

Quantifying progress towards the European Research Area: Alternative indicators of European integration in the field of research

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Abstract

The systematic measurement of knowledge flows over time is crucial to charting progress towards the realisation of the European Research Area (ERA). The present paper aims to explore new ways to extract useful information from a number of disparate data sources. Drawing heavily from the current state-of-the-art in European integration indicator methodology and introducing ideas first developed in the field of regional science, we propose five novel indicators of European integration in research. Our calculations from current data (among the first to cover the EU27 and in many cases associated countries) reveal high levels of ERA integration but little or no progress over the last decade or so - a pattern that is in broad agreement with relevant literature. The ensuing discussion is devoted to the identification of each indicator's weaknesses and possible avenues for improvement.

Introduction

A realised European Research Area (ERA) would entail a space where knowledge can freely circulate. Expressed as such, the ERA vision stems from the realisation that national borders act as a natural brake to the circulation of knowledge. The Council of the European Union (2008) has invited member states and the Commission to seek ways to make the free circulation of knowledge a reality, effectively putting in place a so-called "Fifth Freedom" to complement existing freedoms on the movement of goods, capital, services and persons.

The systematic measurement of knowledge flows over time is crucial to charting progress towards that aim. But the complete and accurate measurement of knowledge flows is a daunting task – aggregate statistics capture, at best, only certain dimensions of knowledge and even then one has to content with very imperfect proxies. Cognisant of these limitations, the present paper aims to explore new ways to extract useful information from a number of disparate data sources. Drawing heavily from the current state-of-the-art in European integration indicator methodology, we propose five novel indicators of European integration in research. As with most things 'new', the proposed indicators are currently at various stages of maturity and will need further work before they can become useful policy tools. Therefore, much of the discussion is devoted to the identification of their weaknesses and possible avenues for their improvement. Notice that most studies so far have covered the issue of European integration for EU member states (and normally for EU15 member states) and that lack of data has prevented from incorporating other countries. This is among the first attempts to expand the analysis to the EU27 and, in many cases, other ERA countries i.e. countries associated to the Framework Programme¹.

Following a review of academic and policy-oriented literature, a number of existing indicators have been identified. Such, 'traditional' indicators, are typically the outcomes of studies making use of data on the international co-authorship of scientific papers (i.e. 'co-publications'). We expand and

¹ These countries currently are: CH, IL, NO, IS, LI, TK, ML, RS, AL, ME, BA (from http://ftp.cordis.europa.eu/pub/fp7/docs/third_country_agreements_en.pdf.)

update past work, relating existing indicators to the context of the ERA and introducing appropriate adjustments for the size of each group (ERA, non-ERA). Three such measures are proposed:

- *Intra- versus Extra-ERA co-publications*
- *Intra- versus Extra-EU co-patents*
- *Homogeneity in the international distribution of co-publications*

In addition, literature on regional science highlights the importance of spatial dependence in knowledge production – i.e. the fact that research activities in any given place are often influenced by related activities nearby. Taking advantage of differences in between- and within-country spatial dependence, we have developed two promising indicators of cross-border knowledge spillovers:

- *Aggregate cross-country knowledge spillovers*
- *Border region knowledge spillovers*

The following section elaborates on the rationale for the use of each indicator and the specific methodology for its construction. Section 3 computes the proposed indicators from current data, discusses the observed trends and comments on each indicator's specific strengths and weaknesses. Section 4 summarises the indicators and proposes some avenues for further development.

Rationale and methodology

Research collaboration within and outside Europe

One way of gauging whether knowledge flows increase over time would be to look at the collaboration patterns between researchers based in ERA countries.

In that respect, an opportunity arises from bibliometric and patent data. Modern databases of scientific publications permit the measurement of a nation's total scientific production by counting the number of papers with at least one author based in that country on the basis of the authors' affiliation address. Likewise, patent databases permit national counts on the basis of the inventor's or owner's address. Custom queries of bibliometric and patent databases allow one to count the number of publications or patents with multiple authors, inventors or owners.

In particular, the ratio of intra- to extra-ERA collaborations can be used as an indicator of the propensity of an individual country (or group thereof) to collaborate within the ERA. With slight variations, the same reasoning can be applied to patent databases, to assess the propensity of applied R&D collaborations to take place within the ERA.

Such ratios are by no means new: Trade-based intra- to extra-EU ratios are routinely used as indicators of integration to the common market (e.g. see Chen, 2004 and Hussain and Faes-Cannito, 2008). Such a ratio is useful to assess the Europeanisation of scientific research collaborations. In this section we build upon this work (Mattson et al., 2008).

Intra- versus Extra-ERA co-publications

Data on scientific co-publications count the number of papers authored by individuals based in a pair of countries. One can thus measure the sum of scientific research collaborations (as registered in joint publications²) of any given ERA country with any other country or group of countries. Such measures are now in common use and have been studied extensively in relevant literature (Luukkonen et al. 1992; Luukkonen et al. 1993; Katz and Martin, 1997; Glänzel et al. 1999).

²Of course scientific co-publications are only a rough proxy of the whole range of possible scientific collaboration activities (Katz and Martin, 1997). Despite its weaknesses, it is among the few quantitative data sources that allow systematic comparisons across countries and over time.

Moreover, a number of studies use such data to measure European integration in research (Frenken, 2002; Frenken and Leydesdorff, 2004; Tijssen, 2009).

The extent to which a given country is integrated into the ERA can be gauged by calculating the ratio of the number of co-publications with partners based in ERA countries to the number of co-publications with partners based outside the ERA. So for a country i in time t the indicator would be equal to:

$$\text{ERA Co-publication integration}_{i,t} = \text{ERA Co-publications}_{i,t} / \text{non-ERA co-publications}_{i,t} \quad (1)$$

As such, higher (lower) values indicate a preference for within-ERA (outside-ERA) co-publications. We can foresee that the magnitude of the ratio will depend on the size of the country groupings represented in the nominator and denominator respectively. So the basic form described in (1) would have to be adjusted for size as follows:

$$\text{ERA Co-publication integration}_{i,t} = \left(\frac{\text{ERA Co-publications}_{i,t}}{\text{ERA publications}_t} \right) / \left(\frac{\text{non-ERA Co-publications}_{i,t}}{\text{non-ERA publications}_t} \right) \quad (2)$$

Thus defined, (2) indicates the relative propensity of a nation's science base to co-publish with scientists from other ERA countries, given a country's overall publication activity.

Though we use overall counts of publications in (2), other proxies of size could be envisaged, e.g. total number of co-publications, in which case the indicator would measure the relative propensity of a nation's science base to co-publish with scientists from other ERA countries, given a country's overall co-publication activity.

A study by Mattson et al. (2008) calculates such a ratio and uses it as an indicator of Europeanisation of shared co-authorship. Chapter 5 in Key Figures 2008 (CEC, 2009) too makes a direct comparison of intra-EU to extra-EU co-publications, employing the former as an indicator of European cooperation and the latter as an indicator of openness to the world. Finally, a study by Fraunhofer, Idea Consult and SPRU (2009) examines co-publications within and outside the EU27 and the group of 15 (pre-2004 expansion) EU member state. The indicator presented here, extends on past work by adjusting for the overall size of the country groupings (ERA / non-ERA).

Intra- versus Extra-ERA co-patents

Just as with publications, patent databases permit national counts on the basis of the inventor's or owner's address. Custom queries allow one to count the number patents with inventors or owners and separate them across jurisdictions.

Using the same rationale as in co-publications, an indicator of integration based on patents – a measure of joint European activities in applied R&D - can be developed. Lack of data on collaboration with ERA countries means that such an indicator will have to be constrained to EU member states.

Therefore, in the case of patents the extent to which a given country is integrated into the EU can be gauged by calculating the ratio of the number of co-patents with partners based in EU countries to the number of co-patents with partners based outside the EU. So for a country i in time t the indicator would be equal to:

$$\text{EU Co-patenting integration}_{i,t} = (\text{EU Co-patents}_{i,t}) / (\text{non-EU Co-patents}_{i,t}) \quad (3)$$

Just as with co-publications, we adjust each side of the fraction with a proxy of size. Our choice of size proxy on this occasion is Gross Expenditure on R&D (GERD), as comparisons using total EPO patents for countries outside the EU would introduce a bias. The indicator then becomes:

$$\text{EU Co-patenting integration}_{i,t} = \left(\frac{\text{EU Co-patents}_{i,t}}{\text{Total EU GERD}_t} \right) / \left(\frac{\text{non-EU Co-patents}_{i,t}}{\text{Total non-EU GERD}_t} \right) \quad (4)$$

As patents rely to a greater extent on tacit knowledge possessed by individuals that is difficult to transmit over communication media, geographical proximity facilitates collaboration. For this reason

one would expect a priori the co-patenting indicators to yield greater values than co-publication indicators.

Though technically feasible, intra- to extra-EU co-patent ratios are not as common as co-publication ratios. This may be a reflection of the difficulties arising in the interpretation of such an indicator. Co-patenting is driven by motivations that sometimes extend beyond the boundaries of R&D collaboration. The interpretation of resulting values needs to be seen under the light of the conditions prevalent in the production of proprietary knowledge – where co-patenting may be conditioned by demand for specific capabilities, disclosure concerns or may form part of broader market-related agreements that have very little to do with R&D.

Depending on the context, numerous variations of (3) can be developed. For instance, there may be a need to correct for extreme values – e.g. the indicator may produce unreliable values for countries with very low patenting activity overall, or countries that collaborate very little in general. For these countries, devising an appropriate method for scaling the indicator becomes an important issue.

Homogeneity in the international distribution of co-publications³

Frenken (2002) proposes a novel measure of European integration in research defined as the degree by which interaction between countries is biased. Using data on scientific co-publications, Frenken (2002) examines whether countries spread their collaborations homogeneously, or, contrarily whether they exhibit a preference for particular partners. Examining only data on scientific co-publications between EU member states he expects that, for any given country, the more homogeneous the spread of co-publication between its EU partners the more integrated is the country in question. Collectively, he expects that the smaller the difference between the observed frequency matrix of interactions and the hypothetical matrix of random interactions, the higher the degree of integration.

The specific function Frenken employs is an entropy-like measure borrowed from information theory defined as follows. For an n number of countries, and with pairwise collaborations between countries i and j , arranged in a n by n matrix, the share of a country's i in total co-publications would be equal to:

$$q_i = \sum_{j=1}^n q_{ij} \quad (5)$$

The difference between the observed share and the expected (i.e. a random interaction) can be thus measured by the natural logarithm of the division of q_{ij} by the products of q_i and q_j :

$$T_{ij} = \ln \frac{q_{ij}}{q_i * q_j} \quad (6)$$

T_{ij} would then be a measure of bias (or conversely, lack of spread homogeneity), which we will refer to hereafter as the Frenken-Theil Index. The degree of collective integration in the ERA is then given by:

$$T = \sum_{i=1}^n \sum_{j=1}^n q_{ij} \ln \frac{q_{ij}}{q_i * q_j} \quad (7)$$

Frenken (2002) applied this indicator to data for the EU15 over the period 1993-2000 and reports evidence of sustained, albeit, slow integration over time.

³ Obviously, this indicator could be applied to co-patenting, but there is no current information for that. For instance, the co-patenting data used for the previous indicator, cannot be broken down by pairs of countries.

R&D Spillovers

An archetypal characteristic of contiguous 'sub-national territorial units', be they neighbourhoods, prefectures, provinces, or larger regions is the presence of spatial dependence. Within a country, neighbouring regions are known to be similar to one another, with similarity being a function of distance. That is, research (and more broadly economic) activity in one region is affected by related activity in nearby regions.

Literature in regional science has revealed that proprietary knowledge production processes tend to be highly localised. As much of the knowledge stock necessary for applied R&D is embodied in people, individual researchers tend to be more productive when they are near populous communities of researchers and places with high levels of knowledge-based economic activity (Varga and Pontikakis, 2009).

Regional scientists employ several quantitative tools to measure the extent to which the level of economic activity in a region is affected by near-by regions. These involve functions that measure the correlation between the values of economic variables in near-by regions. A widely used measure of spatial dependence⁴ is Global Moran's I index of spatial correlation. In its basic form Moran's I, measures the correlation between a variable of interest in a region and the spatially-weighted average of the values of the same variable in nearby regions. More precisely, for an n number of spatial units it is given by:

$$\text{Global Moran's I} = \frac{n}{\sum_i \sum_j w_{ij}} \frac{\sum_i \sum_j w_{ij} (X_i - \bar{X})(X_j - \bar{X})}{\sum_i (X_i - \bar{X})^2} \quad (8)$$

Where, X is the variable of interest (e.g. patents), \bar{X} is the mean of X, and w_{ij} is an n by n matrix of spatial weights (based, for instance, on geographical distance or contiguity between territorial units).

Spatial correlation measures of regional patenting activity in particular are commonly employed devices for the measurement of knowledge spillovers. The underlying assumption being that the presence of positive and statistically significant (i.e. greater than would be expected to occur by chance) correlation in the patenting activity of nearby regions echoes underlying interaction activities which could include the movement of people, sharing of ideas, expertise, infrastructures and the coordination of R&D expenditures⁵. A common finding among such studies is the high incidence of spatial dependence (Paci and Usai, 2000). In other words, as far as applied R&D is concerned, proximity matters. Motivated by this observation in this section we examine two potential applications of spatial correlation measures of patenting as proxies for cross-border knowledge spillovers.

Aggregate cross-country knowledge spillovers

While the occurrence of spatial dependence in R&D related measures between sub-national territorial units is well documented, relatively little is known about the effects of space in R&D at the level of countries. National borders are known to act as a natural 'brake' in the strength of spillover effects. It is therefore reasonable to expect that estimated spillovers will be considerably lower at the level of countries than they are at the level of regions within the same country. To the extent that joint European research policy initiatives aim to bring down barriers to the cross-border circulation of knowledge, one would expect EU cross-country spillovers to increase over time.

As such, at its simplest, we propose the calculation of Moran's I for the levels of patenting of EU member states. In such a setting, greater integration would be identifiable by positive, statistically significant and increasing over time values. For reference, a direct comparison could be made

⁴ Often called 'spatial autocorrelation', it is the spatial analogue to the traditional concept of autocorrelation in econometrics – i.e. the dependence of two observations over time – except that the dependence of interest here has a spatial/geographic dimension and is multi-directional.

⁵ Of course, the *exact nature* of spillovers cannot be identified by what is after all a statistical correlation measure.

between cross-country spillovers and cross-sub-national-region spillovers⁶. This latter measure can then be understood as a "measure of the extent to which EU countries resemble sub-national regions" and by extension the degree to which the EU exhibits qualities (or tendencies) in the field of applied R&D that are commonly found within a unitary state.

Admittedly, given the highly coarse amount of detail in data at the level of countries, this indicator can be no more than suggestive. Ideal extensions to this indicator would be those that bring it into an econometric framework that statistically controls for other variables of importance for R&D and distinguish their effects to those of spillovers. Nevertheless, to the best of our knowledge, its use in the context of European integration is original and, in our view, promising enough to merit further examination.

Border region knowledge spillovers

A complementary approach to the above would be to measure the effect of national borders directly by examining spillover effects between regions situated in the opposite sides of national borders. Observing the trend of cross-border spillover effects over time and comparing them to those observed between national regions would provide a valuable yardstick. This analysis could eventually go beyond patent statistics and potentially extended to other variables of significance for R&D, including scientific publications, researchers, R&D expenditures, highly skilled human resources (such as scientists and engineers) etc.

A noteworthy drawback of this approach though is the fact that border regions tend to (almost by definition) be away from the centre of economic activity, are often home to very little research activity and more than often, a very short history of research. This makes it less likely that the effects of borders will be identified by this indicator (at all, or accurately), as cross-border spillovers may occur between regions that are not immediately adjacent to the national border. Nevertheless, we judge it worth examining in the context of an exploratory analysis.

⁶ An alternative yardstick would be the level of knowledge spillovers observed between US states.

Overview of proposed indicators

Table 1: Comparative features (structure adapted from Stutely, 1994)

<i>Indicator</i>	Intra-Extra Co-pubs (ERA)	Intra-Extra Co-pats (EU)	Homogeneity in co-pubs (ERA)	Aggregate cross-country knowledge spillovers (EU)	Border region knowledge spillovers (EU)
<i>Description</i>	Measures the propensity for scientific collaboration within the ERA.	Measures the propensity for technological collaboration within the EU.	Measures to what extent the distribution of scientific co-publications is biased (or contrarily, homogeneous), towards a specific country (or set of countries) within the EU.	A measure of how patenting in one country affects its neighbours. Can be seen as a proxy of the extent to which EU member states resemble sub-national regions	A measure of how patenting in a border region affects its neighbours on the opposite side of the border. Can be seen as a proxy of the extent to which borders act as a 'brake' to knowledge flows
<i>Policy rationale</i>	Scientists typically (with the exception of very small states) collaborate more within their own country's national borders than internationally. By this analogy, in an integrated ERA countries should collaborate more within than outside the ERA.	In an integrated space for research, the costs for joint applied research with partners within the EU should be lower than with partners outside the EU.	In an integrated space for research, within-EU scientific research collaborations should not be biased towards any one particular country (or group of countries).	In an integrated space for research, knowledge spillovers between member states should be comparable to knowledge spillovers between sub-national regions within their own borders.	In an integrated space for research national borders should not be impeding knowledge spillovers.
<i>Formula</i>	Size-adjusted intra- to extra-ERA co-publications ratio	Intra- to extra-EU co-patents ratio	Frenken-Theil Index of mutual information (Frenken, 2002) in scientific collaboration	Global Moran's I (a measure of spatial correlation) of EPO Patents	Global Moran's I (a measure of spatial correlation) of EPO Patents
<i>Measurement & Interpretation</i>	Ratio, higher values indicate a higher propensity to collaborate with ERA countries (1=equal propensity)	Ratio, higher values indicate a higher propensity to collaborate with ERA countries (1=equal propensity)	Continuous ordinal, Lower values indicate less bias to participate with specific country(-ies), hence more integration	Interval (roughly -1 to +1), higher values indicate a diminishing influence of national borders	Interval (roughly -1 to +1), higher values indicate a diminishing influence of national borders
<i>Yardstick / Reference value</i>	A value of 1 can be considered as the minimum threshold for 'integration'	A value of 1 can be considered as the minimum threshold for 'integration'	0 = no bias (i.e. full integration)	Interregional knowledge spillovers (potentially inter-state spillovers in USA)	Interregional knowledge spillovers (potentially inter-state spillovers in USA)
<i>Periodicity and data availability (source)</i>	Annual, 2000-2006 (DG RTD, RKF, originally CWTS)	Annual, 1977-2005 (ESTAT, NewCronos)	Annual, 2000-2006 (DG RTD, RKF, originally CWTS)	Annual, 1995-2004 (DG RTD, RKF)	Annual, 1995-2004 (DG RTD, RKF)
<i>Geographic coverage (NUTS level)</i>	EU27 plus ERA associates (HR, MK, TR, CH, IS, LI, NO, IL)	EU27 (for pairs), ERA country breakdown	EU27 plus ERA associates (HR, MK, TR, CH, IS, LI, NO)	EU27 (NUTS0 level)	EU15 (NUTS2 level)
<i>Variation</i>	Longitudinal (each MS across time)	Longitudinal (each MS across time)	Longitudinal (each MS across time)	Time series (EU27) (potentially cross-section / longitudinal)	Time series (EU27) (potentially cross-section / longitudinal)

Applications to current data

Research collaboration within and outside Europe

Intra- versus Extra-ERA co-publications

We estimated this indicator using co-publication data drawn from DG RTD's Regional Key Figures (RKF) database (originally compiled by CWTS, Leiden University, using Thomson's Web of Knowledge database). It is noteworthy that this indicator enjoys almost complete ERA coverage (ERA Countries: EU27 and associated countries, i.e. HR, IS, IL, LI, NO, CH, TK; non-ERA Countries covered: US, JP, CN, MK, CA, NZ, KR, RU, MX, AU, IN), albeit for only a relatively short period (2000-2006). Our calculations are presented in Table 2.

With the exception of CN, JP and KR, all the countries examined have average scores more than 1, the value for equal propensity to co-publish within and outside ERA, which also can be considered as the minimum theoretical 'threshold' above which a country is 'integrated' into the ERA. Most EU countries exhibit high values and rarely lower than non-ERA countries, as summarised by the column on averages.

Table 2: Intra- vs Extra-ERA Co-publications adjusted for the size of collaborating groups

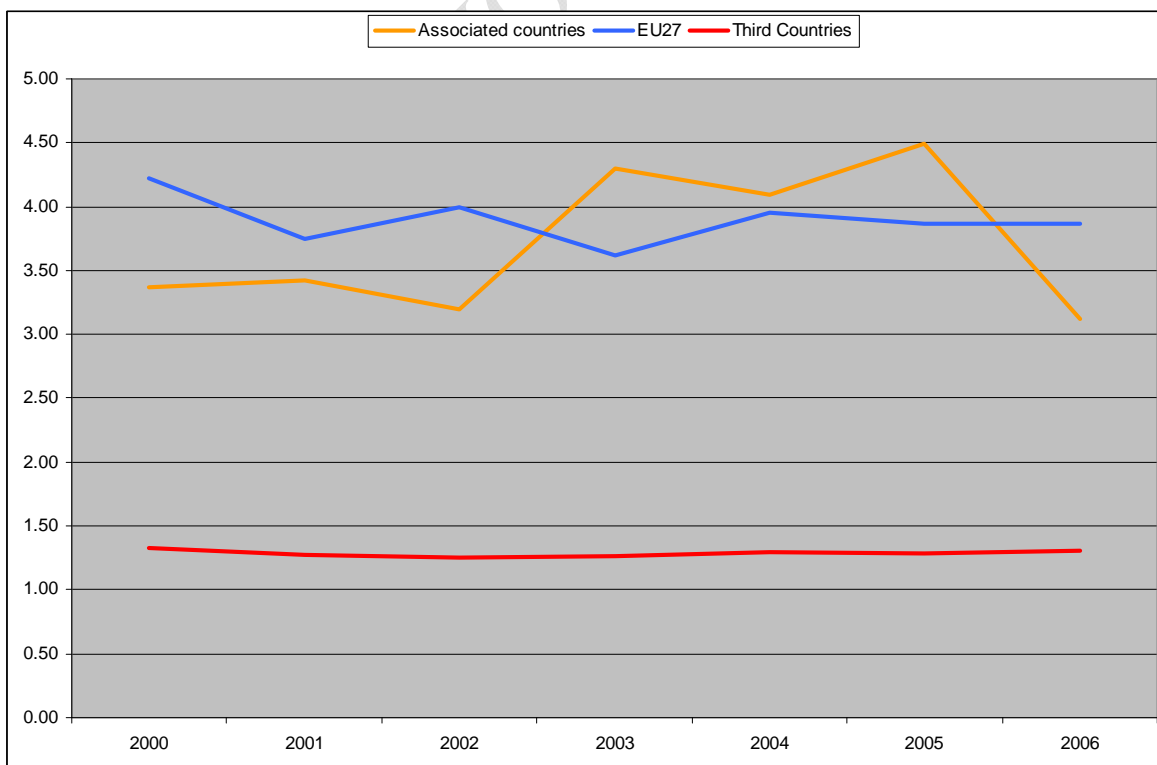
Country	2000	2001	2002	2003	2004	2005	2006	AVERAGE
BE	3.75	3.81	3.61	3.75	3.86	3.77	3.95	3.79
BG	3.33	3.59	4.19	3.52	4.15	4.12	4.43	3.90
CZ	3.61	3.45	3.19	3.44	3.71	3.61	3.80	3.54
DK	3.37	3.17	3.09	3.31	3.43	3.43	3.65	3.35
DE	1.93	1.88	1.87	1.94	2.02	2.05	2.17	1.98
EE	6.77	3.88	4.63	5.40	4.99	5.63	5.70	5.29
IE	4.21	4.16	3.53	3.37	3.03	2.74	2.98	3.43
EL	4.53	4.05	3.49	3.46	3.66	3.19	3.77	3.73
ES	3.01	2.89	2.90	2.99	3.03	3.04	3.18	3.01
FR	2.40	2.37	2.42	2.44	2.50	2.44	2.47	2.44
IT	2.70	2.59	2.61	2.66	2.73	2.71	2.77	2.68
CY	2.75	2.63	2.81	2.81	2.94	2.94	3.34	2.89
LV	4.17	5.00	4.65	4.50	3.92	4.92	3.93	4.44
LT	4.39	4.37	4.80	4.22	4.13	4.90	4.76	4.51
LU	18.19	13.03	17.06	10.60	16.75	10.87	10.26	13.82
HU	2.58	2.75	2.86	2.90	2.91	3.12	3.29	2.92
MT	6.31	2.80	7.97	3.68	4.80	8.26	4.90	5.53
NL	2.90	2.75	2.77	2.92	2.99	3.02	3.05	2.92
AT	3.85	3.69	3.32	3.73	3.69	3.66	3.93	3.70
PL	2.75	2.61	2.42	2.51	2.64	2.64	2.87	2.63
PT	5.10	4.88	4.76	4.40	5.18	4.43	4.52	4.75
RO	3.43	3.62	3.75	3.69	3.93	3.87	4.48	3.82
SI	5.31	4.79	2.91	3.42	2.83	2.76	3.23	3.61
SK	5.20	4.91	4.76	4.52	4.85	4.26	4.75	4.75
FI	2.98	3.09	3.14	3.11	3.36	3.39	3.30	3.20
SE	2.72	2.64	2.55	2.74	2.79	2.73	2.99	2.74
UK	1.75	1.74	1.69	1.78	1.77	1.77	1.81	1.76
HR	3.66	3.47	4.14	4.18	3.68	3.63	4.05	3.83
MK	3.57	3.74	3.24	5.54	5.47	4.74	3.03	4.19
TR	1.55	1.50	1.42	1.37	1.47	1.32	1.43	1.44
CH	2.83	2.86	2.66	2.81	2.91	3.00	2.93	2.86

IS	4.44	5.30	5.14	4.12	4.87	4.57	3.69	4.59
LI	3.79		2.57	8.56	6.91	10.77	3.24	5.97
NO	3.79	3.64	3.19	3.49	3.36	3.44	3.47	3.48
ERA Countries	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
CN	0.84	0.74	0.76	0.70	0.71	0.72	0.69	0.74
JP	0.90	0.81	0.85	0.83	0.85	0.86	0.89	0.85
US	2.37	2.26	2.24	2.19	2.21	2.11	2.08	2.21
AU	1.18	1.22	1.19	1.27	1.28	1.31	1.28	1.25
CA	0.99	0.98	0.99	1.05	1.07	1.08	1.10	1.04
IN	1.24	1.21	1.18	1.15	1.16	1.17	1.16	1.18
RU	3.09	2.98	2.86	2.90	2.89	2.78	2.87	2.91
KR	0.52	0.43	0.43	0.39	0.43	0.43	0.44	0.44
MX	1.27	1.25	1.23	1.19	1.31	1.28	1.35	1.27
NZ	0.89	0.88	0.85	0.97	1.02	1.10	1.17	0.98

The overall picture across the ERA is one of considerable integration (Figure 1): EU27 states collaborate about 4 times more with partners from ERA countries than they do with partners from third countries. The time series though indicates relative stability. This should not come as a surprise: for most EU countries integration at the level of collaboration between individual researchers is a process where most progress was made some time ago. This finding is in agreement with a study by Tijssen (2008), which found no conclusive evidence of large scale transformation processes towards a European Research Area.

In fact, for most 'old' EU member states (EU15), the indicator appears to be decreasing over time, indicative that extra-EU collaborations are growing faster. This adds to the mounting evidence that the EU is increasingly becoming an important collaboration partner at the world stage (Glänzel et al., 1999; CEC, 2009). The relative lack of variation in the time-series dimension is in agreement with the findings of Ponds (2008), who concludes that we may be observing the ultimate limits of the internationalisation of science.

Figure 1: Co-publication integration



In conclusion, the presented indicator can be an appropriate tool for the measurement of integration to the European science base. However, a number of limitations / provisos must be kept in mind: (a) the fact that this is a relative indicator of integration – ERA countries may still collaborate more and more with each other in absolute terms but if they, simultaneously, open more their activities to the world (also an explicit ERA target), then this indicator would show little or no integration. This of course does not diminish its suitability as a component in a possible composite indicator of integration, as it is still useful in distinguishing inwards- from outwards-looking countries. (b) Co-publication does not equal cooperation, as co-publications are only one form of scientific collaboration (Katz and Martin, 1997) (c) the possible bias in journal coverage (ISI list).

Intra- versus Extra-ERA co-patents

We have used data from Eurostat NewCronos database on EPO co-patents. The patent data is based on patent applications, sorted by date of application and assigned to country of inventor. Figures on GERD (measured in millions of purchasing power standard euros, 2000 prices) were drawn from DG RTD's RKF database.

Due to limitations in the Eurostat data, the non-EU group for GERD comprises of: TR, CH, IS, LI, NO, JP, US. This is however only a small fraction of the world total (excluding e.g. the considerable contributions of Australia, Canada, New Zealand and the BRIC countries). Resorting to OECD data would be an option. In addition, missing values have been replaced with averages of the nearest 3-year period for which data was available. Tables 3 and 4 present our estimates of functions (3) and (4) respectively.

Table 3: Intra- vs Extra-ERA Co-patents

Country	'77-'80	'81-'84	'85-'88	'89-'92	'93-'96	'97-'00	'01-'05	AVERAGE
CH	13.80	4.73	5.84	4.58	5.00	4.14	4.92	6.10
LU	3.92	1.97	5.53	5.32	2.53	9.10	8.41	5.68
SI				1.50	1.59	13.08	4.49	5.66
SK						3.92	6.16	5.20
CZ					8.10	4.24	2.63	4.81
LV						2.54	5.58	4.71
AT	7.45	5.25	3.32	2.38	1.96	3.19	3.55	3.86
PT			0.40	1.08	7.05	4.32	3.28	3.62
NO	0.40	3.84	8.02	3.09	1.81	2.42	3.05	3.35
HR						1.28	5.36	2.98
BG					1.03	3.84	3.25	2.80
BE	5.73	1.78	2.22	2.12	2.40	2.27	2.56	2.61
ES	1.25	2.22	4.91	1.97	2.56	2.01	2.61	2.60
NL	3.50	2.66	3.46	2.11	1.85	2.07	1.66	2.41
GR	1.34	1.38	1.49	1.51	3.09	3.75	2.30	2.32
MT							2.22	2.22
LI		1.13	1.14	0.75	2.37	3.23	3.78	2.22
PL			2.26	2.20	1.33	3.04	1.85	2.12
RO					2.87	3.59	0.87	1.92
DK	2.48	1.77	2.28	1.56	1.18	1.73	2.05	1.85
HU		2.05	1.25	2.19	1.31	2.00	1.82	1.76
EE						0.81	1.89	1.62
CY					1.52	1.72	1.52	1.58
FI		1.97	1.63	1.82	1.22	1.33	1.44	1.55
IT	1.20	1.47	1.48	1.49	1.33	1.89	1.44	1.47
TR		1.50	1.00	1.45	1.60	1.35	1.45	1.44
IE	4.50	1.84	0.89	1.00	1.14	1.13	1.06	1.30
SE	1.46	1.65	0.85	1.12	1.26	1.11	1.57	1.30
LT						1.18	1.25	1.23

IS			0.33	4.73	1.19	0.26	0.51	1.19
FR	1.05	0.93	0.96	1.24	1.03	1.06	1.11	1.05
EU27	0.90	0.96	0.95	1.01	0.97	0.98	1.03	0.97
DE	0.60	0.74	0.76	0.83	0.82	0.85	0.94	0.80
UK	0.58	0.59	0.58	0.67	0.67	0.64	0.72	0.64
IL	0.76	0.55	0.36	0.34	0.25	0.31	0.34	0.39

NB: empty cells indicate no data

Table 4: Intra- vs Extra-ERA Co-patents adjusted for the size of collaborating groups

Country	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
EU27	1.83	1.88	1.81	2.00	1.81	1.94	1.98	1.85	2.08	1.83	2.19
BE	4.39	3.16	2.97	4.04	4.91	5.61	3.84	3.92	5.26	5.14	6.48
BG	1.36	2.88	14.68	4.87		2.63	3.57	7.55	14.42	3.29	2.15
CZ	9.60	6.23	3.66	5.11	19.94	3.91	8.54	5.70	4.83	3.92	2.18
DK	2.17	2.36	2.84	3.34	3.29	3.89	2.92	3.73	2.91	2.77	7.49
DE	1.51	1.49	1.64	1.69	1.52	1.68	1.89	1.77	1.92	1.74	1.73
EE				1.58				4.48		0.50	5.93
IE	1.44	3.76	2.75	1.43	2.18	2.36	2.55	2.49	2.24	1.43	1.38
GR	7.46	13.07	4.53	8.65	7.81	7.97	4.39	4.60	6.48	3.17	3.42
ES	3.42	6.35	2.93	5.22	3.54	3.81	3.83	6.60	3.76	4.97	5.90
FR	1.78	2.60	1.91	2.28	2.00	1.96	2.14	1.77	2.48	2.00	2.32
IT	2.71	2.81	4.26	4.44	2.80	3.09	2.41	2.82	2.90	1.80	3.97
CY		2.88	4.57		2.01		2.53	5.35	0.69		
LV	1.46		4.80			4.98	5.11	5.07	14.06	8.56	21.23
LT						2.28	6.91		0.10	0.19	
LU	4.57	5.93		6.93	32.24	13.32	4.27	9.12	9.41	6.46	52.70
HU	2.23	4.78	6.16	3.95	3.41	1.92	4.11	3.59	4.03	2.67	3.04
MT							4.27				
NL	3.28	3.24	3.26	4.45	3.42	4.83	2.91	3.11	3.50	3.22	3.21
AT	2.84	3.88	5.40	6.49	6.24	6.49	7.92	7.15	6.38	6.81	5.78
PL	1.27	4.36	3.54	15.90	0.88	3.27	1.24	1.97	2.37	3.05	9.38
PT	19.65		7.79	14.69	7.99	2.88	6.66	1.31		9.17	8.24
RO		8.64			8.01	5.80	3.35	0.54	3.03	0.58	0.82
SI	1.94		15.11	38.17	22.52		14.08	0.89	11.10	8.98	8.24
SK				5.68	6.39	10.62	5.72	9.91	25.90	5.47	
FI	2.10	2.12	2.05	2.41	3.39	2.37	3.24	2.15	3.35	1.99	3.09
SE	2.72	2.32	1.85	1.93	2.03	2.78	3.06	2.36	3.55	3.40	2.66
UK	1.46	1.30	1.11	1.40	1.25	1.21	1.37	1.29	1.29	1.19	1.78
HR			0.88	0.73	1.26	7.03	3.41			9.74	18.22
MK										3.35	
TR	1.47	4.36	0.28	0.65	2.54	6.93	0.96	5.10	2.30	2.94	2.52
IS		3.80	0.67	0.47		0.34	1.38	0.67	0.45	1.18	1.26
LI	1.39	1.33	8.30	8.65	5.62	2.34	16.00	10.80	1.62	4.95	2.67

NB: empty cells indicate no data

As with co-publications, Tables 3 and 4 present evidence of considerable integration. Controlling for size differences, EU27 countries were about 2 times more likely to collaborate with ERA partners in applied R&D than they were with partners from third countries. It is interesting to note though that two of the EU's most technologically advanced countries (UK and DE) are also among the least 'integrated' – presumably because their technological needs drive them to seek a relatively greater proportion of partners outside the ERA. It appears then that this indicator may also signal something other than integration: technological preferences and industrial structure, where countries with low score may in fact be stronger technologically. This does not diminish the indicator's usefulness in distinguishing between inwards- and outwards-looking countries – which make it potentially a viable component of a possible composite indicator of integration. We also observe that, because of the scaling problems discussed earlier, the indicator produces highly erratic values for small countries (CY, IS, LI, LV, LU). Improvements to the indicator could consider scaling it with some measure of intensity, or the more elaborate scaling methods documented in Katz (2006).

Homogeneity in the international distribution of co-publications

We have used data on co-publications from the RKF database (covering the EU27 & 8 Associated states: HR, MK, TR, CH, IS, LI, NO, IL), providing almost complete coverage of the ERA. The pairwise data were transposed into a 34*34 matrix (=1156 cells per year).

Ideally, values for the matrix's diagonal (i.e. within country co-publications) can be used to normalise the data for size differences across countries. Unfortunately though, we have had no access to data on within-country co-publications, and as a result the computed indicator does not control for size differences⁷.

As Frenken points out progress in the index should not be assessed against the reference level of full integration ($T = 0$, no bias) but rather "from an (unknown) reference level of bias that would occur when institutional and language barriers between countries were to be fully removed" (Frenken, 2002: 352). Our calculated values for individual countries are presented in Table 5.

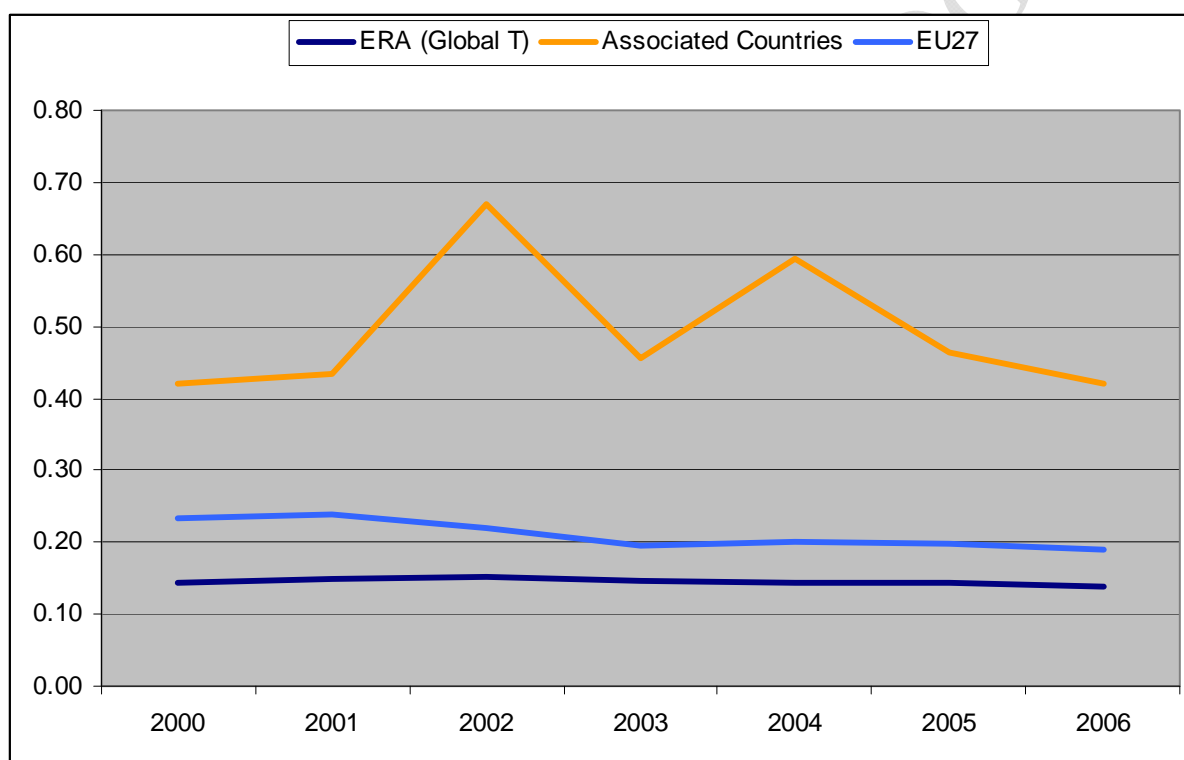
Table 5: T-values in ERA countries (2000-2006)

Country	2000	2001	2002	2003	2004	2005	2006	AVERAGE
BE - Belgium	0.10	0.10	0.11	0.10	0.10	0.10	0.10	0.10
BG - Bulgaria	0.19	0.17	0.13	0.14	0.12	0.13	0.12	0.14
CZ - Czech Republic	0.12	0.13	0.16	0.17	0.15	0.13	0.15	0.14
DK - Denmark	0.12	0.13	0.15	0.14	0.16	0.15	0.13	0.14
DE - Germany	0.18	0.18	0.18	0.18	0.18	0.18	0.17	0.18
EE - Estonia	0.52	0.64	0.57	0.46	0.38	0.48	0.47	0.50
IE - Ireland	0.24	0.26	0.21	0.15	0.17	0.15	0.12	0.19
EL - Greece	0.05	0.06	0.07	0.06	0.07	0.07	0.08	0.06
ES - Spain	0.10	0.10	0.11	0.10	0.10	0.11	0.11	0.10
FR - France	0.15	0.15	0.15	0.15	0.14	0.15	0.14	0.15
IT - Italy	0.11	0.12	0.11	0.11	0.11	0.11	0.11	0.11
CY - Cyprus	0.55	0.51	0.60	0.44	0.47	0.53	0.49	0.51
LV - Latvia	0.47	0.50	0.42	0.42	0.42	0.46	0.55	0.46
LT - Lithuania	0.32	0.42	0.34	0.21	0.24	0.32	0.27	0.30
LU - Luxembourg	0.22	0.29	0.27	0.17	0.21	0.26	0.13	0.22
HU - Hungary	0.09	0.07	0.07	0.07	0.07	0.07	0.08	0.08
MT - Malta	1.36	1.09	0.53	0.49	0.75	0.30	0.37	0.70
NL - Netherlands	0.10	0.10	0.11	0.10	0.11	0.11	0.11	0.11
AT - Austria	0.11	0.14	0.14	0.14	0.13	0.13	0.12	0.13
PL - Poland	0.07	0.08	0.09	0.09	0.09	0.08	0.08	0.08
PT - Portugal	0.07	0.10	0.09	0.09	0.08	0.08	0.09	0.09

⁷ This can be corrected in the near future, making use of information collected as part of DG RTD's upcoming study "Analysis and regular update of bibliometric indicators".

RO - Romania	0.19	0.17	0.16	0.12	0.13	0.14	0.13	0.15
SI - Slovenia	0.18	0.21	0.29	0.26	0.23	0.26	0.22	0.23
SK - Slovakia	0.22	0.23	0.31	0.38	0.33	0.34	0.33	0.31
FI - Finland	0.14	0.16	0.17	0.16	0.16	0.15	0.12	0.15
SE - Sweden	0.16	0.17	0.19	0.18	0.17	0.16	0.14	0.17
UK - United Kingdom	0.17	0.17	0.17	0.17	0.16	0.16	0.16	0.17
HR - Croatia	0.33	0.35	0.37	0.40	0.37	0.28	0.26	0.34
MK - Macedonia, the former Yugoslav Republic of	0.64	0.42	1.12	0.35	1.00	1.01	0.89	0.77
TR - Turkey	0.18	0.19	0.15	0.11	0.09	0.11	0.08	0.13
CH - Switzerland	0.11	0.11	0.12	0.11	0.11	0.11	0.11	0.11
IS - Iceland	0.58	0.57	0.49	0.55	0.55	0.54	0.39	0.53
LI - Liechtenstein	0.91	1.19	2.18	1.48	1.84	1.02	1.05	1.38
NO - Norway	0.19	0.20	0.25	0.19	0.20	0.18	0.16	0.20

Figure 2: Homogeneity in ERA, EU27, Associated Countries (Global T for ERA, average values national values for Associated and EU27)



NB: Lower values denote higher integration

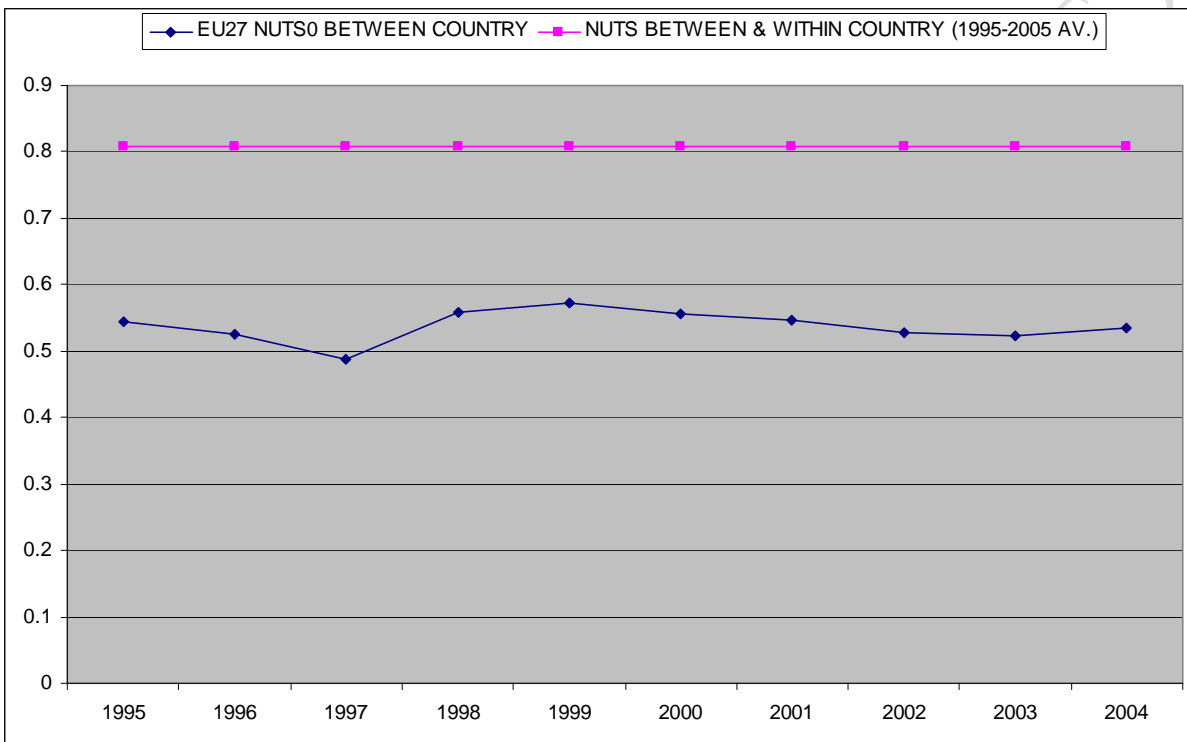
The indicator signals a moderate decrease in T (greater integration) for the EU27 from 2001-2003, but trend is otherwise stable over time. Of course, these results are tentative and more resolute inferences should be made using data that include size adjustments. An important limitation of this indicator in its present form (which could be addressed in the future) is the fact that it does not consider extra-EU collaborations, and thus provides no external reference point. Moreover, a measure of bias is an important, but ultimately partial measure of integration: even highly integrated systems may display uneven patterns of scientific collaboration, due to for instance, disciplinary specialisation. Despite these limitations, the Frenken-Theil Index would be a potentially important component of any composite indicator of European integration in research.

R&D Spillovers

Aggregate cross-country knowledge spillovers

Our calculations are based on data on EPO patent applications sorted by date of application, assigned to country of inventor. We normalised the patents measure by taking natural logarithms, in order to smooth out the large differences between the lowest (1 for LI in 1997) and the highest (22507 for DE in 2004) values. We then calculated Moran's I for the EU27 (NUTS0 regions), assuming a weight matrix of binary neighbourhood contiguity⁸. Our estimates are presented in Figure 1.

Figure 3: Aggregate knowledge spillovers between neighbouring countries (Global Moran's I of EPO Patents)



NB: All values statistically significant at the 95% level.

Figure 3 reveals considerable knowledge spillovers but also appears to indicate stability over time, with no noticeable tendency in the 9 year period under examination.

These results should not be taken at face value. Any interpretation of Figure 1 should bear in mind that the national level may be 'too coarse' to capture border effects and that aggregate cross-border spillover estimates may be biased as we are not controlling for other variables of importance for R&D. Further refinement can be envisaged and will be needed before the stability over time observed here can be confirmed.

Nevertheless, the fact that the observed values are positive, statistically significant and consistent over time tentatively suggests that: (a) cross-border spillovers at the country level are potentially significant in magnitude (b) the importance of borders for patenting has not changed over time.

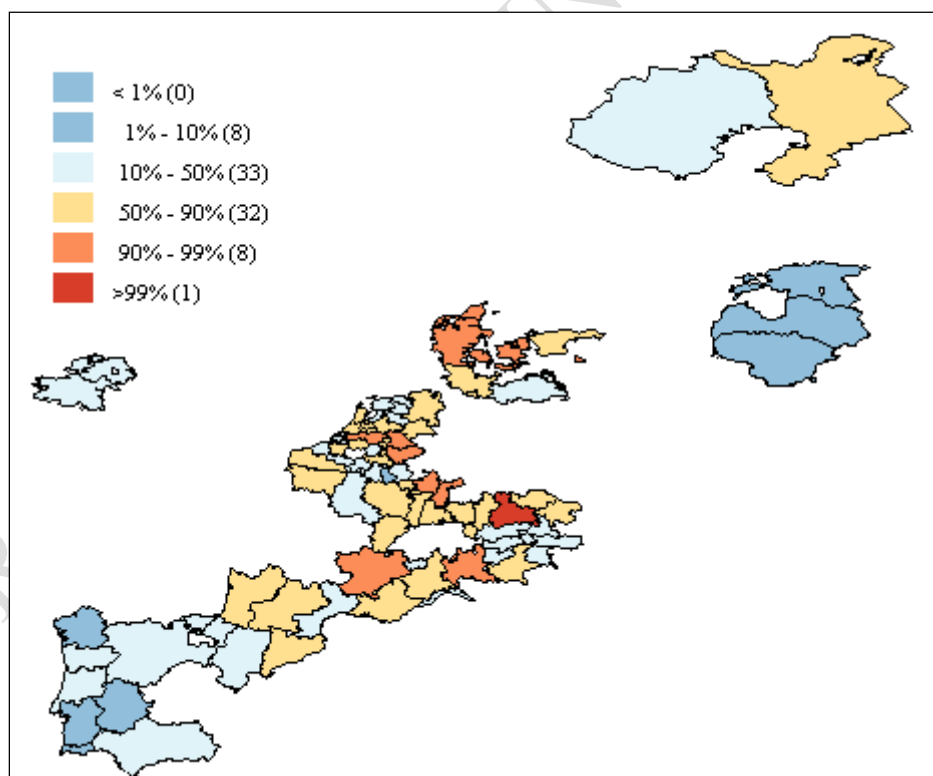
⁸ So called 'Queen contiguity' was used, that considers all neighbouring regions with a common edge and vertex (i.e. neighbours to the north, north-east, north-west, south, south-east, south-west). Exceptions to the contiguity rule included the following pairs of countries that do not share a land border but can be considered neighbours: Greece and Cyprus, Italy and Malta, Denmark and Sweden, UK and France.

In conclusion, an indicator of aggregate knowledge spillovers is potentially good at capturing national border effects. However, as an aggregate statistical correlation, it does not reveal the precise nature of barriers. The indicator is receptive to extensions and further refinement. There are also good reasons to expect that our current estimates suffer from an 'omitted variable' bias – i.e. the spillover effects we are observing may be due to factors other than knowledge flows. Obtaining likewise estimates from a national knowledge production function that accounts for spatial dependence could offer a tractable solution to this problem. In addition, the country level is also probably too coarse to capture different types of spillover effects: in particular, international intra-industry spillovers may be more pronounced and worth investigating too. Moreover, knowledge spillovers may not occur only between neighbouring countries, so a weights matrix that uses measures of distance may be worth attempting.

Border region knowledge spillovers

We have also calculated Global Moran's I for a set of regions situated in the opposite sides of national borders. We have defined the weights matrix as binary neighbourhood. As a result only regions in countries with common land borders were included (Figure 4). Our final sample includes 82 regions. Follow up of this analysis could use other measures of contiguity (or distance) that overcome this limitation. Our estimates are based on a custom Queen contiguity spatial weights matrix in which within-country regional links have been severed, effectively measuring spatial correlation only between regions on the opposite sides of national borders. As before, we normalised the patents measure by taking natural logarithms, in order to smooth out the large differences between the lowest (0 for LU in 2004) and the highest (2701 for Oberbayern in 2000) values.

Figure 4: Border regions in our sample, by EPO patent applications in 2000

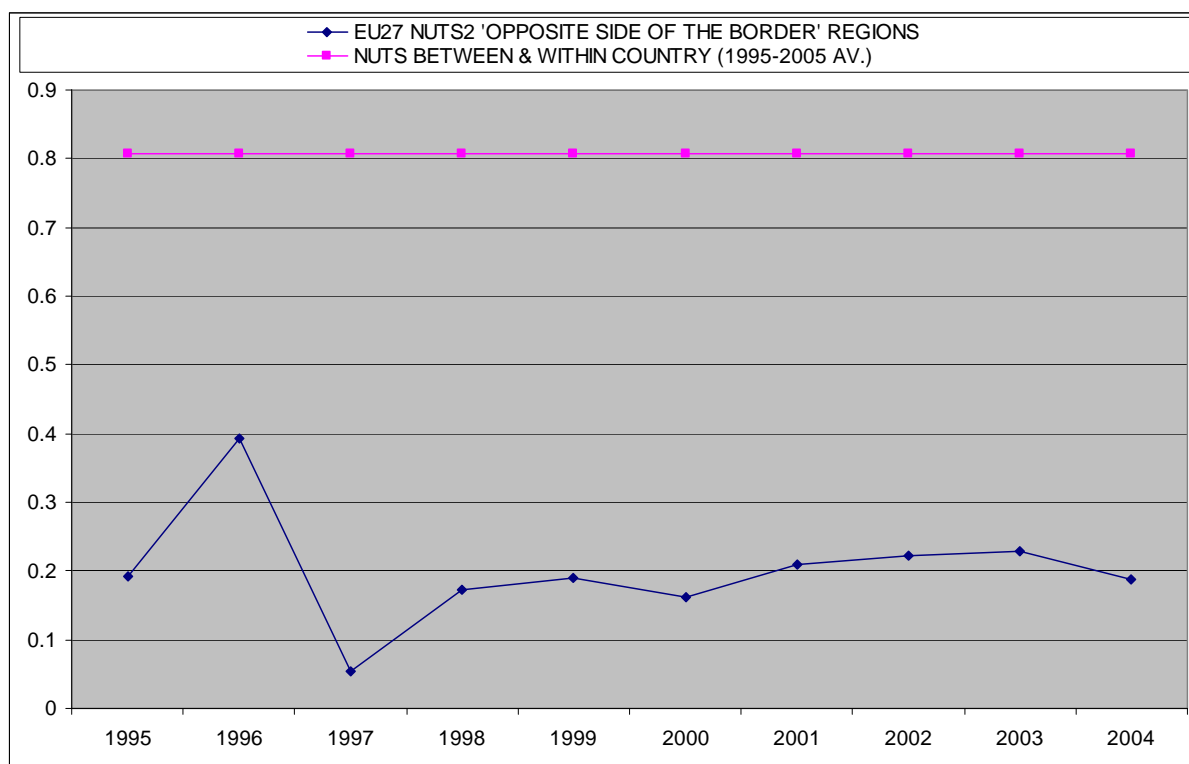


Percentile intervals, number of regions in parenthesis

Source: IPTS (© EuroGeographics for the administrative boundaries)

Figure 5 presents our estimates for the border regions in our sample. All values in the period 1995-2004 were positive and statistically significant at the 95% level. The period average of overall regional knowledge spillovers at NUTS2 (within- and between-country) are also provided for reference.

Figure 5: Knowledge spillovers between regions on the opposite side of national borders (Global Moran's I of EPO Patents)



NB: All values statistically significant at the 95% level.

The results point to considerable knowledge spillovers, albeit relative stability over time. As we are the first to calculate this precise indicator we have no point of reference in literature. Some complementary insights may be given though by related studies: our findings are in agreement with the findings of Branstetter (1996) at the level of individual companies. Using a different methodology, Branstetter (1996) examined the innovation activities of US and Japanese companies and found that knowledge spillovers were primarily intra-national in scope. In direct contrast, the estimation of gravity models on trade data in the preceding decade (1982-1994) provides evidence of ever-closer European economic integration over time (Wei, 1996).

Our own estimates (Figures 3 and 5), if confirmed, would be a testament to the continuing importance of national borders for research, even within the EU. They also appear to indicate that, despite numerous policy initiatives for cross-border collaboration (e.g. the various iterations of the INTERREG programme), there is no increase in the level of spillovers over time.

In conclusion, the proposed indicator of border region knowledge spillovers is a potentially sound candidate for capturing national border effects. It does however come with limitations. First of all, in common with its aggregate counterpart, this indicator does not reveal the precise nature of barriers: in-depth case studies would be needed for that. Moreover, it does not capture distance-dependent spillovers between regions that are not adjacent to the border. Additionally, in its present form it can only provide global values for the EU regions considered. A variation of our methodology using a Local Moran's I or a LISA (Local Indicator of Spatial Association) measure, could particularise barriers to specific border regions or particular national border pairs (e.g. Spain-France, France-Germany, France-Italy etc.). However, due to the small overall number of cross-border regions, point estimates may be unreliable. This limitation could be overcome with more finely grained patenting data (e.g. at NUTS3 level)⁹. At the present stage though, using the existing measure for the identification of 'ideal types' or 'clubs' of regions (and investigate their tendency to converge/diverge over time) appears more realistic. Another possible improvement includes the

⁹ Using data from the OECD's REGPAT database could provide an answer to this problem.

application of regional knowledge production functions, with e.g. spatially lagged regressions as in de Dominicis et al. (2007).

Conclusions and future developments

We have presented five novel indicators of European integration in research drawing from the latest developments in literature and applying them to current data. These should be seen in the context of exploratory work on ERA indicators rather than final products.

Our analysis of a number of different indicators of integration has revealed that most ERA (and certainly EU) countries exhibit high levels of integration. However, examining data over the last decade or so, most indicators show no progress on integration. This echoes closely findings in the relevant literature using more traditional indicators (Tijssen, 2009; Ponds, 2009).

More work will be needed to consolidate the proposed indicators and further examine their robustness. Some of our estimates (particularly for small countries) clearly show a need to better account for size differences. In addition, indicators on knowledge spillovers would benefit from additional statistical controls (e.g. in a knowledge production function framework) as well as comparable estimates from outside the EU. The OECD's REGPAT database may permit international comparisons with large federal states such the USA, Canada or Australia and thus provide a more intuitive yardstick of the ultimate 'ceiling' for integration. Some of these indicators are receptive of extensions that would allow them to cater for a greater number of important dimensions for the emerging European Research System. In the long run, one could envisage the development of a composite indicator of integration that utilises (among others) the proposed indicators as components.

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