 2011; European Commission 2011). Still, most of the scientific research concerning research collaborations is concerned with larger countries, but also with regions (as also reviewed by Frenken et al. 2009). Some aspects of regional studies can be incorporated into the discussion of small countries, but small countries very often also comprise a separate linguistic area, which can be expected to add to the fragmentation of research networks with other countries (Hoekman et al. 2010). More importantly, research policy and funding decisions are made mainly at the national level making the regional studies inappropriate to use. There are studies which aim to highlight the specific aspects of small countries concerning research collaboration (Thorsteinsdóttir 2000a, b; Meyer 2009; Masso and Ukrainski 2009a). However, the discussion lacks clarity in several aspects, starting with the definition of smallness in the context of science systems. More specifically, the question of science policy in small countries and the role of such countries in European research integration are not addressed.

By empirically studying different samples of countries, the size of the science systems seems not to have an overly large impact on variation of collaboration intensity across countries and it seems that there is no relationship between the size and collaboration pattern. However, for very small countries there seems to be an increased propensity to external collaboration (as also found in the case of Iceland by Melin 1999).

Smallness of a country is viewed as a constraint for building up domestic human and financial resources for science and expertise in different fields, even for a critical mass of domestic R&D (Berghäll et al. 2002). It is argued that small countries can compensate such disadvantages in resources through international cooperation (Thorsteinsdóttir 2000b). There are several reasons why collaboration in science is seen as desirable, of which some are considered particularly beneficial or even vital for research in small countries. A high collaboration level with larger countries allows for the utilisation of scale advantages (specialisation and funding) of large states (Frenken and Leydesdorff 2004), which can be especially important for research demanding a larger or more expensive research infrastructure. Seeking expertise through international networks may be necessary for scientists

in small countries to avoid insulation in increasingly specialised fields of science (Lu-ukkonen et al. 1992). International collaboration could be a prerequisite for scientists from small countries for being able to publish in recognised journals (*Ibid.*).

Based on the case of Luxembourg, it has been shown that in small countries research activities are thematically, spatially and institutionally dispersed and domestic collaboration is often hindered because of large diversity which conflicts with the coupling of competence (Meyer 2009). Therefore, scientists in small countries may find it easier to seek complementary competence from abroad. On the other hand, it is also found that some aspects of smallness are favourable for intra-national collaboration because of the more transparent and flexible institutional system of research, greater density and frequency of relationships (know-who), more personal relationships, etc. (Cogan and McDevitt 2003; Meyer 2009). An additional reason for higher international collaboration can also stem from the experience of education abroad and associated connections researchers in small countries often have (Franklin 1988).

Small countries are facing a dilemma in science policy: if they focus on high-level research (involving higher international cooperation) they may risk having limited local relevance and if they focus too narrowly on the local issues, they will risk isolation internationally (Thorsteinsdóttir 2000b). Similarly, extending the list of scientific fields supported by public funding may result in a limited capacity to seek excellence in any of those fields. Inter-country and international cooperation patterns are influenced by the choices in science policy, which can be quite diverse in small countries. Some researchers find a lack of thematically targeted or goal-oriented science policy in small countries, often also a top-down process without specific mechanisms for new emerging areas (Thors-teinsdóttir 2000b), but in other countries, a bottom-up approach is rather seen with stronger foresight present (Meyer 2009). It has also been argued that in smaller countries the influence of researchers on scientific policy is greater and the policy networks of small scale could be characterised by short lines of communication and informality (Bruyninckx 2005). The aspirations of researchers to engage in international cooperation may thus be better met at the national policy level.

Thorsteinsdóttir (2000a) finds that the collaboration can be initiated by the scientists of larger countries recognising the availability of specific research material rather than scientists of smaller countries seeking additional resources, which can also contribute to the somewhat occasional pattern of international cooperation of small countries. Small countries are generally very sensitive to outside developments and therefore the cooperation patterns may vary over time. Estonian indicators show, for example, that the country portfolio in cooperation patterns has altered during the period 2000–2009 with growing collaboration frequencies with Southern Europe next to the traditional Nordic and German partners (Raud et al. 2011). Leydesdorff and Wagner (2008, p. 323) suggest that during the 1990s (after the changes of political systems in Europe), the actors in scientifically advanced core countries of collaboration networks are the ones that have "*made careful choices to limit their partners to specific countries*".

EU-wide initiatives have encouraged more integrated research activities in Europe. Financial incentives have been a significant motivation for researchers from small and large countries in participating in EU-funded research collaborations [evidence for Finland is presented in Hakala et al. (2002) and for France and the UK in Pohoryles (2002)]. Other motives include gaining experience, increasing the international visibility, training and career advancement, but also opportunities to disseminate research results (Hakala et al. 2002). Scherngell and Barber (2009) show by analysing EU FP5 data that the geographical distance effect is weaker than technological distance in explaining the existence of public

research networks. It is argued that collaboration within European funding frameworks has led to more durable links between collaboration partners (Pohoryles 2002; Barber et al. 2006). Okubo and Zitt (2004) argue that regardless of the FPs, network patterns have remained quite fixed and are built on previous cooperation, and the EU policies have done little to change the collaboration ties especially for the large European countries such as Germany, France and UK, whereby co-authorship of articles still remains primarily limited to national collaboration rather than international. It has been concluded that Europeani-sation has been more common amongst smaller European countries (Okubo and Zitt 2004; Tijssen 2008).

Empirically, higher collaboration frequencies have been generally found in the case of small countries (see, for example, the review in Thorsteinsdóttir 2000a). Melin (1999), based on a sample of universities in the US and Northern Europe, concluded that except for the very extreme cases in terms of scientific size (with Iceland at one end and United States at the other) there is hardly any indication of decreasing international collaboration with increasing size of the country. Thus, the presence and magnitude of the effect of the size of the country is not so straightforward and calls for further elaboration.

Methodology for measuring the integration of research in Europe

Scientific cooperation is often measured via two indicators—scientific co-publications in different countries and participation in collaborative science projects in European FPs. In this article, we analyse the state of co-publication patterns in 3 years (2000, 2005 and 2009), which may not reflect long-term processes very well, but for countries such as Estonia and Latvia, earlier data may be not adequate to use. In addition, we also use FP6 participation indicators which enable us to test our proposed methodology on different data for revealing any differences from the co-publication networks.

It has to be noted first, that such indicators have several limitations. Katz and Martin (1997, p. 7), in defining research collaboration find that it comprises a set of researchers who:

(a) Work together on a research project in its full duration or a large part of it, or who make frequent or substantial contribution;
(b) Those whose names or posts appear in the original research proposal;
(c) Those responsible for one or more of the main elements of the research.

In some cases also:

(d) Those responsible for a key step (e.g. original idea, hypothesis, theoretical interpretation) and
(e) The original project proposer and/or fund raiser even if the person contributes subsequently to project management only.

Co-authorship indicators that are frequently used to reflect research collaboration do not conceptually overlap with the collaboration as stated above (Katz and Martin 1997). They differ by leaving out the importance of place of cooperation connected with the transfer of tacit knowledge, but also the broader context of socially constructed science. In addition, although international co-authorship is very frequent,[1] it does not mean that this reflects

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[1] Based on the Elsevier Scopus database, it is estimated that less than 26 % of papers are the product of one institution alone, and over a third have multiple nationalities sharing authorship (Knowledge, Networks and Nations 2011).

intensity of collaboration between the actors (Luukkonen et al. 1992). Apart from this, some research collaborations (especially applied research, or industry-related research) aim at other outputs than co-authored articles (e.g. new techniques, products, patents, etc.). Therefore, the co-authorship indicators may underestimate the research collaboration phenomenon.

In the EU, research cooperation is encouraged by specific programmes (including FPs) that create research networks which may be quite different from spontaneous ones. These are often spread more widely geographically, bring together researchers from different institutional backgrounds and may go beyond traditional academic links (Gusmão 2001). We measure collaboration in FPs by the shares of researchers in different countries participating in joint projects. The indicator of funding shares in joint cooperation projects would be also available in databases. This would better reflect the relative contribution of different collaboration partners; however it may systematically underestimate the contribution of researchers from new member states as the cost/wage level is substantially lower, but also varying across countries. As the EU FPs are concentrated on a few technological areas this forms a factor limiting the basis for cooperation activities. Despite the abovementioned limitations the FP participation measures directly address the EU-wide collaborations, which probably include relatively more cooperation with industry partners compared to the publication analysis.

For our research purposes we adapt the methodology proposed by Frenken (2002) and thereafter Frenken and Leydesdorff (2004) for measuring the integration of science between countries through scientific collaboration.[2] This methodology uses the matrix distribution of relative frequencies of interactions among countries and takes into account both intra-national and international collaboration (Frenken and Leydesdorff 2004). The degree of international collaboration is evaluated by the use of Theil's mutual information measure (Theil 1967), initially developed for measuring the information contained in the input–output tables of economic industries (i.e. whether sales from one industry to another are on the average larger or smaller compared to the random distribution of sales).

The measure was initially applied for measuring the scientific collaboration by Frenken (2002), as follows.[3] Suppose we analyse the collaboration in a sample consisting of N countries (e.g. in this article $N = 28$) and q_{ij} denoting the share of collaborations between country i and j in the total number of collaborations (e.g. joint publications, joint research projects) between any countries i and j; thus $0 \leq q_{ij} \leq 1$ and $\sum_i \sum_j q_{ij} = 1$. Thus, national collaborations are the ones with $i = j$ and international ones are the ones with $i \neq j$; due to symmetry $q_{ij} = q_{ji}$. The share of any country i in the total number of collaborations is:

$$q_i = \sum_{j=1}^{N} q_{ij} \left(\text{and also } q_j = \sum_{i=1}^{N} q_{ij} \right). \tag{1}$$

The key variable in the calculations T_{ij} measures the bias in the observed collaboration relative to the random collaboration corresponding to the product of the shares of countries q_i and q_j:

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[2] We here leave out the detailed description of methodology proposed by Luukkonen et al. (1992) as their aim was to assess the patterns of cooperation activities in individual countries rather than integration within the EU research system.

[3] The notation we use hereby differs somewhat from the one used in Frenken (2002) and is more close to standard mathematical notation.

$$T_{ij} = \ln \frac{q_{ij}}{q_i \times q_j}. \tag{2}$$

The measure is positive (negative) when the collaboration in the country pair is more (less) frequent than expected from the product of the country shares $q_i \times q_j$. The degree of integration in the network of N countries is measured by the sum of T_{ij} weighted by the individual country shares q_{ij}:

$$T = \sum_i \sum_j q_{ij} T_{ij} = \sum_i \sum_j q_{ij} \ln \frac{q_{ij}}{q_i \times q_j}. \tag{3}$$

The measure T has been shown to hold non-negative values. The boundary case $T = 0$ corresponds to the case when there is no bias in the collaboration and the intensity of collaboration is the same everywhere, i.e. $q_{ij} = q_i \times q_j$; that corresponds to perfect integration in research (Frenken 2002). Here it can be seen why that is the measure of information because in the case $T = 0$, the collaboration matrix contains no information since the individual collaboration pairs can be derived from the product of the country shares q_i and q_j.

By analysing subsets of the matrix of T_{ij} one can calculate additional indicators. For instance, following Frenken (2002), one can calculate the variables measuring the intra-national collaboration ($T_{i=j}$, over values for which $i = j$) and international collaboration ($T_{i \neq j}$, over values for which $i \neq j$):

$$T_{i=j} = \frac{1}{\sum_{i=1} \sum_{j=1} q_{ij}} \left(\sum_{i=1} \sum_{j=1} q_{ij} \ln \frac{q_{ij}}{q_i \times q_j} \right) (i = j) \tag{4}$$

$$T_{i \neq j} = \frac{1}{\sum_{i=1} \sum_{j=1} q_{ij}} \left(\sum_{i=1} \sum_{j=1} q_{ij} \ln \frac{q_{ij}}{q_i \times q_j} \right) (i \neq j) \tag{5}$$

Finally, measures for the integration of individual countries could be calculated by summing over the respective rows in the matrixes:

$$T_i^{\text{ALL}} = \frac{1}{q_i} \sum_{j=1}^{N} q_{ij} \ln \frac{q_{ij}}{q_i \times q_j}, \tag{6}$$

i.e. we would attain the measure for each of the N countries. Measure for the intra-national collaboration of country i derives then as follows:

$$T_i^{\text{INTRA}} = \ln \frac{q_{ii}}{q_i \times q_i} \tag{7}$$

The methodology described above takes into account the differences in the country sizes by accounting for both international and intra-national collaboration. Frenken and Leydesdorff (2004, p. 12) note that …"*the measure adjusts for the size of the countries, i.e. the higher probability of scientists in larger countries to interact with the fellow national citizens compared to scientists in smaller countries*". We find that measures (4), (5), (6) and (7) should be elaborated further for better alignment to the purpose of analysing the integration from the perspective of countries with very different size. The argument could be that as collaboration requires co-authors from both of the participating countries the limiting factor is the size of the smaller country in the respective country pair and the homogenous distribution of collaborations may be neither achievable nor desirable.

Data

The data involves counts of different institutional addresses for publications contained in the Web of Science (WoS), which does not correspond to co-authorship, but rather inter-institutional analysis (see also Katz and Martin 1997). More precisely, we use the publications' data from the ISI databases, these are the Science Citation Index (SCI), Social Science Citation Index (SSCI) and Arts & Humanities Citation Index (A&HCI) (many other studies, e.g. Frenken et al. (2009) have used only the SCI data). For the analysis, we downloaded the full bibliographic records of the publications from the WoS. For comparison, earlier studies (Frenken et al. 2009) have used the CD-ROM version of the database; Costas and Iribarren-Maestro (2007) have undertaken a comparative analysis of the CD-ROM and WoS versions of the ISI databases. The data for this study was downloaded in August 2011. The total number of records was 423,093 in 2009, 360,904 in 2005, and 317,135 in 2000. Thus, our contribution to the literature is, in addition to the small country view, also the replication of the results for a later time period as well as a wider EU-sample.

We included all publications with authors from any of the 28 European countries,[4] but in order to concentrate on the scientific collaboration within the EU and to reduce the number of records, we excluded the publications with authors from major countries of collaboration outside of Europe (i.e. USA and Russia). Among the different kinds of publications we included only articles, and thus excluded abstracts, books, etc. In the WoS version of the ISI data, the authors' address is divided between two fields, the "Author Address" and "Reprint Address". Costas and Iribarren-Maestro (2007) list a number of differences in the authors' institutional address information in the two databases. While Frenken et al. (2009) used three listings of the addresses (to reduce computational burden and to account for the differences in the extent of collaboration across different fields), we used the seven different listings of the addresses, i.e. only the first seven addresses (countries) of the authors of the particular article.

To identify collaborations, we looked at all pairs of the addresses, which is thus equal to $C = N!/(N - 2)!2!)$, where N is the number of addresses in the publication record and $N!$ is the factorial of the number N, i.e. records with three addresses give a maximum three collaborations and records with four addresses give a maximum of six collaborations (the number of combinations from the set of four elements by two elements). It should be noted here that often this analysis corresponds to inter-institutional analysis and not to co-authorship by leaving out the joint papers of the members of the same institution (Katz and Martin 1997). In our case we have included all of the co-publication articles even if both authors belong to the same institution (while having different postal addresses): the reason is that typically nationally oriented co-publications (especially in a national language other than English) are under-represented, because in WoS only a small minority of nationally oriented journals is included (Zitt and Bassecoulard 2004).

For the analysis of collaboration patterns across scientific fields, we have aggregated the publications to more broad categories according to the hierarchy of the Frascati manual,

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[4] The sample includes the following countries: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom. As in other studies, the UK contains records with addresses from England, Wales, Scotland and Northern Ireland.

i.e. to the following fields: Humanities, Social Sciences, Agricultural Sciences, Medical Sciences, Natural Sciences, Engineering and Technology.

As mentioned in the introduction, besides co-publication analysis we have also studied FP6 participation data (European Commission 2008), which encompass participating researchers in successful proposals for analysing the cooperation patterns in Europe.

Results

By analysing the co-authorship data, we have replicated (and expanded in sample and time dimensions) the analysis conducted by Frenken (2002) presented in Table 1. Frenken (2002) identified growing integration of research for the period 1993-2000 implying that the collaboration patterns have become more uniformly distributed among EU countries. Our results are not directly comparable, because our sample involves significantly more countries. However, we find that overall collaboration distribution (which includes both intra-national and inter-national collaborations) has become less uniform from 2000 to 2009. We should note that in Frenken (2002) the T value in 2000 was 1.461, although in our data for 2009 it is 1.173 and in 2000 1.086. The difference has to do with broadening the sample by 12 countries and as expected, the accession of new countries to the EU shows weaker connectivity considering this larger community. As Frenken notes, the process of integration in Europe was slow even in case of 15 "core countries", but it should not be compared with the uniform distribution of cooperation ($T = 0$), but "*from an (unknown) reference level of bias that would occur when institutional and language barriers between countries were to be fully removed*" (2002, p. 352). A more recent analysis by Chessa et al. (2013) has shown that within EU-15, the interregional collaboration links in co-publications have grown since 2003 more slowly compared to similar connections among non-EU OECD members.

The value of our intra-national collaboration indicator (average of 2.14) is however rather similar to the one in Frenken (2002) (the average of 2.04). This means that in Frenken's analysis countries tend to do 7.7 times ($e^{2.04} = 7.7$) more internal cooperation (compared to 8.5 times in our case) as in the case of no national bias. The dynamics of this indicator are similar to the overall (total) T-index. The only indicator reflecting slightly increased connectivity concerned international co-publications, but the change has been so marginal that we can conclude that this has been stable.

Figure 1 also shows, that all countries have a positive bias to collaborate nationally (indicator $T_{i=j}$).[5] Similarly to Frenken (2002), small countries tend to have a larger (exception is perhaps Luxembourg) and large countries a smaller bias to cooperate nationally, and in the case of international cooperation there is also bias to cooperate with the neighbouring countries. Concerning intra-national cooperation only, small countries show larger mean T values in all observation years, clearly showing that national cooperation is less homogenous. These results are also very clearly related to the methodology we use here. As the institutional addresses are considered by identifying collaborations, the institutional set-up (reflected by the few different addresses of authors in our data) of a small country becomes a relevant limiting factor in reflecting the number of co-publications. For example, in Estonia research is performed mainly in six universities, however, in terms of scientific publications, three public universities (University of Tartu, Tallinn

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[5] By looking at the matrix of country patterns, the only exception is Germany which has a slightly higher tendency to cooperate with Austria as compared to national cooperation (but the difference is small).

Table 1 T values for different types of co-publications in 2000, 2005 and 2009

Source Authors' calculations following the methodology in Frenken (2002)

Year	Total	Intra-national	Inter-national
2000	1.086	2.069	−0.834
2005	1.125	2.154	−0.829
2009	1.173	2.223	−0.827

University of Technology, Estonian University of Life Sciences) are clearly the most active ones and account for most of the research output, but also receive most public funding (Masso and Ukrainski 2009a, b). In Latvia, in addition to the six public universities, 12 public research institutes (that have not been incorporated into the university system as in Estonia) and two private research institutes perform R&D activities as well (Raud et al. 2011). In Luxembourg, the main public sector research performers are the University of Luxembourg, the three public research centres and CEPS/INSTEAD, however the difference from the other small states in the sample is the high relevance of private R&D activities conducted in a few large firms (ERAWATCH 2010a), which may not translate into scientific publications. Private R&D activities are important also in the case of Slovenia. In terms of public funding, however, institutions belonging to the latter group, including the Slovenian Academy of Sciences and Arts and 15 public research institutions attract almost half of the total funds available and together with four universities close to 80 % (ERAWATCH 2010b). Public R&D activities in Malta are very much concentrated in the University of Malta (over 90 % of all the activities performed in all 13 public sector institutions as well as the vast majority of funding available) (NSO 2011). In Cyprus R&D is mainly carried out by five higher education institutes and five public research organisations (ERAWATCH 2010b).

In international collaboration, smaller countries show not so considerable biases compared to large countries as in case of intra-country collaboration. It has to be noted, that Luxembourg has the third smallest T value for international co-publication after UK and Germany, showing very homogenously distributed connections in Europe. Also, Malta's T value is comparable to that of Denmark. However, other small countries (Slovenia, Cyprus, Latvia and Estonia) have higher T values of international collaboration showing less homogenous connectivity pattern.

T-values of FP6 participation (scale on the right axis in Fig. 1) show broadly similar results to co-authorship, but the connectivity is more homogenous in Europe compared to co-authorships. Earlier reviews have found that per researcher, FP6 and FP7 participation is relatively higher in small countries. This evidence is found, for example, in Malta and Cyprus, but also in Estonia and Slovenia (European Commission 2011). Our data show that smaller countries have significantly higher T values, so indicating the lower homogeneity of connections in FP6. However, here our results also confirm the earlier findings showing that the small country group itself is not homogenous. These small countries differ remarkably by the amount of national public funding available, the degree of internationalisation of the research system and the success rate of the proposals of the country's research institutions (European Commission, 2011, p. 261).

Frenken (2002) also noted that in the EU15, the smaller countries (Greece, Ireland, Portugal, and Finland) had a lower degree of integration compared to the large countries (UK, Germany, and France). Figure 2 indeed shows that countries with a smaller overall scientific output (denoted as q_i in the previous calculations) are less homogenously integrated (with higher T_i values) while countries with higher shares in overall scientific output are more uniformly connected, i.e. collaborate more widely within Europe. Compared to
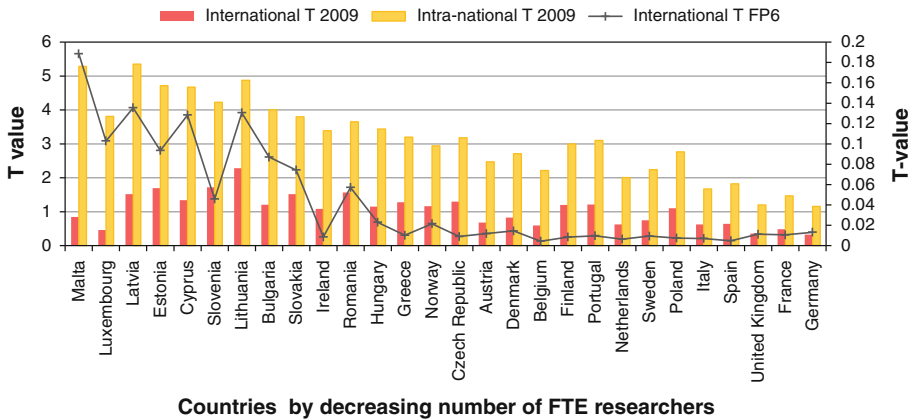
Fig. 1 *T* values of international and intra-national co-authorships (*left axis*), FP6 participation (*right axis*) ordered by increasing country size among 28 European countries (Source: Authors' calculations)

the overall trend, given its size Poland seems relatively less integrated, while France, Germany and the UK are relatively more integrated if one reflects the state of the collaboration processes in 2009. The explanation was that large countries could benefit from the higher degree of diversification and specialisation of scientific research that makes the researchers of larger countries more attractive as cooperation partners (Frenken 2002).

Although the *T*-index is decreasing with the growing size of the science system, this relationship is not that clear in case of very small countries, which show quite different *T* values. Figure 2 shows that Luxembourg, Malta and Cyprus have more homogenous connectivity compared to Slovenia, Estonia and Latvia. We have also tested here the sensitivity of the *T*-index values to artificially merging some countries. For example, by merging UK and Germany, with their initial overall *T*-index values of 0.716 and 0.692, respectively, the index of the new artificial country becomes 0.404, implying that the connectivity of this country within Europe improves significantly. This merger would impact the overall index value as well by raising the *T*-value from initial 1.173 to 1.201. By merging some smaller countries, for example Latvia and Estonia with the initial *T* values of 2.368 and 2.863, we yield *T*-value of 2.515, which lies in the middle of the two earlier values, and the European level T-value grows from initial 1.173 to 1.180. Both cases show, that although the connectivity of the artificial territories improves, the overall distribution of connections in Europe becomes less uniform as the number of countries is reduced. In fact, this could also have impacted our different results from Frenken (2002) for 2000.

Here, we followed the methodology used by Frenken (2002) by assessing the size of the country by its share in total collaboration. If we further assume that some countries for whatever reasons are generally relatively more or less collaborative (as, for example, the studies of culture suggest, cf. Hofstede 2001), we could use the share in total number of researchers (or researchers in FTE) instead. Figure 3 shows that the share in co-publications can differ from the share of researchers quite significantly for several countries.

Tijssen (2008) noted that although small countries have significantly expanded their international collaborations beyond EU borders, the interconnectivity within the European science system can especially be attributed to the group of small member states in 2001–2005. By looking at the dynamics of co-publication shares from total co-publications in Europe over a decade, this trend continues as smaller countries have been constantly
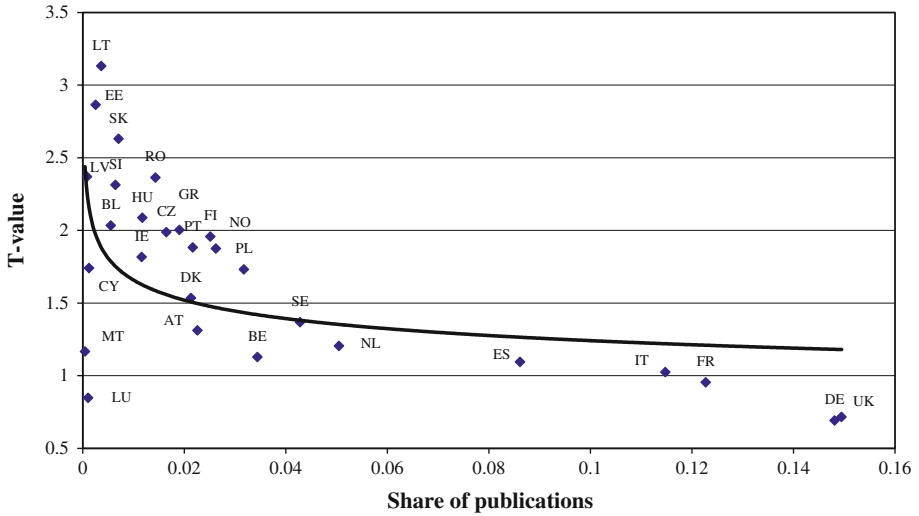
Fig. 2 *T* values on the *vertical axis* and log trend lines of international and intra-national (total) co-authorships ordered by a country's share in total number of co-authorships among 28 European countries on *horizontal axis* (Source: Authors' calculations)
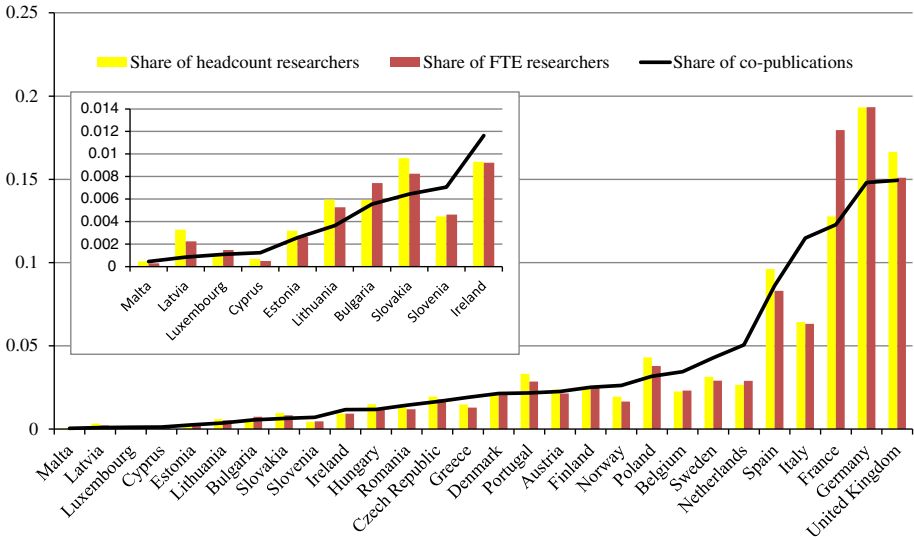

Fig. 3 Dynamics of the shares of co-publications and share of researchers on the *vertical axis* (Source: Authors' calculations)

expanding their shares in total number of co-publications while the largest ones have contracted in collaborations. However, the collaboration patterns of small countries are very erratic, which is also reflected in *T* values (Fig. 4). We can see that Luxembourg and Malta have become more uniformly connected to the other countries in Europe whereas Estonia and Latvia show the contrary trend.
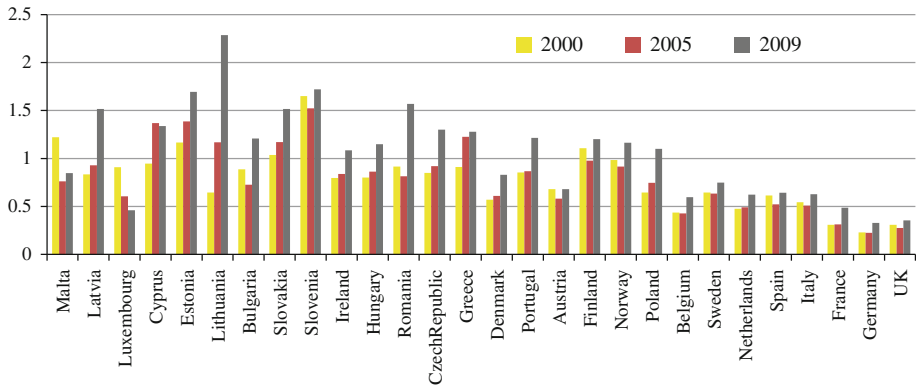
Fig. 4 Dynamics of the *T* values by year, countries are ordered by the growing share of co-publications (Source: Authors' calculations)

Discussion

In the previous analysis the central concern was the size of the country or research system, but in this section we would like to pay attention to the additional factors that are not directly observable and measurable by this methodology, but address some relevant interwoven factors. The impact of a particular country's science policy on collaboration is extremely relevant. It is difficult to identify the policy measures that affect collaboration activities the most, because several project-based research funding measures can enhance scientific cooperation in teams and in most European countries many such policy instruments are in place. However, lower availability of public funding may be offset by specific grants encouraging scientists to engage in FP applications. For example, in the small country group Cyprus has refunded some costs related to successful acquisition of EU funding such as proposal writing and travelling (ERAWATCH 2010c), Luxembourg has supported the preparation of FP projects, although the instrument closed in 2011 (ERA-WATCH 2010a), and Slovenia offered small-scale awards to FP applicants (ERAWATCH 2010c). In this variety of mechanisms creating incentives for cooperation, the policy dimension in driving collaborations could be studied further. One aspect that is not considered in our analysis, but would also be relevant, is the variation of the size of research systems—in some small countries the research system is relatively larger if investments into the system are considered (Luxembourg and Slovenia), but in some larger countries the research system can also be smaller (Romania). The same goes for number of researchers. Cole and Phelan (1999) have discussed that a larger science system does not mean more productivity in scientific output (papers), rather they find some evidence of rapidly diminishing returns to increasing the number of researchers in a country (this hypothesis was first posed by De Solla Price(1963)).

One very important aspect related to collaboration in small countries concerns the specialisation in research. Table 2 indicates that there are rather large differences even across the broadly defined scientific fields in the integration. The intra-national bias in Table 2 is perhaps surprisingly lowest in the social sciences and humanities, and highest in the medical sciences. Similarly, in international collaboration the integration is highest in humanities, followed by social sciences and natural sciences. Our results may at first seem

Table 2 *T* values by broad scientific fields

Field of science	Total	Intra-national	Inter-national
Social sciences	0.558	1.596	−0.180
Natural sciences	0.586	1.878	−0.282
Humanities	0.475	1.589	−0.113
Medical sciences	1.079	2.152	−0.553
Agricultural sciences	0.833	2.085	−0.257
Engineering and technology	0.795	2.110	−0.296

Source Authors' calculation

contradictory to Kyvik and Larsen (1997), who explained how so-called "hard fields" are more international because of their highly codified language, specialised audiences and focus on topic with universal relevance, but "soft fields" have fewer incentives for internationalisation, diverging more by countries. However, it should be stressed that we measure the distribution of cooperative activities, not the frequencies and our results reveal that hard fields have more concentrated cooperation activities whereas soft ones are more uniformly spread. Small countries here may also show different cooperation patterns if one counts for their varying scientific specialisation.

Leydesdorff (1992) discussed that the number of collaborations or collaboration frequency is not a good measure of integration, because it does not show the spatial pattern of collaboration. In the case of small countries, the pattern of collaboration cannot be very homogenously distributed across Europe because of the limited competence fields. Thorsteinsdóttir (2000a) proposed that the scientific collaboration in small countries can be initiated by the scientists of larger countries rather than domestic ones seeking additional resources, which is also the reason for the non-homogenous pattern of international cooperation in smaller states (Fig. 5). One additional factor that seems to play quite a significant part in the case of small countries (although it needs more analysis) is EU FP funding. For that purpose, we looked at the acknowledgment of EU FP6 funding source in our publications' data. The significance varies and is dependent on the citation culture in different countries, but based on our calculations, for example in the case of Malta, 60 % of co-publications have the acknowledgement of EU FP. In other small countries this share is significantly lower, varying between 20 and 30 %.

It is important to note a specific limitation of such methodology arising for the small countries with respect to the science policy. In order to achieve greater integration in science or more uniform distribution of collaborations in the EU, some co-publications would need to shift from one country to another simultaneously, implying for small countries which already have a high share of internationally co-authored papers (for example, Malta and Luxembourg) that they would need to limit either the number of intra-country or international collaborations, while at the same time widen the scope of collaboration partners (because the share of collaborations is very high already).

Another issue with which all integration indicators discussed in this article fail to deal is the selection of collaboration partners. The aim of EU integration processes could be to foster the collaborations of small countries with scientific frontier research institutions (countries) in those few fields they are specialised in. This collaboration pattern target may be very different considering the research specialisation of small countries by scientific fields, but would allow for better use of the limited resources in small countries as well as
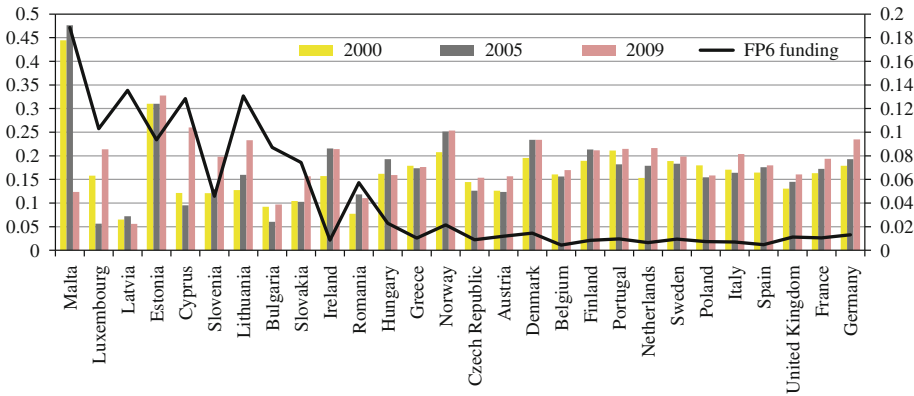
Fig. 5 Shares of international co-publications in a country's total co-publications and share of publications with acknowledgement of EU funding in total number of co-publications (Source: Authors' calculations)
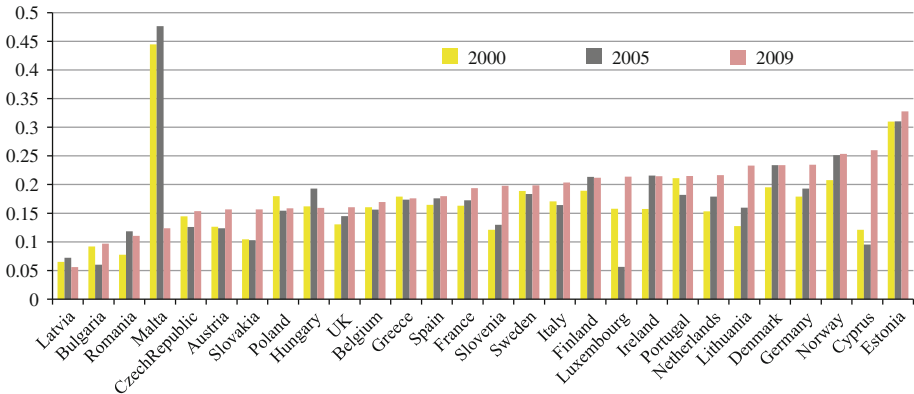

Fig. 6 Shares of co-publications with top 100 European institutions (according to the Times Higher Education Ranking) in total number of international co-publications of a country (Source: Authors' calculations)

the transfer of frontier-knowledge to these countries. Here, we used for elaboration the example of cooperation with top universities in Europe (in our case top 100 institutions from the Times Higher Education ranking) and as illustrated by Fig. 6, this pattern is generally quite stable across time, except for the small country group. Greater stability is visible at the level of 30 % of all co-publications with top European universities in Estonia and around 6 % in Latvia, while steady growth characterised Slovenia and Lithuania.

In addition, several different aspects of collaborations for addressing specific social, economic or cultural issues in these countries may require tighter regional cooperation (generally studied a lot, but not so much with a focus on small countries), but also among small countries themselves. The geographical aspect is very important as small countries in our sample are typically located at the periphery of the EU and have different national languages which could shape further their cooperation patterns, as also discussed by Frenken et al. (2009).

Conclusions

We have aimed in this article to elaborate research collaboration in Europe from the perspective of small countries. By employing the methodology used in Frenken (2002) and Frenken and Leydesdorff (2004), we found that small states are relatively less homogenously collaborating with countries in the European research system. We found greater fragmentation in the internal as well as external collaboration patterns, however, in first case the differences are much larger showing the advantages of larger countries in finding suitable domestic cooperation partners in research. We have also shown that the homogeneity estimates are sensitive to the size of the country (and possibly also to the methodology how we measure the size or the potential of the countries to collaborate). These measures also vary quite significantly over time in individual countries, especially in smaller ones.

Although the pattern of collaboration revealed several similarities among small countries relating to the greater outward orientation and fragmented patterns of internal co-publications, several other aspects need to be accounted for in future research. Our current analysis did not consider national research funding mechanisms that can play a significant part in supporting and sustaining different collaboration patterns in science. Additionally, integration, as far as it is measurable via co-publications, can be very different by research disciplines and therefore the scientific specialisation of a small country can possibly also determine the way it is integrated into the whole science system in Europe. As the resources of small countries are extremely limited they cannot rely on very wide and homogenously distributed activities across EU member states. It would be desirable in the internationalisation processes to focus as much as possible on the frontier (research) collaborations, because the role of scientists in a small country also involves the task of translating the scientific knowledge to the society. Although this calls for further analysis, small countries seem to have different strategies in this respect.

Appendix

Table 3 Indicators characterising the research systems of European countries in 2009 (if this year was missing, the latest available year before 2009 was used)

Country	GBAORD per inhabitant (EUR)	GBAORD (M. EUR)	Headcount of researchers	FTE of researchers
Germany	254.0	20,832.593	437,780	311,500
France	231.9	14,927.589	289,478	289,478
Spain	189.8	8,699.846	217,716	133,803
United Kingdom	179.4	11,049.837	377,210	243,338
Italy	162.9	9,778.400	145,623	101,821
Poland	27.6	1,051.668	97,474	61,105
Turkey	n.a.	n.a	114,436	57,759
Norway	482.0	2,313.321	44,145	26,605
Denmark	399.1	2,199.820	48,442	35,306

Table 3 continued

Country	GBAORD per inhabitant (EUR)	GBAORD (M. EUR)	Headcount of researchers	FTE of researchers
Finland	362.1	1,928.414	55,195	40,849
Switzerland	345.1	2,620.638	45,874	25,142
Netherlands	307.5	5,070.068	60,106	46,657
Sweden	287.6	2,661.751	71,055	46,784
Austria	257.3	2,149.916	53,590	34,501
Belgium	212.9	2,289.370	51,278	37,214
Ireland	208.8	929.020	21,080	14,880
Portugal	146.0	1,551.500	75,073	45,909
Czech Republic	83.1	870.254	404,240	28,759
Croatia	70.4	312.446	11,915	6,931
Greece	60.3	673.200	33,396	20,817
Hungary	42.5	426.559	33,739	20,064
Slovakia	35.2	190.396	21,832	13,290
Lithuania	20.9	69.856	13,518	8,490
Romania	16.8	360.433	30,864	19,271
Bulgaria	15.5	117.822	13,416	11,968
Luxembourg	396.0	195.447	2,470	2,401
Iceland	229.1	73.167	4,134	2,861
Slovenia	136.4	277.150	10,124	7,446
Cyprus	105.4	83.966	1,565	820
Estonia	71.9	96.366	7,226	4,307
Malta	23.9	9.865	1,092	485
Latvia	16.8	37.977	7,447	3,621

Source Eurostat database

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