Internationalisation of EU research organisations

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Internationalisation of EU research organisations

A bibliometric stocktaking study

International research collaboration (IRC) is at the core of contemporary higher education and science systems, and the percentage of internationally co-authored publications globally and across Europe is on the rise. The aim of this study is to analyse, based on large-scale data on publication and citation trends over time (within the last decade), the changing nature of academic knowledge production in all European Union Member States (EU-28) and the trend towards its radically increasing internationalisation.

The study combines theoretical knowledge about IRC with the most up-to-date empirical data and their analysis. This quantitative study analyses the macro-level of countries and the meso-level of flagship institutions to assess the cross-national and cross-institutional differentiation in the pace of these changes and their depth. The report uses Scopus and SciVal data for 2007-2017, and the analysis of collaboration in research is based on bibliometric data on publications and citations.

The empirical analysis is preceded by a section on the motivations and another on the major barriers connected with the processes of research internationalisation. The study suggests policy options to improve international research collaboration at the European level.

AUTHOR

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Executive summary

1. Introduction

International research collaboration (IRC) is at the core of contemporary higher education and science systems. The percentage of internationally co-authored publications globally and across Europe has been on the rise, as has been the mean distance between collaborating scientists. The present study is theoretically grounded in the global research literature concerning IRC (its motivations and drivers, advantages, costs, and major barriers) and its empirical part is used to support selected findings from previous research. In this way, the report combines theoretical knowledge about IRC with the most up-to-date empirical data and its analysis.

The aim of the study is to analyse, based on large-scale data on publication and citation trends over time (within the last decade), the changing nature of academic knowledge production in all European Union Member States (EU-28) towards its radically increasing internationalisation. This quantitative study analyses the macro-level of countries and the meso-level of institutions to assess the cross-national and cross-institutional differentiation in the pace of these changes and their depth. The study examines bibliometric data about the internationalisation of research in the theoretical context of international scientific collaboration literature and suggests policy options concerning its improvement at the European level. The empirical analysis is preceded by a section on the motivations and one on the major barriers connected with the processes of research internationalisation.

2. Drivers of IRC

IRC depends to a large extent on the approach of scientists as 'calculating individuals': scientists collaborate in research internationally because it is profitable to them in terms of academic prestige, scientific recognition, and access to research funding. Consequently, the convergence between individual-level motivations and drivers for internationalisation with departmental-, institutional- and national-level research policies is needed. The drivers of IRC also include increased visibility, new knowledge and contacts of value for the future. Apart from geographic proximity (or spatial proximity) as an important factor in IRC, cultural proximity also matters. What has been reported in the literature is the role of the 'invisible college', the tendency of graduates to collaborate only with other graduates of their schools, with similar cultural and academic traditions, forming strong professional network ties. The academic excellence issue means that, at both individual and institutional levels, attractiveness of the potential research partner plays a crucial role in IRC. Not only is the formation of a collaboration proportional to the academic excellence of its participants, but also its impact advantage. Research shows a significant relationship between academic excellence and the probability of co-authorship: the more experienced the researcher, the higher the tendency to collaborate; the more highly ranked the academic department to which the researcher belongs, the higher his propensity to collaborate; and the higher the author's rank, the higher his or her inclination to collaborate. Not all sciences are equally driven by the internationalisation demand: the four types of international collaboration are: data-driven collaboration (as in genetics, demography, epidemiology); resource-driven collaboration (as in seismology, zoology); equipment-driven collaboration (as in astronomy, high-energy physics); and theory-driven collaboration (as in mathematics, economics or philosophy). Wagner (2005) shows that different motivations for international collaboration affect the extent and patterns of the internationalisation of research as viewed through internationally co-authored papers. Availability of resources increases the level of IRC. Beyond that, scientists create and sustain the connections that form the global knowledge network largely because they 'become resources to others … connections are retained as long as they are of mutual (or potential) interest to participating members' (Wagner 2018: 62). In short, networks mean (international) collaboration.

3. Barriers to IRC

Barriers to IRC may include macro-level factors (geopolitics, history, language, cultural traditions, country size, country wealth, geographical distance); institutional factors (reputation; resources); and individual factors (predilections, attractiveness). They also include lack of funding, finding collaborators, communications (different languages, managing personal/family commitments, managing work commitments and time commitments to initiate/conduct the collaboration. The costs of collaboration can take a variety of forms. First, travel and subsistence costs are substantial. Costs of international physical mobility have been on the rise across all European science systems for all staff categories, including scientists and management personnel. Another cost is time as an academic resource. Additional requirements can reduce the available time and energy for actual research activities. Finally, collaboration increases administrative costs of research: with more people and more institutions involved, greater effort is required to manage the research.

4. Data sources and methodology

The data analysed in this report have been retrieved from Scopus, the largest abstract and citation database of peer-reviewed literature covering almost 40 000 journals, book series and conference proceedings by some 6 000 publishers (owned by Elsevier) and SciVal, an Elsevier's research intelligence tool offering access to research performance of 230 nations, as well as 12 600 institutions and their associated researchers worldwide. SciVal uses Scopus data from 1996 to the current date, which covers 48 million records. SciVal receives a weekly update of new data from Scopus. The choice of Scopus rather than the Web of Science (WoS) global indexing data set in this report was motivated by higher coverage of academic journals, especially in EU-13 countries. The report uses the 2007-2017 data, assuming the timeframe to be long enough to analyse basic trends in research performance and changing collaboration types over time. The analysis of collaboration in research is limited to a single output data type: bibliometric data on publications. The overall approach to IRC was unambiguous: IRC was analysed in the context of the three other collaboration types: institutional RC (multi-authored research outputs, where all authors are affiliated with the same institution in a European country), national RC (multi-authored research outputs, where all authors are affiliated with more than one institution within the same European country), and single authorship (or no collaboration, single-authored research outputs where the sole author is affiliated with an institution in a European country).

5. Results

At macro-level

Empirical analyses show that both the number of internationally co-authored articles and their percentage share in the national output have been on the rise in the last decade across all EU-28 countries. The number of articles written in international collaboration in the period studied (2007-2017) was 2,193,504 in the EU-28 and 1,437,621 in the United States of America (USA), compared with merely 588 087 in China; however, the highest growth in the number of these publications per year in the same period was for China (by 309.02 %). Within countries and between them, there is substantial cross-disciplinary differentiation, with different increases between different fields of science. In the EU-28, the largest number of articles published in international collaboration in 2017 was by far for natural sciences (175,150; and 109,624 in the USA), followed by medical sciences (84,325; and 64,029 in the USA) – and the lowest for the humanities (5,480; and 2,880 in the USA). In 2017, the share of internationally co-authored papers was 44.4 % for EU-28 countries (47.1 % for EU-15 countries and 39.2 % for EU-13 countries, 40 % for the United States and merely 22.2 % for China). IRC in Europe is thus at similar levels than in the USA and 150 % more popular than in China.

The share of national collaboration was the highest for China (30.2 %), followed by the United States (23.7 %), and EU-28 countries (18.9 %, with a significant difference between the EU-15 and EU-13 groups: 19.2% and 15%.3, respectively). The share of institutional collaboration is in the range of 45.4 % (China) and 24.1 % (EU-15, considerably bigger for EU-13 countries, 33.5 %). Finally, the share of single-authored publications is the smallest in China (2.4 %) and in the rest of the groups of countries it remains at a level of only 9.5-12.1 %. The same trends (2007-2017) and the same patterns (2017) are clear for all of the EU-28 countries studied. There is not a single EU-28 country in which IRC has not been on the rise in the period studied and in all countries it was a dominating collaboration type in academic science in 2017. The vast differences in the total number of internationally co-authored publications among the European countries studied needs to be kept in mind in all percentage-based IRC trends.

EU-28 countries also differ significantly in terms of their IRC in terms of two other parameters: their collaborating partner countries and the Field-Weighted Citation Impact (FWCI, or the ratio of citations received relative to the expected world average for the subject field, publication type and publication year) of their internationally co-authored publications. The biggest number of internationally co-authored papers is observed between China and the USA, followed by the United Kingdom (UK) and the USA, Germany and the USA, as well as France and the USA. The dominant feature of IRC in Europe is its powerful collaboration with the USA: the UK, Germany, and France collaborate more intensively with the USA than with any other European country. In 2013-2018, 172,887 papers were written jointly by UK and US scientists, 141,195 papers written jointly by German and US scientists, and 93 308 papers written jointly by French and US scientists. In contrast, the highest number of papers written by two intra-European collaborative partners is only 90,202 (papers co-authored by German and UK scientists in the period studied). While China is the most powerful global partner of US science, only one country in Europe, the UK, is collaborating widely with China (with 63,625 papers written jointly in the period studied).

At meso-level

The analysis at the macro-level of countries is accompanied in this report by the analysis at the meso-level of (selected, flagship) institutions. In most general terms, collaboration trends over time and collaboration patterns for 2017 (according to the four collaboration types: institutional, national, international and single-authorship) are similar for EU-28 countries and for their flagship institutions; however, the internationalisation trends are more intense for flagship institutions than for countries.

The percentage share of international collaboration is on average lower for flagship universities located in EU-13 countries than for those located in EU-15 countries. While no flagship universities located in EU-13 countries exceeded the level of 60 % of international collaboration for the period 2007-2017 and only three exceeded that of 50 %, five flagship universities in EU-15 countries exceeded the level of 60 % of international collaboration (University of Luxembourg, University of Vienna, Karolinska Institutet, KU Leuven and University of Oxford). Only in four EU-28 flagship universities was the share of internationally co-authored publications in a single year of 2017 smaller than 50 % (all of them located in central and eastern Europe). For all the universities studied, the percentage share of internationally co-authored papers increased substantially between 2007 and 2017.

The patterns indicate that the biggest increase in citation impact per international collaboration is observable for institutions located in EU-13 countries: the top five includes institutions from the Czech Republic, Slovakia, Croatia, Poland and Romania. The increase is as follows: Charles University (Prague) by 336.9 %, Comenius University (Bratislava) by 290 %, University of Zagreb by

266 %, Jagiellonian University (Cracow) by 184.1 % and Babes-Bolyai University (Cluj-Napoca) by 166.7 %. IRC in EU-13 flagship institutions is a substantial factor increasing international visibility of published research as measured through a proxy of citation impact. For the majority of EU-15 flagship institutions, in contrast, the citation impact per international collaboration does not increase so much compared with the citation impact per institutional collaboration. IRC pays off the most in the former and pays the least in the latter group of flagship institutions. For instance, in the case of the five institutions with the lowest increases, the increase in citation impact associated with international collaboration compared with institutional collaboration is in the range of 50 %-70 % (University of Oxford, University of Vienna, University of Luxembourg, KU Leuven and Utrecht University).

6. Policy options

Policy option 1: IRC should be at the centre of national research policies

National higher education (HE) systems focused on increasing the international visibility of their academic knowledge production need to install the internationalisation of research at the centre of their national research policies. If IRC were central to national research policies, English should also be acknowledged as the language of global science today because, increasingly, 'non-native English speakers face challenges when trying to publish' (Powell 2012). Academic and scientific English holds the key to success on the international scale.

Installing the internationalisation of research at the centre of national research policies refers to all levels of operation of HE systems, from national to institutional, and from departmental to individual. Internationalisation-supportive research policies should promote top international publications in academic employment, rather than merely top national publications and should promote international, rather than merely national, collaboration in research. They should promote international publication channels both in direct block funding to their institutions and in indirect, individual-level competitive research funding.

National models of successful universities, departments, research teams and individual scientists need to be clear: no academic success is possible and no large funding is awarded at any level to those units and individuals that are not internationalised in research. No professorships are available (or renewable) to scientists whose research performance profile is predominantly national – rather than international. For the research internationalisation agenda to be successful, highly internationalised institutions, departments, research teams and scientists need to be better off than local ones; the international needs to be promoted over the local in research in the different variants of national research assessment exercises. IRC should matter more for funding and academic prestige and it needs to be consistently promoted at all levels of academic organisation.

Policy option 2: Large-scale funding should be provided for IRC

Increasingly, top scientists globally opt for collaborative, networked science that is locally rooted through training and institutions and nationally funded. European countries should consider supporting their academic faculty to become more internationalised in research and providing large-scale funding for IRC to avoid creeping isolation at a global level.

Internationalisation costs are increasing across all national systems in Europe. Internationalisation costs include both such traditional items as travel and subsistence costs for hundreds of thousands of travelling scientists and such new items as subscriptions to global indexing data sets and global academic journals. Doctoral students, postdocs, junior and senior scientists travel for academic business increasingly frequently, and use access to global knowledge bases to an unprecedented degree. Journal and book subscription and ICT infrastructural costs are critical to the success of IRC and these are also increasing, both globally and in EU-28 countries. As international academic travel, access to global academic journals and books and ICT infrastructure are the core of internationalisation, the rise of internationalisation-related costs needs to be noted and reflected in both budget size and its internal distribution. IRC costs – and it costs a lot.

Policy option 3: Individual scientists should be at the centre of national research internationalisation agendas.

National systems determine conditions in which academic institutions operate, thriving or fighting for survival; however, in IRC the critical node is the individual scientist who will (or will not) collaborate internationally in research, will (or will not) publish in international collaboration and will (or will not) publish in top academic journals.

The national aggregate of individual-level research performance determines national research performance, and the aggregate of individual-level collaboration patterns in research determines dominating national collaboration patterns. In IRC, the abstract levels of 'countries' and 'institutions' are ultimately aggregates of individual scientists collaborating and publishing, more (or less) internationally. Understanding this individual-level determination of successes or failures of IRC is critical in understanding the future of IRC.

The individual scientist matters so much for IRC today because the modalities of IRC depend almost entirely on scientists themselves. They decide whether and with whom to collaborate, institutionally, nationally and internationally, and the decision to internationalise in research depends on individual choices based on reputation, resources, research interests, and the attractiveness of the potential research partner. In the empirical section of this report, different national and different institutional collaboration patterns have been shown in detail, with different levels of IRC between systems and within systems. However, the data used are merely aggregates of individual-level data derived from publications.

The crucial point is to create sufficiently attractive internationalisation-supportive research policies at various levels, from institutional to national (and international), to make sure that scientists are increasingly involved in IRC. A bottom-up approach, with maximum flexibility as to how, with whom and on which topic to collaborate internationally in research, unreservedly combined with the hard line of research excellence as defined through top publications alone, should always work better than any other set of recommendations for IRC programmes.

The international visibility of national research output hinges on prevailing patterns of collaboration and publishing. These can be changed over time by means of careful policy measures that promote advantageous patterns while discouraging others.

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List of abbreviations

ASJC	All Science Journal Classification
CEEC	Central and Eastern European Countries
EC	European Commission
ERA	European Research Area
ERC	European Research Council
EU	European Union
EU-13	Group of 13 EU countries: Bulgaria (BGR), Croatia (HRV), Cyprus (CYP), Czech Republic (CZE), Estonia (EST), Hungary (HUN), Latvia (LVA), Lithuania (LTU), Malta (MT), Poland (POL), Romania (ROU), Slovakia (SVK) and Slovenia (SVN). ISO 3-character country codes used
EU-15	Group of 15 EU countries: Austria (AUT), Belgium (BEL), Denmark (DNK), Finland (FIN), France (FRA), Germany (DEU), Greece (GRC), Ireland (IRL), Italy (ITA), Luxembourg (LUX), Netherlands (NLD), Portugal (PRT), Spain (ESP), Sweden (SWE) and United Kingdom (GBR). ISO 3-character country codes used
EU-28	Group of 28 EU countries: EU-13 and EU-15.
FOS	Fields of Science and Technology
FWCI	Field-Normalized Citation Index
GDP	Gross Domestic Product
GERD	Gross (domestic) expenditure on research and development
HE	Higher education
HEI	Higher education institution
IRC	International Research Collaboration
ISO	International Organization for Standardization
NUTS 1	Nomenclature of territorial units for statistics: major socio-economic regions
NUTS 2	Nomenclature of territorial units for statistics: basic regions for the application of regional policies
NUTS 3	Nomenclature of territorial units for statistics: small regions for specific diagnoses
OECD	Organisation for Economic Co-operation and Development
R&D	Research and development
RC	Research Collaboration
SJR	SCImago Journal Rank
SNIP	Source-Normalised Impact per Paper
STEM	Science, Technology, Engineering, Mathematics
WOS	Web of Science

Countries in this report and their ISO 3-character country codes

AUT	Austria
AUS	Australia
BEL	Belgium
BGR	Bulgaria
CHE	Switzerland
CHN	China
CYP	Cyprus
CZE	Czech Republic
DEU	Germany
DNK	Denmark
ESP	Spain
EST	Estonia
FIN	Finland
FRA	France
GBR	United Kingdom
GRC	Greece
HRV	Croatia
HUN	Hungary
IRL	Ireland
ITA	Italy
LTU	Lithuania
LUX	Luxembourg
LVA	Latvia
MLT	Malta
NLD	Netherlands
POL	Poland
PRT	Portugal
ROU	Romania
RUS	Russian Federation
SVK	Slovakia
SVN	Slovenia
SWE	Sweden
USA	United States of America

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1. Introduction

1.1. The changing dynamics of research collaboration

International collaboration in research is at the core of contemporary higher education and science systems. The number and percentage of internationally co-authored publications globally and across Europe have been on the rise, as has the mean distance between collaborating scientists, as the national and institutional data on international collaboration partners show. Academic enterprise takes international collaboration in research for granted, but its costs are rocketing. The phenomenal growth of collaboration between scientists located in different countries (and between institutions located in different countries) started after 1989, when the bipolar world in which scientists belonged either to the Soviet block or to Western countries collapsed.

In the last three decades, academic science has been increasingly global, and academic scientists clearly belong among the winners of the end of the Cold War (see Wagner 2008). The growth of international scientific collaboration is the most remarkable feature of the new global geography of science. While in 1970, internationally co-authored papers constituted only 1.9 % of articles indexed in Web of Science, in 1980 the share was 4.6 %, in 1990 it was 8.9 %, in 2000 it reached 16.1 % and in 2013 almost every fourth publication (23.1 %) had authors from more than one country (Olechnicka et al. 2019: 78).

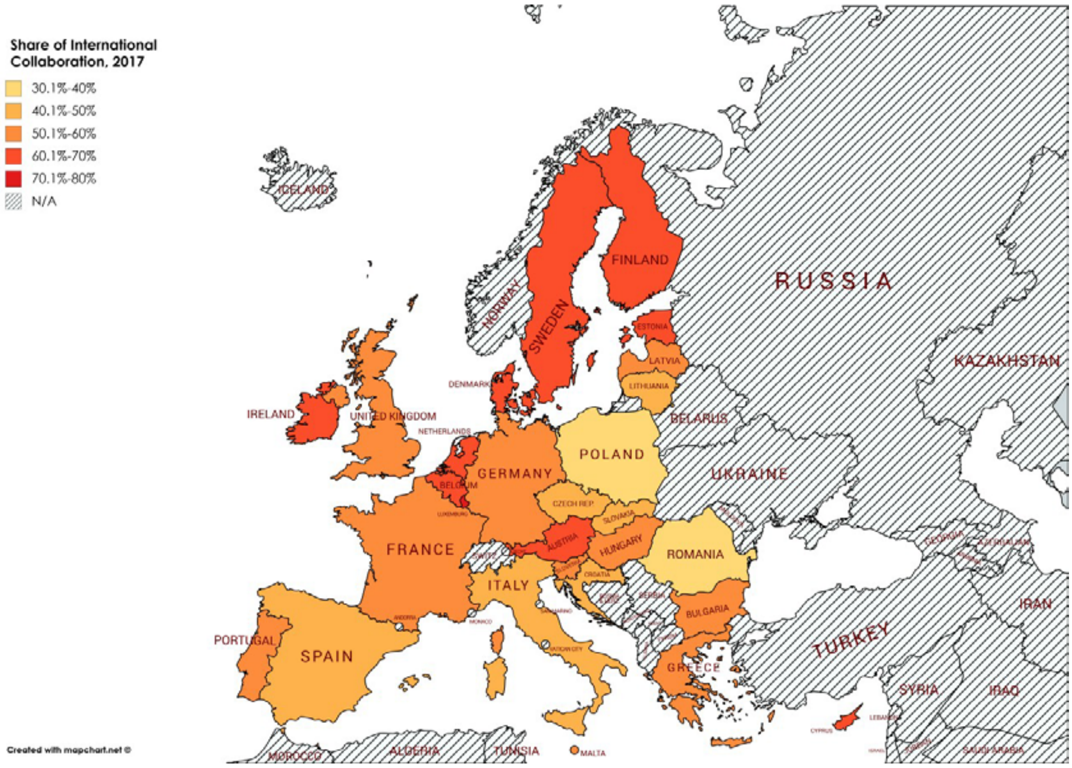
Both the number of internationally co-authored papers and their percentage share in the national publication output has been on the rise in the last decade across EU-28 countries (and across the world generally), with different dynamics of internationalisation in different countries and European regions (especially EU-15 vs. EU-13). Figure 1 and Figure 2 show the extent of the increase in the percentage share of international collaboration in 2007-2017; a mirror picture of these processes is the decrease in the percentage share of national collaboration in the same period, as shown in Figure 3 and Figure 4. These four maps show about a decade of fundamental changes and indicate that the processes of increasing international collaboration and decreasing national collaboration in research have different intensities across EU-28 countries. The direction of change is exactly the same, but the processes occur with different speeds.

In 2017, the two large EU-13 higher education systems in Poland and Romania had the lowest percentage share of international collaboration (Table 3). This finding is especially worrying because the two East European countries are relatively big and have been undergoing substantial higher education and science system reforms over the last decade. Higher density means higher levels of international collaboration (in Figure 1 and Figure 2) and higher levels of national collaboration (in Figure 3 and Figure 4). At the same time, significant differences across fields of science are observable. The dynamics of internationalisation in research also differs at the lower levels of disaggregation, especially if Europe is viewed through the lenses of NUTS 2 or NUTS 3 (subnational statistical units) regions or individual cities in which universities are located. However, the focus in this report is countries and institutions (selected, national flagship universities).

Figure 1. Percentage share of international collaboration, EU-28 countries, 2007 (in %).

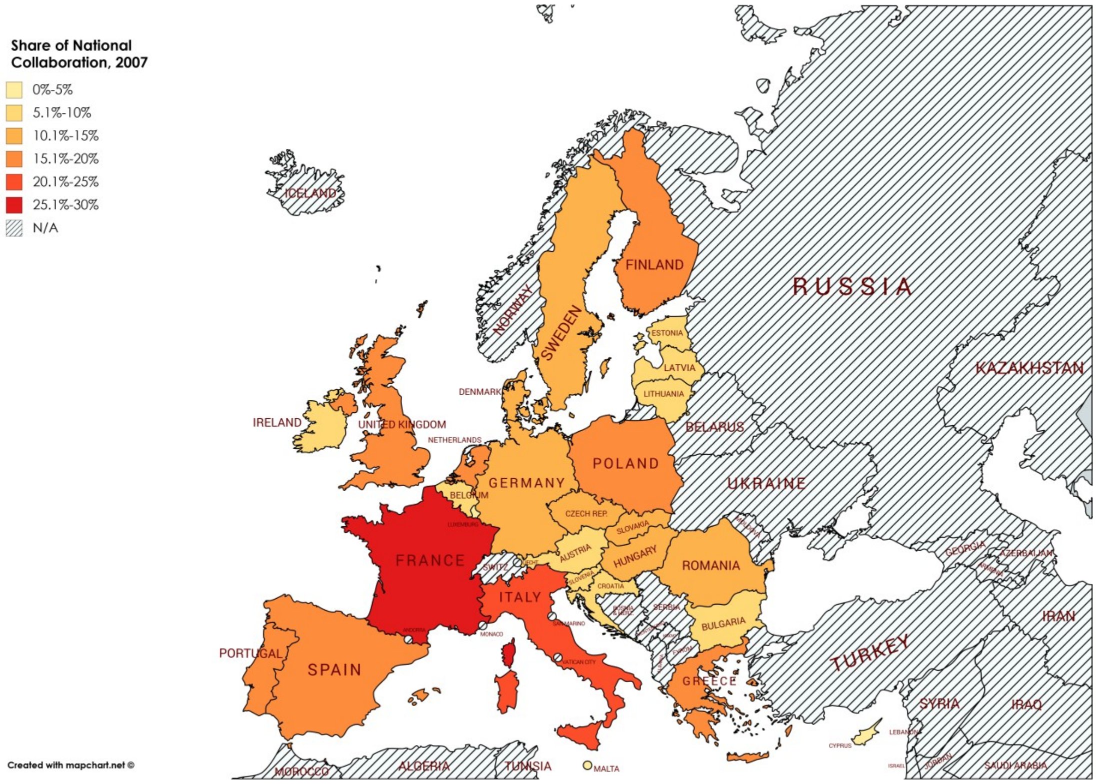
Source: author's own calculations based on SciVal (2019) data

Figure 2. Percentage share of international collaboration, EU-28 countries, 2017 (in %).



Source: author's own calculations based on SciVal (2019) data

Figure 3. Percentage share of national collaboration, EU-28 countries, 2007 (in %).



Source: author's own calculations based on SciVal (2019) data

Figure 4. Percentage share of national collaboration, EU-28 countries, 2017 (in %).

Source: author's own calculations based on SciVal (2019) data

1.2. International science and global science

While earlier academic science has certainly been international, today it is global and it is important to keep the concept of international science separate from that of global science in discussing internationalisation in research. The internationalisation statistics still uses large-scale national comparative data. International science implies that collaboration occurs fundamentally between nation-states and that groups of researchers from these nations work together, usually funded by their governments (Birnholtz 2007). Global science in contrast, describes activities in which 'researchers are free to join forces to tackle common problems, regardless of where they are geographically based'. The arguments for global science are summarised below, with 'knowledge-creating community' meaning in this context academic scientists. Global science is growing not because nations are promoting it, but because it serves the needs of those working within the knowledge-creation system. 'The invisible college is driven by the needs of the knowledge-creating community, which in turn is driven by the desire to do original and creative research' (Wagner 2008: 31-32).

The global character of science rather than the traditionally international character of it is of a critical importance for the study of international collaboration in research. In this report, global science as geographically located within EU-28 countries is analysed through globally-indexed publications and their authors' affiliations. However, the global scientific network is currently woven around the USA as a scientific powerhouse (Olechnicka et al. 2019; see Chang et al. 2013; Costa et al. 2013; Sa et al. 2017; Kato and Ando 2013; Lorigo and Pellacini 2007 and Qiu 2015 for field-specific studies). The US is the biggest international collaborative partner for China but also for the UK, Germany, France, Italy, Spain and the Netherlands, the biggest knowledge producers in Europe (see Table 6). The USA constantly occupies a stable position as the central hub of the global scientific collaboration network and it should be noted that China has gained a prominent position in the first decade of the 21st century. Consequently, the two comparator countries in this report focused on EU-28 countries are the USA and China.

International collaboration in research is reported to be increasing the overall competition in science: scientists are located in universities located in cities, regions, and countries. Therefore competing scientists mean also competing regions, and attracting top scientists to some of them rather than others increases their geographical concentration. Hubs (or centres) and peripheries in research collaboration (hitherto referred to as RC) emerge and evolve over time (as analysed in Lepori et al. 2013; Schubert and Sooryamoorthy 2010; Choi 2011).

Patterns of co-authorship in research journals have been changing: in some academic fields collaboration is merely a matter of choice while in others it is a matter of necessity. One set of patterns is the increasing average number of publication authors, closely related to academic fields, generally low in humanities and high in the natural sciences and medical sciences (to use the OECD classification of the six Fields of Science from *Frascati Manual*). Another set of patterns, much more interesting for the present study, is different collaboration types revealed in internationally-indexed publications. The pace of change related to internationally co-authored publications, or to what is termed in this study 'international research collaboration' (hitherto referred to as IRC), is not only different among the EU-28 countries studied (compared with the USA and China); it also differs substantially between fields of science within countries. This study shows cross-regional and intraregional European differences (EU-15 vs. EU-13) and within-nation differences from the perspective of the different fields of science and trends over time.

1.3. Different levels of RC

Both collaboration in research and its subtype, international collaboration in research, are generally difficult to define. However, for the purposes of this study a clear definition is adopted: IRC means publications co-authored by authors institutionally affiliated with institutions located in different countries. In this way, the definition adopted in the study will be fully compatible with the definition used in the global data set from which it derives data (Scopus and SciVal) for the two levels of analysis: national and institutional (Chen et al. 2019).

RC can be defined as a 'system of research activities by several actors related in a functional way and coordinated to attain a research goal corresponding with these actors' research goals or interests' (Laudel 2002: 5). Thus, collaboration presupposes that a shared research goal is defined by activities rather than by the actors involved, and the term is reserved for research that includes personal interactions. Given this definition, collaboration need not be focused on publishing articles. Collaborations may have no publication objectives at any point. There are many cases of collaborations that are not 'consummated' in a co-authored paper (Katz and Martin 1997). In addition, the writing of co-authored papers does not necessarily imply a close relationship between the authors (Luukkonen et al. 1992). Collaboration is largely a matter of social convention among scientists; what constitutes a collaboration varies across organisational levels and changes over time (Katz and Martin 1997). Broader notions of collaboration are not easy to measure, and therefore, many studies of RC 'begin and end with [a] co-authored publication' (Bozeman and Boardman 2014: 2-3).

Research literature has been dealing with the question of why academic scientists collaborate with other academic scientists. Perhaps the best answer is the simplest one: 'scientists collaborate because they benefit from doing so' (Olechnicka et al. 2019: 45). From this perspective, scientists are increasingly collaborating internationally because they are benefiting increasingly from this type of collaboration.

Collaboration is in the centre of academic careers as it increase academic recognition (Kwiek and Antonowicz 2015). Scientists compete for recognition (Merton 1973; Cole and Cole 1973; Hermanowicz 2012) but vary in their tendency to collaborate internationally: 'The more elite the scientist, the more likely it is that he or she will be an active member of the global invisible college', that is, collaborating with colleagues in other countries (Wagner 2008: 15; Piro et al. 2016; see Kwiek 2018c on collaboration patterns of Polish top research performers and Kwiek 2016 of top performers in 11 European systems).

The core (centre)-periphery distinction needs to be born in mind while analysing IRC. The global nature of science seems to increase the differences compared with its international nature. The world of science is unequal as is the world of international collaboration in science. New realities, and especially competitive pressures, seem to strengthen old differences rather than flatten them (Knight 2010). 'The dynamics of research internationalisation are unequally spread across the world, and the resulting global network is not horizontal, but shows a clear centre-periphery pattern…. The positive impact of collaboration is spatially diversified not only due to the varied intensity of scientific collaboration, but also because of the inherent disparities between collaborators. Hence, the advantages of collaboration are not necessarily evenly distributed among collaborating units' (Olechnicka et al. 2019: 77; Frenken et al. 2009 and Zanotto et al. 2016). In technical terms, different collaboration pairs lead to different average citation impacts of internationally co-authored publications (Nomaler et al. 2013; see FWCI in Table 5 for details): some internationally co-authored publications are systematically more highly cited than others.

Following Katz and Martin (1997), IRC, at an individual level, means collaboration between academics located in different countries (and not between academics with different nationalities located in the same country or in the same institution), while national collaboration means collaboration within a single country. However, international collaboration rests upon a much larger base of domestic activities (Georghiou 1998; Wagner 2006; Kwiek 2019b).

IRC can be either formal or informal (within or outside formal agreements and externally funded projects), and international publication co-authorship always requires a published product as an outcome of the cooperative efforts (Georghiou, 1998; Melin and Persson 1996). Informal collaboration works well when partners know and trust each other: 'during their professional careers, scientists establish many informal collaborations which form a substratum of their social network. It can serve as a source of inspiration and a reservoir of possible partners for joint research and other activities requiring cooperation' (Olechnicka et al. 2019: 45). Informal collaborations may evolve into formal cooperation.

Traditionally, IRC has been dominated by informal collaboration, which does not require formal international scientific agreements (Georghiou 1998). Scientists often 'self-select fellow collaborators … simply because the collaborator offers new ideas or complementary capabilities' (Wagner 2006: 3). Apart from the 'solo research' mode in science, internal collaboration (within the same organisation), domestic collaboration (within the same country), and international collaboration (between countries) must be clearly differentiated (Jeong et al. 2011: 969).

1.4. Local and cosmopolitan researchers

Some scientists are more consistently internationalised than others, and this distinction permeates European research. For internationalists, the international academic community is a reference group, while locals publish predominantly for the national academic community (Kwiek 2018a).

At an individual level, internationalisation plays an increasingly stratifying role, as more international collaboration tends to mean higher publishing rates (and higher citation rates), and those who do not collaborate internationally are increasingly likely to lose out in terms of resources and prestige, a process referred to as 'accumulative disadvantage' (Cole and Cole 1973: 146). Gouldner (1957) contrasted immobile and institution-oriented scientists (loyal to inside reference groups) to mobile, cosmopolitan, career-oriented scientists (loyal to outside reference groups). Professionals identify themselves with their reference group and refer to it in making judgments about their own performance. In this regard, cosmopolitans and locals differ sharply in their attitude to research, their sources of recognition, and their academic career trajectories (Wagner and Leydesdorff 2005). In a study of Norwegian scientists, Kyvik and Larsen (1997: 261) related the local/cosmopolitan opposition to publishing modes rather than to international collaboration: 'while locals can be said to have the Norwegian scholarly community as a frame of reference, cosmopolitans take the values and standards of the international scientific community as a comparative frame of reference. Those who are locally oriented subsequently will tend to publish in Norwegian, while those who have a cosmopolitan attitude will be more inclined to compete for recognition in an international setting'.

However, IRC does not occur at the expense of national RC; in fact, internationalists collaborate domestically on a massive scale, although this dimension of RC has rarely been studied (Sooryamoorthy 2014; Jeong et al. 2011). Internationalists tend to collaborate domestically more often than locals (Kwiek 2018a). European internationalists also collaborate more often domestically—in other words, international collaboration seems not to exclude collaboration with national peers. For instance, in the Polish case (Kwiek 2019b), only one in five internationalists (20.5 %) do not collaborate domestically. We can only speculate about the reasons for domestic non-collaboration, which may include lack of time for both types of collaboration, lack of funding for domestic collaboration, lower quality of national peers, or limited opportunities to co-publish internationally. Interestingly, only half of locals collaborate domestically. In other words, half of those who do not collaborate internationally also fail to collaborate domestically. This effect is highly differentiated across fields; about two-thirds of locals in humanities and social sciences do not collaborate domestically (63.3 %). The highest share of locals collaborating domestically is in the life sciences (71.6 %).

Internationalisation in research is thus highly discipline-sensitive. Previous research suggests that the 'collaborative imperative' dominates in academic science, especially in the hard disciplines (Lewis 2013; Kyvik and Larsen 1997; Sooryamoorthy 2017; Van Rijnsoever and Hessels 2011). In some disciplines, only internationally co-authored publications lead to academic recognition (Lewis et al. 2012) and, increasingly, to accessing national and international competitive research funding (Jeong et al. 2014; Melin 2000).

The vertical stratification of institutions (reflected in national and international ranking systems) and scientists (reflected in changing requirements for career progression) is reshaping national science systems globally and across Europe (Hermanowicz 2009; Nolan and Hunter 2012; Hunter 2015). In general, more productive scientists tend to collaborate more with international colleagues and the most productive or top performers are much more internationalised than their lower-performing colleagues (Kwiek 2019a: 23–71; Abramo et al. 2011b; Abramo et al. 2018). However, while research performance is directly correlated with intensity and propensity for international collaboration, the reverse correlation is not evident (Abramo et al. 2011a; see also Huang et al. 2011).

1.5. IRC, reward systems in science and individual scientists

As reward systems operate differently across countries and academic disciplines (Merton 1973), seeking international recognition is reported to be more or less 'necessary' (Kyvik and Larsen 1997: 260), depending on country affiliation and discipline. The level of internationalisation in research depends also on what Whitley (2000: 220) termed 'the structure of reputational audiences', which is different for different disciplines: reputation comes from different audiences, lay groups or groups of colleagues, national or international. Locals produce knowledge for local research markets and audiences; internationalists produce it for international markets and audiences, or both local and international ones (Kyvik and Larsen 1997).

The level of international orientation depends on the researchers themselves (Wagner and Leydesdorff 2005). Faculty internationalisation is reported to be disproportionately shaped by deeply ingrained individual values and predilections rather than institutions and academic disciplines (Finkelstein et al. 2013).

Academic discipline, employing institution and type, and national reward structure all matter for international collaboration. However, the decision to internationalise is ultimately personal, and concepts such as 'self-organisation' (Wagner and Leydesdorff 2005: 1610; Melin 2000: 39; Wagner 2018: 84; Hsiehchen et al. 2018) and 'informal collaboration' (i.e., conducted outside formal agreements) (Georghiou 1998: 612) are especially relevant in this regard.

The decision to collaborate internationally in research is thus always made by an individual academic working in an academic institution in a national setting. Within the global knowledge network, the motivation to internationalise comes from scientists themselves, and 'political ties or national prestige do not motivate the alliances of researchers' (Wagner 2018: viii; Kato and Ando 2017).

Policy-makers and funding agencies have encouraged IRC in the expectation that it will produce higher impact rates in science and technology, foster publications, and improve the quality of training (Jeong et al. 2014; Landry and Amara 1998; de Wit et al. 2015; de Wit and Hunter 2017). While the world seems to collaborate in research mostly on nation-by-nation basis, Europe is exceptional in terms of its long-term, large-scale intra-regional RCs (Hoekman et al. 2010; Georghiou, 1998), including collaborations funded by subsequent EU framework programmes for research in the last two decades.

According to traditional accounts of university academics (as presented over the decades in the sociology of academic careers literature), publishing defines academics more than any other academic activity. It is of critical importance to academic careers, progression across academic ranks, academic remuneration, as well as academic recognition or prestige. While national publishing is important in the vast majority of national systems, international publishing, especially in top academic journals, as the measurable form of IRC, is very important.

1.6. Win-win IRC and universities as prestige maximisers

The advantages linked to research internationalisation need to be juxtaposed with the costs (and possibly risks) of it. The personal decision to engage in international collaboration in research needs to be viewed in the context of the trade-off between collaboration investments and expected collaboration effects (Bikard et al. 2015). Maintaining too many or too demanding relations with international collaborators in research can lead to high costs of collaboration resulting from, among others, information overload, unclear responsibility, and communication constraints of diverse origins— the cost captured by the notion of high 'coordination costs' (Olechnicka et al. 2019: 111).

Apart from direct benefits of IRC, there are also indirect benefits, especially when collaborations are driven by external goals of their political, economic or cultural nature (a good example are historic scientific links between Europe and the USA, with an initial impact coming from large-scale military assistance, Georghiou 1998: 622).

Benefits and costs of IRC can be different for different stakeholders, even benefits and costs related to a single international collaboration.

There may be win-win collaborations in which both institutions and individual scientists win (probably the vast majority of collaborations). However, there are also three other options: win-lose collaborations, lose-win collaborations, and lose-lose collaborations, depending on whether only scientists or only institutions or both scientists and institutions are losing. In most general terms, the losses can be either financial, or reputational, or both.

For instance, there may be IRCs in which institutions are clearly on the losing side— having their internationally collaborating scientists spending time away from their employing institutions, away from institutional colleagues and students, and at the same time not publishing in top academic journals (the major source of academic prestige which is transferable from individual scientists to their institutions). Win-win IRCs would be those collaborations which provide reputational gains to scientists and financial and/or reputational gains to their institutions. Win-win collaborations— linking winning scientists with winning institutions— are best explained in the prestige maximisation model of higher education institutions.

According to this model, universities act largely as 'prestige maximisers' (Melguizo and Strober 2007: 634; Slaughter and Leslie 1997: 114), as institutions, departments and individual scientists constantly seek to maximise their prestige. The model focuses on individual prestige generation through publications, research grants, patents and awards. However, not all publications and research grants generate prestige; elite journals and highly competitive research funding are preferred. This model views prestige largely as a rival good, based on relative rather than absolute measures, where prestige accumulation is a zero-sum game (Brewer et al. 2002: 30). In a zero-sum game, 'what winners win, losers lose' (Hirsch 1976: 52).

Academia is becoming ever more competitive, encouraged by deliberate government policies that emphasise 'prestige, at all levels from the national system to the individual' (Blackmore 2016: 1). Like individual scientists, universities compete in prestige markets, grounded in the traditional ethos of academic work, where publication is highly valued. In particular, the model posits a strong link between individual and institutional prestige: 'In maximising their individual prestige, faculty members simultaneously maximise the prestige of their departments and institutions' (Melguizo and Strober 2007: 635). Individuals who help to enhance their institution's prestige are rewarded with higher salaries (Kwiek 2018b); more publications in prestigious outlets and more prestigious research grants elevate institutional prestige, leading ultimately (albeit not directly) to higher individual salaries. This model explicitly assumes purposeful behaviour on the part of all actors in pursuit of their own self-interest and prestige. In particular, it assumes the existence of competitive markets in higher education (Melguizo and Strober 2007: 635).

The theory of academic capitalism posits that Anglo-Saxon universities reorient themselves to win this game (Taylor et al. 2016). Research commonly takes priority over instruction, and public research funding is on the rise, further consolidating the prestige economy (Rosinger et al. 2016) in which universities increasingly operate. Across the world, national, institutional and departmental policies and research assessment exercises prioritise prestigious journals over the less prestigious. As prestige maximisers, universities (and individual scientists) have to compete for critical resources, and as the theory of academic capitalism argues, publication in elite journals is a key dimension of this competition (Slaughter and Leslie 1997: 114).

Consequently, the win-win IRC can be defined as the one in which both individual scientist and his or her institution maximise their prestige — as universally measured through highly cited publications published in top academic journals, as well as highly competitive research grants received or top academic awards granted. Interestingly, at the lower level of aggregation, while scientists and their institutions may be on the winning side, students can be on the losing side. The costs and benefits of IRC for scientists and their institutions (most often described in terms of research achievements) may be different from its costs and benefits for students.

1.7. Aims of the present study

The aim of the study is to analyse, based on large-scale data on publication and citation trends over time (within the last decade), the changing nature of academic knowledge production in EU-28 countries towards its radically increasing internationalisation. This quantitative study analyses the macro-level of countries and the meso-level of institutions to assess the cross-national and cross-institutional differentiation in the pace of these changes and their depth. The study examines bibliometric data about the internationalisation of research in the theoretical context of international scientific collaboration literature and suggests policy options concerning its improvement at the European level. The empirical analysis is preceded by a section on the motivations and one on the major barriers connected with the processes of research internationalisation.

2. Drivers behind the need to internationalise research

2.1. Motivation, informal communication and research resources

The most common level for the analysis of IRC in the research literature has been the individual level (see e.g. Katz and Martin 1997). The benefits of collaboration include the sharing of knowledge, skills and techniques ('if two or more researchers collaborate, there is a greater probability that between them they will possess the necessary range of techniques'), the transfer of knowledge and skills (especially that much of the knowledge may be tacit), a clash of views and a cross-fertilisation of ideas, and finally, collaboration provides intellectual companionship (Katz and Martin 1997: 14-15). Moreover, collaboration has the effect of expanding a network of contacts in the scientific community: 'an individual researcher may have good contacts with 50 or 100 other researchers in his or her field around the world whom he or she can contact for information or advice. By collaborating with others in another institution or country, the individual can greatly extend this network. In addition, collaboration can enhance the potential visibility of the work. Using their network of contacts, one's collaborators can diffuse the findings, either formally or through informal discussions' (Katz and Martin 1997: 15).

A major driver of international collaboration in research is motivation: individual motivation and project motivation (Jeong et al. 2014: 524). Status understood through the proxy of academic position is a key factor in understanding IRC. Consequently, collaborations expected to provide higher productivity and publication rates may appeal more to researchers at lower levels of academic careers (Franceschet and Costantini 2010). Younger researchers might be more likely to undertake international collaboration than researchers who require less academic achievement for promotion. In addition to personal motivation, motivation driven by the type of work can also influence the likelihood of international collaboration in research. 'Researchers tend to be less collaborative during operational tasks than during strategic ones, implying that researchers will prefer to collaborate in fields where they can share basic ideas and fundamental knowledge rather than in fields where they may develop commercially viable results, because development-oriented research would require more attention to complex matters such as the sharing of outputs (for instance through patents), effective and frequent communication in dealing with the complexities of research, and the exchange of results' (Jeong et al. 2014: 524).

Collaboration in science is driven by multiple motivations at the microlevel of individual scientists; while the motivations of national governments and individual institutions are generally clearly formulated and can be studied on the basis of national and institutional documents, the motivations of scientists are best studied through survey and interview methodologies (see Kwiek 2019a on intra-European differences). The reward system in science and the ethos of science as the two important driving forces behind internationalisation of research have been intensively studied in the sociology of science literature for about half a century.

However, the transition from international science to global science as a dominating paradigm may be parallel to the processes of the increasing importance of individual-level motivations, at the expense of the importance of national motivations (see Wagner et al. 2015). Interestingly, the power of institutional motivations seems to be stable over time; this is especially understandable in the context of prestige maximisation theories which link the individual prestige gained by scientists to institutional prestige gained by institutions that employ them. As IRC, especially in the form of highly cited internationally co-authored publications, increases individual prestige, it is powerfully supported at the institutional level (deans, rectors, presidents, governance boards).

As scientific collaboration involves relationships between people (Villanueva-Felez et al. 2013), personal factors play an important role in this process: personality, preferable modes of scientific work, mutual trust, understanding, and working styles. Collaborating scientists not only can utilise others' competences, but they can also acquire hardly transferable tacit knowledge. On top of this, publishing is the core activity of academic scientists and of higher education and science systems (Hara et al. 2003; Gorraiz 2013).

The drivers of international collaboration are also resources, academic excellence and informal communication (Jeong et al. 2014; Jacob and Meek 2013; Leydesdorff and Wagner 2008; Ynalvez and Shrum 2011; and Van Rijnsoever and Hessels 2008; see Fraunhofer ISI Idea Consult SPRU 2009-15 and Table 1 for more details). As the authors summarise their research, 'our empirical results suggest that substantial financial and attentional resources, academic excellence, individual motivation, and active informal communication play significant roles in encouraging international collaboration' (Jeong et al. 2014: 521). This study also shows practical implications: it is necessary to provide substantial resources for research budgets (enlarging the budget of research projects) and research time-frames (reducing scientists' teaching loads and providing sufficient time for research projects) in order to promote voluntary and spontaneous, that is to say bottom-up or self-organised, international collaboration which is known to produce superior research outcomes.

Scientists constantly seek potential partners with whom they can profitably collaborate (Iglic and Kronegger 2017; Zheng et al. 2014; Ma et al. 2014). The academic excellence encourages forming international partnerships (Wagner 2006; Ahn et al. 2014; Mihut et al. 2017). A research organisation's brand matters as much as its international prestige, in the current circumstances, often expressed through the ranks in international academic rankings. The same pattern is relevant for the collaboration between individual scientists: 'potential research partners may expect a steeper increase in research output by collaborating with an excellent research group…. Academic excellence may increase the tendency of researchers to participate in international collaboration because of the relatively high benefits of international collaboration and the lowered cost of searching for it' (Jeong et al. 2014: 521; Abramo et al. 2014). Researchers may tend to be less collaborative regarding research that yields commercially profitable results: because of the differences in legislation between countries, there might be legislative barriers as to the sales of the products/services that would hinder researchers to collaborate internationally (as is the case with patents). However, this study is focused on international collaboration in research as viewed through the proxy of internationally co-authored publications indexed in global databases; international collaboration as viewed through joint patents is an interesting avenue for future research.

Table 1. The drivers of IRC.

- Geographic proximity: neighbouring countries often have similar research or complementary interests and common publication profiles.
- History: Ties that form human, linguistic or other ties, because of historical interactions (including colonial relationships) support present day collaborations.
- Common language: A shared language facilitates collaboration.
- Specific problems and issues: Common problems, such as disease control or natural disaster mitigation.
- Economic factors: Factors include investment in a particular field because of research priorities set by scientists and policymakers, individual scientists collaborating with particular universities, and the need to share facilities and equipment.
- Expertise: Collaborations can be driven by the need for the best, or most appropriate, expertise to pursue the objectives of the scientific query. - The presence of particular research equipment, databases, and laboratories in a country can give rise to international collaboration.
- Political factors: Globalisation and internationalisation, the ambitions concerning ERA, support to third countries in dealing with global challenges etc.

2.2. The role of informal communication in IRC

Previous research findings emphasise the importance of networks for IRC, knowing people in one's own field and communicating with them (Melin 2000), with an important role of such concepts as personal chemistry, respect, trust, and joy. Personal chemistry is reported to be 'a prerequisite for research collaboration. The individuals quite simply have to like each other and get along well' (Melin 2000: 36). The message of interviews conducted with scientists (Melin 2000: 36) is clear: 'leave it to the researchers themselves. They are the experts, they know what they need to do in order to advance their work and move on, and the politicians and funding agencies should provide the money and facilities.… Attempts to direct collaboration towards a certain country for instance, are viewed with great suspicion by the researchers'.

There are two types of informal communication which are major drivers of international collaboration in research: passive informal communication and active informal communication. Research literature shows that most scientific collaborations begin informally. The role of informal communication in fertilising RC has also been emphasised (Katz and Martin 1997). Informal communication usually starts with accidental encounters that lead researchers to explore opportunities of collaboration. Face-to-face communication plays a critical role, because it is generally considered to be a direct method to build a mutual understanding and trust between the collaborators (Jeong et al. 2014). Most collaborations begin with a face-to-face meeting (Laudel 2002) rather than with merely electronic communication (with substantial implications for overall costs of IRC).

Apart from passive informal communication, there is also active informal communication for which the temporary change in a researcher's location is needed. As commented, 'on-site networking with foreign researchers may widen the human capital that domestic researchers might lack: a second-hand introduction to another researcher may also increase the likelihood that potential research partners participate in international collaborations' (Jeong et al. 2014: 525).

The drivers of IRC also include increased visibility, new knowledge and contacts of value for the future. A pragmatic attitude to collaboration means that 'when there is something to gain, then a particular collaboration will occur, otherwise it will not. Very often, there has to be a personal chemistry at play as well, sometimes even friendship. Furthermore, the collaborations have taken place without other initiators than the researchers themselves.… There seems to be a strong pragmatism at work together with a high degree of self-organisation.… Initiatives and directives from politicians and funding agencies are not welcomed by the scientific community and can lead to the establishment of contact with people other than the scientifically most interesting ones' (Melin 2000: 39-40).

2.3. Geographic and cultural proximity in IRC

Apart from geographic proximity (or spatial proximity) as an important factor in IRC (see Ahlgren et al. 2013; Heringa et al. 2014; Hoekman et al. 2010; and Kabo et al. 2014; Pan et al. 2012; Sanchez-Jimenez et al. 2017), also cultural proximity matters. What has been reported in the literature is the role of the 'invisible college', the tendency of graduates to collaborate only with other graduates of their schools, with similar cultural and academic traditions, forming strong professional network ties (Luukkonen et al. 1992; Katz and Martin 1997; Crane 1972). The academic excellence issue means that at both individual and institutional levels, the attractiveness plays a crucial role in IRC (Wagner 2008). Not only the formation of a collaboration but also its impact advantage is proportional to the academic excellence of its participants (Jones et al. 2008).

Research shows a significant relationship between academic excellence and the probability of co-authorship: the more experienced the researcher, the higher the tendency to collaborate; the more highly ranked the academic department to which the researcher belongs, the higher his propensity to collaborate; and the higher the author's rank, the higher his or her inclination to collaborate (Jeong et al. 2011). Fundamentality as a concept related to IRC means that the more basic the field, the greater the proportion of international co-authorships. And the concept of external fund inspiration means that research funding is an important dimension of RC.

2.4. Why researchers engage in IRC

Wagner (2005: 6) presented a useful classification of sciences by motivation for international collaboration. Not all sciences are equally driven by the internationalisation demand: the four types of international collaboration are data-driven collaboration (as in genetics, demography, epidemiology), resource-driven collaboration (as in seismology, zoology), equipment-driven collaboration (as in astronomy, high-energy physics), and theory-driven collaboration (as in mathematics, economics or philosophy). Wagner (2005) shows that different motivations for international collaboration affect the extent and patterns of the internationalisation of research as viewed through internationally co-authored papers.

The classification of sciences has to be imposed in analysis on the classification of factors relating to the organisation of international collaboration in research. Wagner (2006: 2) enumerates five major reasons why researchers engage in international collaborative activities: (1) they can increase their visibility among peers and exploit complementary capabilities; (2) they are able to share the costs of projects that are larger in scale or scope; (3) they are able to access or share expenses for physical resources; (4) by working together, they can achieve greater leverage by sharing their data; and (5) they need to exchange ideas in order to encourage greater creativity. International collaboration in research can be located along a continuum from highly distributed to highly centralised (horizontal axis related to locations of research) and along a continuum from organised or top-down to spontaneous or bottom-up (vertical axis related to funding) (Wagner 2006: 2).

As incentive and reward systems in European science evolve to become more output-oriented (Kyvik and Aksnes 2015; Kwiek 2019a; see Kwiek 2018b on productivity-earnings links); individual scientists are under increasing pressure to cooperate and co-publish internationally. In general, multiple-institution papers are more highly cited than single-institution papers, and internationally co-authored papers are more highly cited than those with domestic co-authors (Narin and Whitlow 1990). Collaboration is increasing at author, institution, and country levels (Gazni et al. 2012). This increase in collaboration is attributed to the use of performance-based funding systems.

At the same time, the Mertonian principle of priority of discovery suggests that IRC is driven primarily by reward structures in highly competitive science systems, especially in the hard sciences (Kyvik and Larsen 1997). As Wagner and Leydesdorff (2005: 1616) have argued, 'highly visible and productive researchers, able to choose, work with those who are more likely to enhance their productivity and credibility.' According to Wagner and Leydesdorff, 'the many individual choices of scientists to collaborate may be motivated by reward structures within science where co-authorships, citations and other forms of professional recognition lead to additional work and reputation in a virtuous circle' (2005: 1616).

The relationships between international cooperation and research productivity have been widely discussed in research literature, with a general assumption that collaborative activities in research, including international collaborative activities, tend to increase research productivity (see the various theoretical and data-driven papers: Teodorescu 2000; Godin and Gingras 2000; Lee and Bozeman 2005; Shin and Cummings 2010; Fanelli and Larivière 2016; Kwiek 2014; Rostan and Ceravolo; Rostan et al. 2014; Jung et al 2014; Woldegiyorgis et al. 2015 and Abramo et al. 2011a).

2.5. IRC intensity in different academic fields and academic generations

However, the national and international collaboration intensity is not uniform across different academic fields (Abramo et al. 2009). As Lewis (2013: 103) showed on a sample of academics interviewed in Australia, New Zealand and the UK, research in 2008 in these countries was done 'alone' by about two third of academics in the humanities and only by one in fourteen academics in natural sciences (65.6 % vs. 7.4 %); it was done 'with others' by only one in seven in the humanities and by three fourths in natural sciences (13.5 % vs. 75.3 %) for the rest of academics, the option was 'mixed'.

Availability of resources increases the level of IRC (Kyvik and Larsen 1997; Jeong et al. 2014). Beyond that, scientists create and sustain the connections that form the global knowledge network largely because they 'become resources to others … connections are retained as long as they are of mutual (or potential) interest to participating members' (Wagner 2018: 62). In short, networks mean (international) collaboration.

IRC varies by academic generation (Kwiek 2018a; Marquina and Jones 2015) as well as by country and academic discipline (in this report: field of science or FOS as defined by the OECD). Scientists entering universities in different eras encounter different career opportunities and academic norms (Stephan and Levin 1992). Changes in productivity and collaboration patterns across academic generations are in part explained by changing norms of appropriate academic behavior, in which international collaboration figures prominently (Kyvik and Aksnes 2015).

As Kwiek (2019a) has shown, a cross-generational European comparison reveals that the highest percentage share of scientists collaborating with international research partners is found among the oldest generations. In the 11 countries studied, the percentage share of internationally collaborating scientists was never highest for the youngest academic cohort. This is perhaps unsurprising, as IRC needs time to develop as well as access to funding (Jeong et al. 2014). However, there were substantial cross-country differences, notably between Germany, Poland, and Portugal on the one hand and the Netherlands, Ireland, and the UK on the other. In the former group, the share of internationalists (defined as scientists collaborating with international colleagues in research) in the youngest generation was about 40-45 %, rising to about 80 % in the latter countries.

Academics are central to the success of internationalisation in research: they can be more or less (or not at all) internationally-minded in their research (Isabelle and Heslop 2011). The imperative to internationalise is reported to be stronger in smaller and more peripheral countries: 'For systems on the periphery, the imperative to internationalise is strong and unambiguous. … For core systems and those closer to the core, especially large systems, the motives are weaker and more ambiguous. There is simply less at stake. … In all cases, the decision to 'engage' internationally comes down to the decision of individual academic staff and their institutions' (Finkelstein and Sethi 2014: 237-238). The role of individual scientists in IRC is fundamental: faculties, institutions, academic disciplines and, finally, the whole national systems, can be more or less internationalised in research not only because public funding available for IRC is higher or lower; perhaps more importantly, they can be more or less internationalised because individual scientists tend to make their own decisions favouring or not favouring IRC. An aggregate of individual choices define the strength of internationalisation in research at all levels, from faculty-levels to institutional levels to national ones.

3. Barriers linked to research internationalisation processes

Barriers to IRC may include macro-level factors (geopolitics, history, language, cultural traditions, country size, country wealth, geographical distance); institutional factors (reputation; resources); and individual factors (predilections, attractiveness) (see Georghiou 1998; Hoekman et al 2010; Luukkonen et al. 1992; Knoben et al. 2006; Kumar et al. 2014; Jiang et al. 2018; Plotnikova and Rake 2014; Lorigo and Pellacini 2007).

A recent extensive study of IRC among women engineers and its barriers shows a number of potential barriers to international collaboration: lack of funding, finding collaborators, communications (different languages, managing personal/family commitments, managing work commitments (obligations in the place of employment), and time commitments to initiate/conduct the collaboration (Fox et al. 2016; see Larivière 2016; Bozeman and Gaughan 2011; Misra et al. 2017).

Funding is essential for international projects and it is a crucial component for agencies promoting international collaboration. Funding is a potential driver for IRC and the lack of funding is a significant barrier for it. Locating research partners is essential and finding collaborators across distant regions is recognised as a potential challenge. Absence of face-to-face communication at conferences or research sites may impede international collaboration (Ynalvez and Shrum 2011). 'Home and work conflict can shape IRC through constraints on geographical mobility, and in turn, international collaboration. This is because household and family demands can make geographic mobility difficult to manage' (Fox et al. 2016: 6; see Jonkers and Cruz-Castro 2013). Most importantly, 'barriers to collaboration are compounded when research involves scientists from different countries, regions, and educational systems' (Fox et al. 2016: 6). For women engineers, and possibly, by extension, for women scientists in general, the highest ranking impediments are the two relatively external barriers: lack of funding and finding collaborators. In this sense, IRC is strongly gendered, as is international research mobility in general (see Ackers 2008), and the main factors inhibiting IRC are external rather than internal to the science system.

Transaction costs in collaborations can be ex ante transaction costs (required to establish a contract) and ex post transaction costs. In collaborative research, the latter costs include joint decisions made by the researchers regarding research objectives and orientations, preparation of grant proposals, work plans, research design and methodology, use of financial resources, human resources, equipment and data, and preparation of publications (Landry and Amara 1998: 904). The interplay of possible future publications, current coordination costs, and current additional funding is important in discussing benefits and costs of collaboration.

The costs of collaboration can take a variety of forms. First, travel and subsistence costs are substantial. Although scientists use electronic communication, international collaboration requires face-to-face meetings, be they informal or formal (in project meetings and in conferences and seminars).

Moving between geographical locations on the part of scientists — a principal component of IRC — is a considerable research cost to institutions. And indirectly, to individual countries through either core funding or competitive funding, especially through various national research funding agencies. Costs of international physical mobility have been on the rise across all European science systems for all staff categories, including scientists and management personnel.

Another cost is time as an academic resource. According to resource allocation theory, the attentional resources that scientists and their teams can invest in research in terms of their commitment and time are always limited. This theory holds that 'the resources allocated to a function will decrease as resources allocated to other functions increase' (Jeong et al. 2014: 523).

Consequently, the decision to engage in research teamwork 'is ultimately a resource allocation decision by which members must decide how to best allocate their limited resources' (Porter et al. 2010: 241), as time is often a more valuable resource than research funding (Katz and Martin 1997). Additional requirements can reduce the available time and energy for actual research activities (Jeong et al. 2011). Collaboration also involves personal decisions based on 'trust' and 'confidence' (Knorr Cetina 1999), as well as 'purpose', involving multiple issues that range from 'access to expertise' to 'enhancing productivity' (Beaver 2001: 373).

Time in international collaborations is spent in preparing a joint proposal or securing joint funds from research sponsors, and in jointly defining the research problems in planning the research approach. Different parts of the research may be carried out at different locations, again introducing time costs: 'time must be spent keeping all the collaborators fully informed of progress as well as deciding who is to do what next. Differences of opinion are almost always inevitable and time will be needed to resolve these amicably. … Moreover, besides these direct time costs, there are also such indirect time costs is a recovering from the effects of travel, working in an unfamiliar environment, and developing new working and personal relationships with one's collaborators' (Katz and Martin 1997: 15).

The next cost of collaboration is increased administrative costs of research: with more people and more institutions involved, greater effort is required to manage the research. And still another cost when institutions are collaborating is the clash of different management cultures, financial systems, rules on international property rights, differences over reward systems, promotion criteria and timescales etc.

Finally, IRC is part of RC in general. 'All international cooperation rests upon a much larger base of domestic activity. Given the costs of cooperation (and the existence of a considerable amount of research for which no cooperation is necessary) there is only so much which a given national base can support, particularly as cooperation funds are largely for incremental costs only' (Georghiou 1998: 625). The phenomenal growth of IRC from cross-national and cross-institutional perspectives will be discussed in two empirical sections of the study.

As research is becoming increasingly distributed, and as IRC through internationally co-authored publications is becoming the dominating mode of publishing across the EU-28 systems, coordination costs need to be taken into consideration. Empirical studies show that RC involving multiple universities impose significantly higher coordination costs then do single university collaborations.

Participating universities often have dissimilar institutional structures, different cultures and norms (Cummings and Kiesler 2007), a good example being tiers of academic journals to publish. 'Geography also increases the coordination costs for multi-university collaborations. Geographical distance can slow group communication and consensus making, and a problem at one location may go unnoticed by researchers at the other universities. Higher coordination costs of collaborating across universities are likely to complicate both disciplinary and multidisciplinary research, potentially affecting the success of these collaborations' (Cummings and Kiesler 2007: 1621). However, despite increasing coordination costs of IRC, its growth expressed by a simple measure of the number and the percentage share of internationally co-authored papers seems unstoppable. Across EU-28 countries, internationally co-authored papers become the norm, not the exception, as the two empirical sections of this report show.

4. Data sources and methodology

4.1. Data sources and timeframe

The data analysed in this report have been retrieved from Scopus, the largest abstract and citation database of peer-reviewed literature covering almost 40,000 journals, book series and conference proceedings by some 6,000 publishers (owned by Elsevier) and SciVal, an Elsevier's research intelligence tool offering access to research performance of 230 nations as well as 12,600 institutions and their associated researchers worldwide.

The core of SciVal is based on output and usage (especially citation) data from Scopus. SciVal uses Scopus data from 1996 to current date, which covers 48 million records. SciVal receives a weekly update of new data from Scopus. Scopus coverage is multi-lingual and global and about 15 % of titles in Scopus are published in languages other than English. Scopus coverage is inclusive across all major research fields. The choice of Scopus rather than the Web of Science (WoS) global indexing data set in this report was motivated by higher coverage of academic journals, especially in EU-13 countries. However, it can be assumed that the trends and patterns, cross-national and cross-institutional differences shown based on WoS data would not be substantially different from those based on Scopus/SciVal data. At the same time, an analysis of country-based ratios of indexed to non-indexed scientific publications is beyond the scope of this study. It can be assumed that in general the indexed/non-indexed ratio is much higher for natural sciences than for social sciences and humanities because indexing systems were at first designed primarily for journals in natural sciences.

The report uses the 2007-2017 data assuming the timeframe to be long enough to analyse basic trends in research performance and changing collaboration types over time. Both patterns (in most instances, 2007 contrasted with 2017 or merely 2017) and trends over time (from 2007 to 2017, year by year) are shown at the selected levels of analysis. At the time of writing, the Scopus data for 2018 were not complete enough to be used. The comparator countries for EU-28 countries are the USA and China, the two biggest academic knowledge producers. Standard ISO 3-character country codes are used throughout the report. The Scopus and SciVal data sources aggregate publication and citation information from tens of millions of publications and therefore both missing values and discrepancies can be found in them. However, they should not have decisive impact on discussion on trends.

In general, being an exploratory study, the report does not analyse input (such as R&D expenditure or human resources available in national research and development sectors, as in OECD 2019) and its analysis of collaboration in research is limited to a single output data type: bibliometric data on publications (see Bar-Ilan 2008).

A single publication type, article, is studied in the report (and subsequently the other types for which full data are available, such as reviews, conference papers, editorials, short surveys, book chapters and books, are not examined). 'Publications' in this report mean 'articles' or 'papers' and the three words are used interchangeably. All publication and citation data have been aggregated to six major Fields of Science: engineering and technologies, agricultural sciences, humanities, natural sciences, medical sciences and social sciences, following OECD's *Frascati Manual*; for specific purposes, also an aggregation to all Fields of Science combined has been used. For each analysis, an appropriate level of data aggregation is mentioned.

The empirical core of this report is provided by the data collected from Scopus and SciVal in January 14-28, 2019. The procedures used in the data collection were as follows: 28 countries (EU-28) and 22 flagship institutions were selected. All the data refer to academic research rather than corporate research. Academic-corporate collaboration and its impact as well as patent data have not been studied. The 'Overview' and 'Collaboration' modules in SciVal were used to analyse countries and institutions separately and the 'Benchmarking' module was used to analyse them comparatively. In each case, each of the six Fields of Science were selected as a filter and the data were exported to a spreadsheet file (XLS). Subsequently a unique dataset was created based on all data exported. The data are fully replicable; however, while some data types are updated yearly (e.g. CiteScore Percentiles in the case of Scopus-indexed journals), other data types are updated on a weekly basis (e.g. Citation Count). Therefore, for instance while CiteScore Percentiles of top journals will remain the same throughout 2019, citation counts and scholarly outputs will vary, for both current and past years.

4.2. Definitions

The data used included:

Collaboration (the extent of international, national and institutional co-authorship, as well as no collaboration or single-authorship, percentage and total value; field-weighted data included only two collaboration types: international collaboration and national collaboration), 2007-2017, articles only.

Collaboration Impact (the average number of citations received by publications that have international, national or institutional co-authorship, as well as single-authorship), 2007-2017, articles only.

Scholarly Output (the number of publications of a selected entity: countries and institutions), 2007-2017, articles only.

Citation Count (total citations received by publications of the selected entities: countries and institutions), self-citations included, 2007-2017, articles only.

Field-Weighted Citation Impact (FWCI) (the ratio of citations received relative to the expected world average for the subject field, publication type and publication year), self-citations included, 2007-2017, articles only.

Outputs in Top Citation Percentiles (the number of publications of selected entities – countries and institutions – that are highly cited, having reached a particular threshold of citations received), shown as field-weighted, self-citations included. Threshold used: 1 %, 10 % and 25 %, percentage and total value. 2007-2017, articles only.

Publications in Top Journal Percentiles (the number of publications of selected entities – countries and institutions – that have been published in the world's top journals), shown as field-weighted, self-citations included. Threshold used: publications in 1 %, 10 % and 25 % of top journals, percentage and total value. CiteScore Percentiles used (rather than SNIP or SJR), 2007-2017, articles only.

Citations per Publication (the average number of citations received per publication), self-citations included, 2007-2017, articles only.

4.3. Two levels of analysis: the meso-level of institutions and the macro-level of countries

The internationalisation of EU academic research is measured at two separate levels closely related to each other: the meso-level of institutions and to the macro-level of countries. And, at a higher level, the aggregates of EU-28, EU-15, and EU-13 are analysed in the global context of China and the USA. China, the USA, and EU-28 are the three largest global producers of scientific output.

The selection of 22 institutions across EU-28 countries is methodologically justified as follows. Among several approaches analysed in preliminary stages of the project, the most suitable one was chosen: in each EU-28 country for which global bibliometric data are available, a single national flagship institution was preliminarily chosen for further analysis. As a whole study is grounded in detailed research-related (output and citation) data on internationalisation (rather than in the data related to internationalisation of teaching or service), CWTS Leiden Ranking 2018 (http://www.leidenranking.com/) was consulted at the level of individual institutions. This ranking was chosen because it uses bibliometric data (rather than survey data on institutional reputation) so that the Leiden Ranking fits the research purpose of the study better than any other global ranking. Among the criteria applied to European institutions, the number of publications listed among the top 10 % highly cited publications was used (with a threshold of 100 publications published in 2017; consequently, institutions from relatively resource-poor or small systems of Bulgaria, Cyprus, Latvia, Lithuania, Romania and Malta are not analysed to avoid the problem of vastly different scale of institutional research outputs). The list of institutions analysed is shown in Table 13.

4.4. The overall approach to collaboration in science in this study

IRC was analysed in the context of the three other collaboration types: institutional RC (multi-authored research outputs, where all authors are affiliated with the same institution in a European country), national RC (multi-authored research outputs, where all authors are affiliated with more than one institution within the same European country), and single authorship (or no collaboration, single-authored research outputs where the sole author is affiliated with an institution in a European country). In this approach, compatible with the Scopus and SciVal data sets used, the four collaboration types are complementary and the whole academic knowledge production — in the form of peer-reviewed publications — can be divided between publications which have been produced with no collaboration involved or with institutional collaboration involved, national collaboration involved or international collaboration involved.

The study is theoretically grounded in the global research literature about IRC (its motivations and drivers, advantages and costs, major barriers etc.) and its empirical part is used to support selected findings from previous research. In this way, the report combines theoretical knowledge about IRC, especially the knowledge produced in the last decade, with the most up-to-date empirical data and its analysis.

The exact definitions of all metrics used in the report (and especially the metrics used in the SciVal data set) are provided in inserted boxes (see www.scival.com).

4.5. Research metrics used in the study

Collaboration Metrics

Collaboration in SciVal indicates the extent to which an entity's (country, organisation, individual scientist) publications has international, national, or institutional co-authorship, or single authorship.

Each publication is assigned to 1 of 4 mutually exclusive collaboration types, based on its affiliation information: international, national, institutional, or single authorship. A single publication may of course display each of international, national and institutional collaboration in its affiliation information, but a single collaboration type is assigned to ensure that the sum of an entity's publications across the 4 categories adds up to 100 % of the publications with the necessary affiliation information.

When field-weighting collaboration, a score is calculated using the same methodology as for the calculation of the Field-Weighted Citation Impact. The document level international/national collaboration ratio is computed based on the expected international/national collaboration for that document type, publication year grouping and subject area assignment. The option to field-weight is only available for collaboration on the international and national level.

- Field-weighted collaboration of 1.00 indicates that the entity's collaboration has been exactly as would be expected based on the global average for similar publications; the Field-Weighted collaboration of 'World', or the entire Scopus database, is 1.00.

- Field-weighted collaboration of more than 1.00 indicates that the entity's collaboration has been more than would be expected based on the global average for similar publications; for example, 2.11 means 111 % more than the world average.

- Field-weighted collaboration of less than 1.00 indicates that the entity's collaboration has been less than would be expected based on the global average for similar publications.

Collaboration Impact Metrics

Collaboration impact in SciVal indicates the citation impact of an entity's publications with particular types of geographical collaboration: how many citations do this entity's internationally, nationally, or institutionally co-authored publications receive, as well as those with a single author?

Publications are assigned to 1 of 4 mutually exclusive geographical collaboration types, as explained for collaboration. This assignment applies to the entity's publications only, and the count of citations received is not limited to the geographical collaboration status of the citing publications themselves; if an internationally collaborative publication is cited by another publication with single authorship, that citation is still counted.

Field-Weighted Citation Impact (FWCI) Metrics

Field-Weighted Citation Impact (FWCI) in SciVal indicates how the number of citations received by an entity's publications compares with the average number of citations received by all other similar publications in the data universe: how do the citations received by this entity's publications compare with the world average?

• A Field-Weighted Citation Impact of 1.00 indicates that the entity's publications have been cited exactly as would be expected based on the global average for similar publications; the Field-Weighted Citation Impact of 'World', or the entire Scopus database, is 1.00.

• A Field-Weighted Citation Impact of more than 1.00 indicates that the entity's publications have been cited more than would be expected based on the global average for similar publications; for example, 2.11 means 111 % more than the world average.

• A Field-Weighted Citation Impact of less than 1.00 indicates that the entity's publications have been cited less than would be expected based on the global average for similar publications; for example, 0.87 means 13 % less than the world average.

Similar publications are those publications in the Scopus database that have the same publication year, publication type, and discipline, as represented by the Scopus journal classification system.

This parameter allows an easy understanding of the prestige of an entity's citation performance by observing the extent to which its Field-Weighted Citation Impact is above or below the world average of 1.00. It presents citation data in a way that inherently takes into account the lower number of citations received by relatively recent publications, thus avoiding the dip in recent years seen with Citation Count and Citations per Publication.

5. Empirical analysis – A macro-level of European countries

Both the total number of articles (Figure 5), the total number of number of internationally co-authored articles (Figure 6) and their percentage share in the national output (Figure 7) have been on the rise in the last decade across all EU-28 countries (and across the world generally). Figure 6 shows the IRC trend in nominal terms (increasing publication numbers) and Figure 7 shows the IRC trend in percentage terms (increasing share of internationally co-authored articles among all articles published).

Of the three largest global producers of academic publications, EU-28 in 2017 had the highest share of its articles written in international collaboration (44.4 %), and China the lowest (22.2 %), with the USA closer to EU-28 with its share of internationally co-authored publications (40 %). The difference between EU-15 and EU-13 countries was substantial (47.1 % vs. 39.2 %, Figure 10). EU-13 countries substantially lag behind in its research internationalisation: in five of them, in 2017 the share of their internationally co-authored publications was lower than 50 % (Czech Republic, Lithuania, Croatia, Romania and Poland) (see Table 3 for details). The EU-15/EU-13 divide is caused by the long-term isolation of Central and Eastern Europe from global science networks, followed by severe underfunding of its research systems after the collapse of Communism. Internationalisation in research is very expensive and requires a certain basic threshold of public research funding; this threshold was not secured in the last three decades, only recently public funding for R&D being increased in some EU-13 countries. Also dominating national publication patterns matter: in EU-13 countries, the institutional pressures (through academic job requirements and academic promotion requirements) on publishing internationally and publishing in international collaboration have been weak. Cross-disciplinary differences (analysed according to the 6 FOS) are also substantial, with the highest percentage share of articles written in international collaboration for the natural sciences and the lowest for the humanities (Figure 8).

The number of articles written in international collaboration in the period studied (2007-2017) was 2,193,504 in the UE-28 and 1,437,621 in the USA, compared with merely 588,087 in China; however, the highest growth in the number per year in the same period was for China (by 309.02 %) (Table 2). Within countries and between them, there is substantial cross-disciplinary differentiation, with different increases between different FOS (see Table 25 in Data Appendices). In the EU-28, the largest number of articles published in international collaboration in 2017 was by far for the natural sciences (175,150; and 109,624 in the USA), followed by the medical sciences (84,325; and 64,029 in the USA), and the lowest for the humanities (5,480; and 2,880 in the USA). However, the coverage of academic journals in the humanities in Scopus (as well as in WoS) is very low compared with that of the other five FOS. Cross-national differences by FOS in 2007-2017 show the power of internationalisation in research by FOS which, apart from individual predilections, may also reflect evolving national priorities in international research collaboration. By way of example, Table 26 and Table 27 in Data Appendices provide full data for each year for a single FOS (medical sciences): both total number of internationally co-authored publications and their percentages over time.

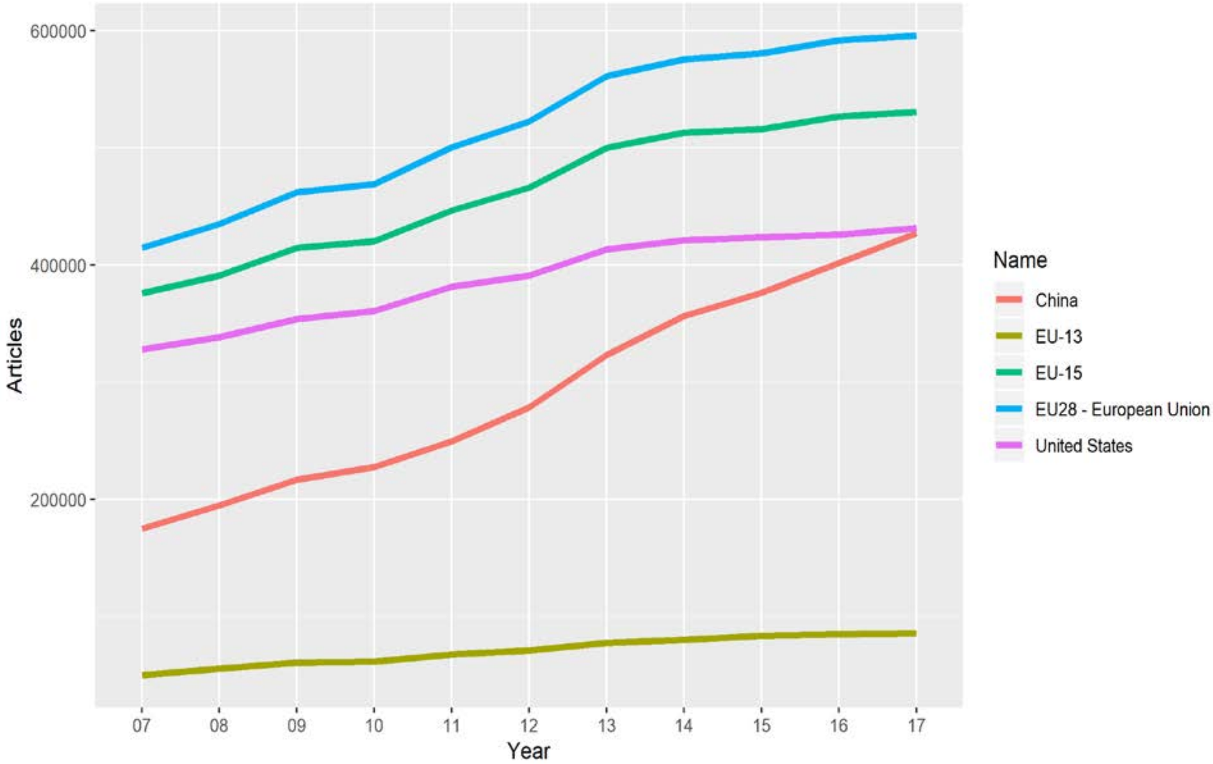
Table 2. IRC trends: Articles published in international collaboration, EU-28 and comparator countries, in descending order, 2007-2017.

	Total 2007-2017	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2007-2017 increase (2007=100 %)
EU 28	2,193,504	138,822	148,702	162,043	168,451	181,515	194,036	214,625	229,385	240,750	253,065	262,110	188.81
EU-15	2,090,453	133,074	142,640	154,887	160,969	173,280	185,206	204,208	217,530	228,248	240,651	249,760	187.69
USA	1,437,621	91,442	98,020	104,687	110,001	118,887	127,742	140,912	150,679	158,521	165,367	171,363	187.40
GBR	627,614	39,057	41,788	45,398	47,376	50,491	54,226	60,959	65,674	70,395	74,423	77,827	199.27
CHN	588,087	23,045	27,133	32,232	36,142	42,247	48,170	57,778	66,974	75,600	84,507	94,259	409.02
DEU	565,404	37,408	39,260	42,928	44,709	47,969	51,007	55,275	58,104	60,707	63,154	64,883	173.45
FRA	419,152	27,526	29,832	32,633	33,312	35,398	37,439	40,893	43,082	44,472	46,752	47,813	173.70
ITA	297,908	18,087	19,557	21,174	22,076	24,099	25,964	29,235	31,619	33,617	35,647	36,833	203.64
EU-13	271,846	17,357	18,277	20,163	20,212	21,848	23,373	26,393	28,278	30,174	32,182	33,589	193.52
ESP	270,493	14,726	16,522	18,485	20,160	22,493	24,619	27,216	29,395	30,612	32,617	33,648	228.49
NLD	218,813	12,948	13,821	15,514	16,788	18,053	20,185	21,912	23,258	24,323	25,620	26,391	203.82
SWE	156,763	9,666	9,998	11,003	11,724	12,639	13,814	15,193	16,420	17,757	18,925	19,624	203.02
BEL	135,491	8,213	8,929	9,698	10,305	11,351	12,037	13,334	14,542	15,315	15,677	16,090	195.91
DNK	99,049	5,475	5,902	6,441	7106	7,800	8,701	9,689	10821	11,740	12,418	12,956	236.64
AUT	95,792	5,674	6,164	6,675	7,222	7,984	8,651	9,493	10,143	10,710	11,451	11,625	204.88
POL	87,509	5,662	5,802	6,363	6,362	6,703	7,382	8,416	9,127	9,767	10,738	11,187	197.58
FIN	74,482	4,696	4,879	5,299	5,534	5,964	6,537	7,202	7,924	8,509	8,812	9,126	194.33
PRT	72,686	3,444	4,091	4,618	4,986	5,764	6,536	7,548	8,197	8,563	9,351	9,588	278.40
CZE	60,501	3,459	3,707	4,044	4,323	4,659	5,101	5,731	6,606	7,234	7,537	8,100	234.17

GRC	56,439	3,637	3,836	4,335	4,364	4,701	5,069	5,478	5,978	6,103	6,458	6,480	178.17
IRL	47,931	2,641	3,118	3,518	3,907	4,097	4,264	4,658	5,095	5,150	5,640	5,843	221.24
HUN	38,689	2,672	2,700	2,975	2,945	3,311	3,570	3,706	3,953	4,110	4,377	4,370	163.55
ROU	28,659	753	926	1,940	2,252	2,506	2,813	3,291	3,364	3,526	3,682	3,606	478.88
SVK	21,562	1,375	1,491	1,547	1,544	1,755	1,882	1,977	2,219	2,381	2,674	2,717	197.60
SVN	20,083	1,126	1,282	1,424	1,449	1,703	1,916	2,027	2,104	2,298	2,354	2,400	213.14
HRV	16,569	793	885	1,113	1,227	1,450	1,598	1,651	1,783	1,897	2,047	2,125	267.97
BGR	15,144	1,235	1,257	1,398	1,225	1,240	1,279	1,398	1,409	1,428	1,580	1,695	137.25
EST	10,531	509	536	586	706	829	956	1,110	1,192	1,260	1,408	1,439	282.71
LTU	9,251	513	566	591	588	705	801	833	999	1,113	1,212	1,330	259.26
CYP	7,951	326	398	496	592	638	745	811	805	927	1,044	1,169	358.59
LUX	6,779	207	269	363	393	481	584	737	902	907	943	993	479.71
LVA	4,030	231	241	243	230	273	294	379	412	487	591	649	280.95
MLT	1,723	60	70	74	92	109	157	164	213	237	269	278	463.33

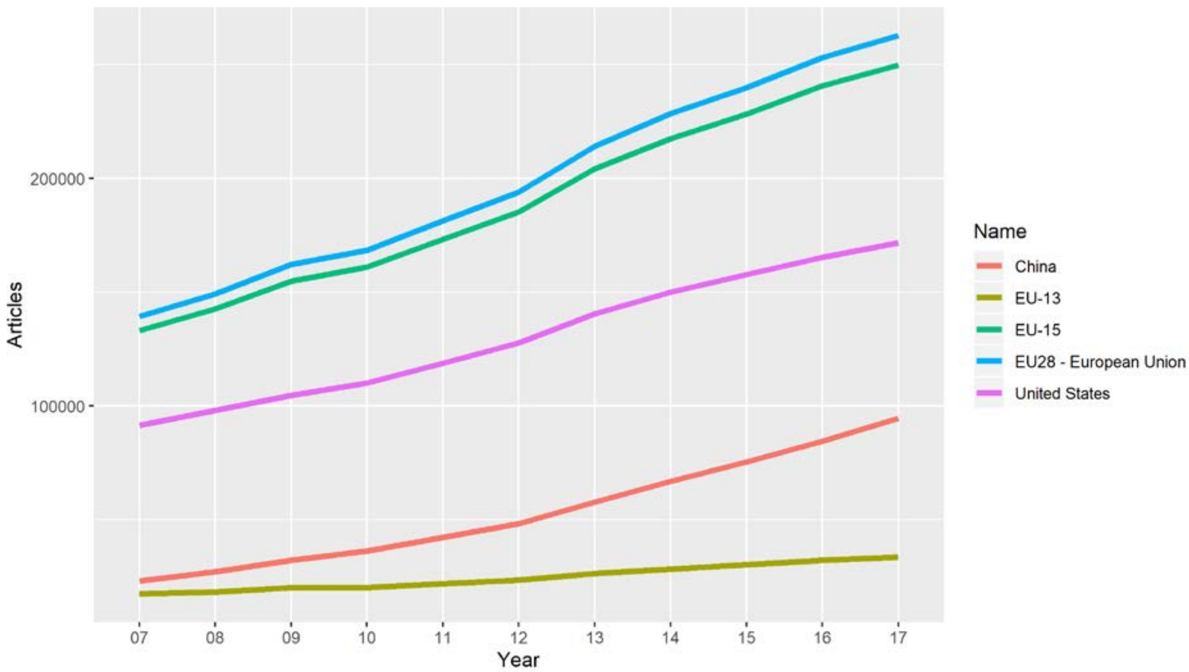
Source: author's own calculations based on SciVal (2019) data

Figure 5. Comparative research performance: the total number of articles published, regional and intra-regional (UE-15 and EU-13) differences, 2007-2017.



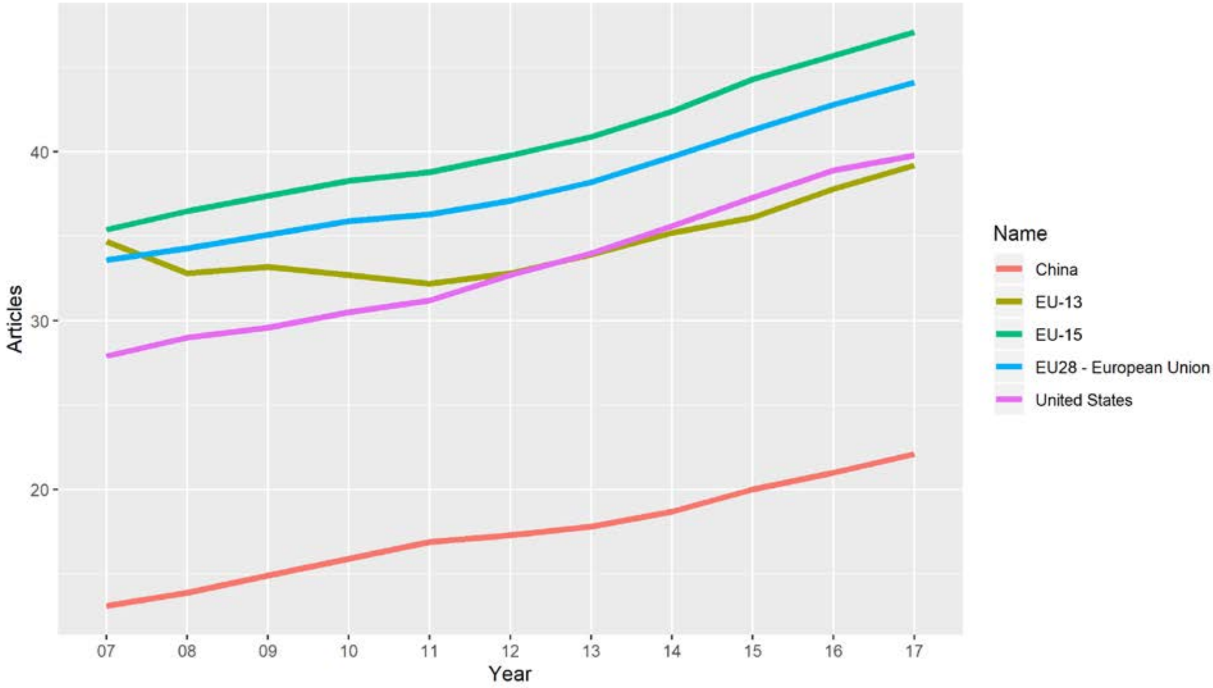
Source: author's own calculations based on SciVal (2019) data

Figure 6. IRC trends: the number of articles written in international collaboration, regional and intra-regional (UE-15 and EU-13) differences, 2007-2017.



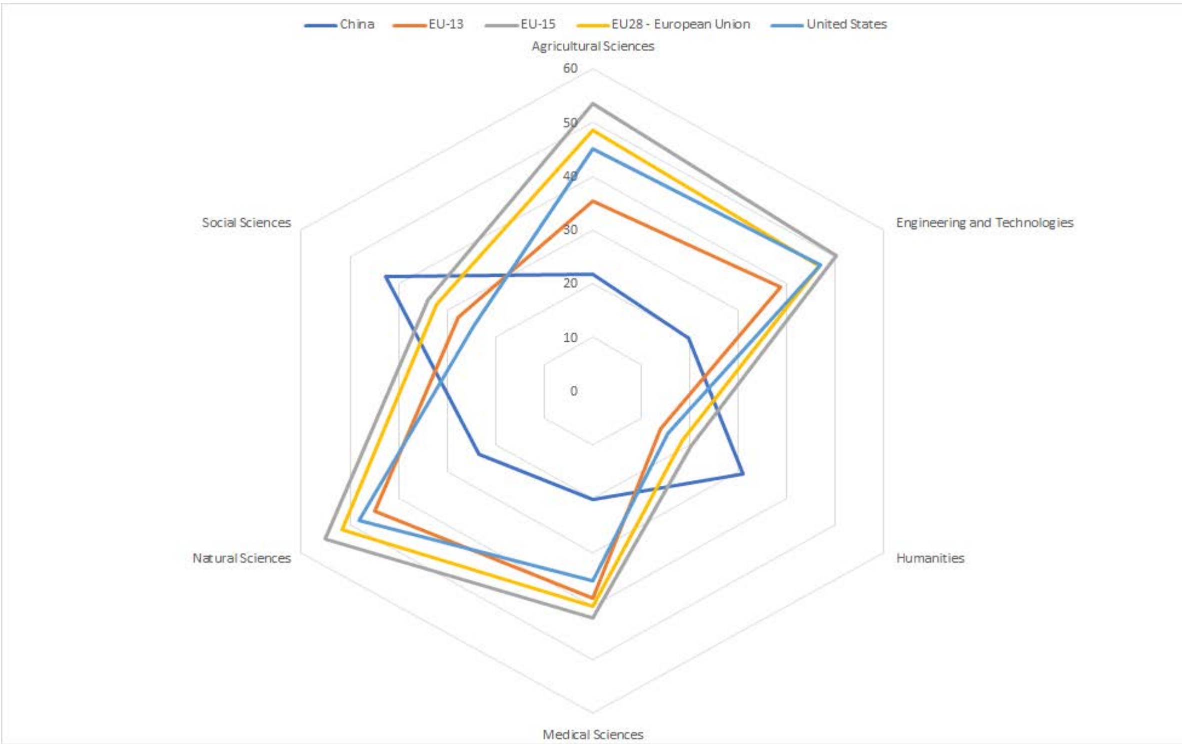
Source: author's own calculations based on SciVal (2019) data

Figure 7. IRC trends: the percentage share of articles written in international collaboration, regional and intra-regional (UE-15 and EU-13) differences, 2007-2017 (in %).



Source: author's own calculations based on SciVal (2019) data

Figure 8. IRC pattern: the percentage share of articles written in international collaboration by field of study, regional and intra-regional (UE-15 and EU-13) differences, 2017 (in %).



Source: author's own calculations based on SciVal (2019) data

5.1. Collaboration trends and patterns: the four collaboration types

In analysing IRC, both trends over time (2007-2017) and patterns (2017) are significant. Interesting patterns of collaboration are shown in Figure 9 and Figure 10. The first figure shows regional and intra-regional (EU-15 and EU-13) collaboration trends over time, with the percentage share of the four types of collaboration (international, national, institutional, and no collaboration) changing in 2007-2017. At this level of aggregation, China shows the highest percentage share of institutional collaboration and EU-15 shows the lowest percentage share of institutional collaboration in both points in time. In all five groups of countries, the most significant trend is the increasing percentage share of international collaboration over time combined with the decreasing percentage share of institutional collaboration over time. The percentage share of single-authored publications is also slowly decreasing in all five groups of countries, and it is generally very low.

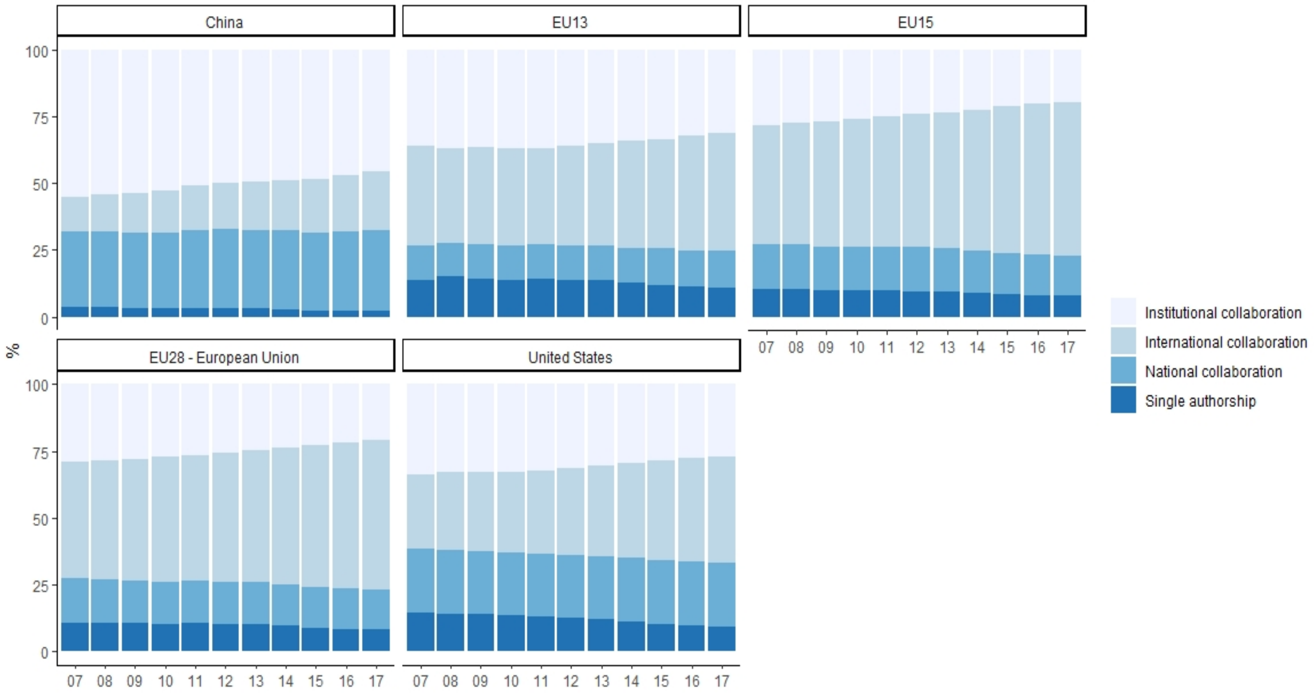
In 2017 (Figure 10), the share of IRC was 44.4 % for EU-28 countries (47.1 % for EU-15 countries and 39.2 % for EU-13 countries, the percentage difference between the shares for EU-28 and EU-15 resulting from a relatively small number of publications with authors affiliated with new EU member states compared with a very high number of publications with authors affiliated with old EU member states: in 2017, out of 262,110 internationally co-authored publications with authors affiliated with EU-28 countries, only 33,589 had authors affiliated with new EU member states, with 7 countries having less than 3,000 such publications, Table 2). For the United States, the share of IRC was 39.8 % and for China it was 22.2 %. The share of internationally co-authored publications in Europe is thus 4.6 percentage points higher than in the USA and 22.2 percentage points higher than in China, for different reasons, and two in particular: being a leader in a global science system in the case of the USA and catching up in it in the case of China.

The share of national collaboration was the highest for China (30.2 %), followed by the United States (23.7 %), and EU-28 countries (19.3 %, with a significant difference between the group of EU-15 and that of EU-13 with 19.2 % and 15.3 %, respectively).

The share of institutional collaboration is in the range of 45.4 % (China) and 24.1 % (EU-15, considerably bigger for EU-13 countries, 33.5 %).

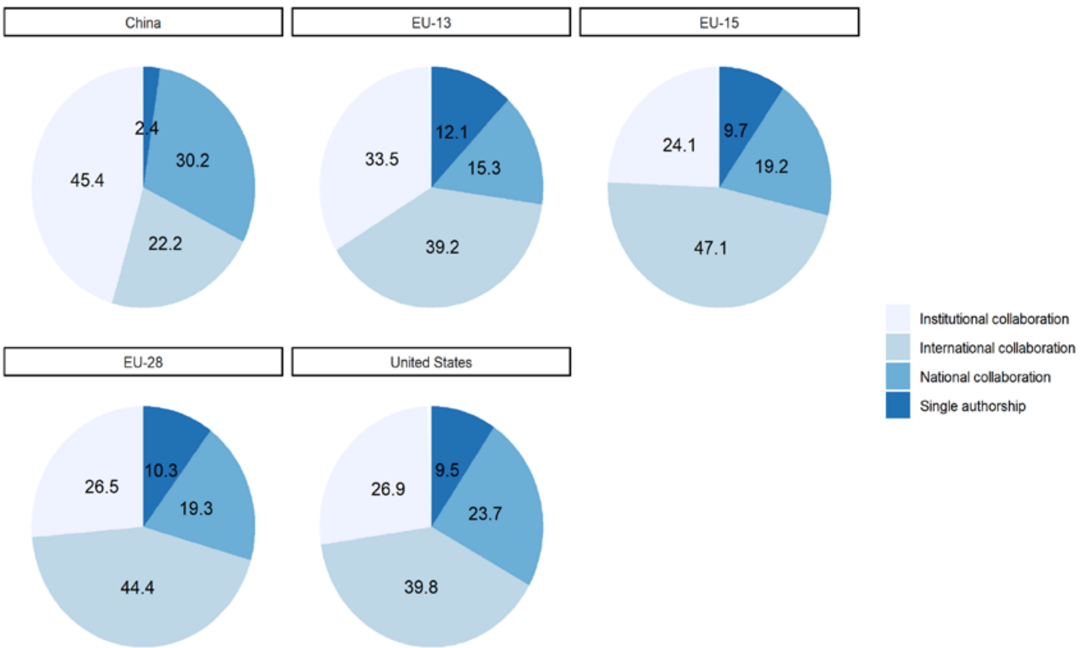
Finally, the share of single-authored publications (meaning no collaboration) is the smallest for China (2.4 %) and in the rest of groups of countries, it remains only at the level of 9.5-12.1 %.

Figure 9. RC trends: regional and intra-regional (UE-15 and EU-13) collaboration trends over time (the four collaboration types), 2007-2017 (in %).



Source: author's own calculations based on SciVal (2019) data

Figure 10. RC patterns: regional and intra-regional (UE-15 and EU-13) collaboration patterns (the four collaboration types), 2017 (in %).



Source: author's own calculations based on SciVal (2019) data

The same trends (2007-2017) and the same patterns (2017) are clear for all the EU-28 countries studied (Figure 11). There is not a single EU-28 country in which IRC has not been on the rise in the period studied (Table 2) and only six countries, all new EU member states, in which the level of international collaboration was lower than 50 % in academic science in 2017 (Figure 12; the exceptions being Croatia, Czech Republic, Lithuania, Poland, Romania and Slovakia).

However, different scales of IRC expressed by the total number of internationally co-authored publications per country in EU-28 countries need to be emphasised (Table 2): while in the United Kingdom, the European leader, in 2017 it was 77,827 (followed by Germany with 64,883 publications, France with 47,813, Italy with 36,833 and Spain with 33,648), in the largest EU-13 system it was only 11,187 (Poland); in ten systems (predominantly in EU-13), it was smaller than 3,000. The vast differences in the total number of internationally-co-authored publications among the European countries studied needs to be kept in mind in all percentage-based IRC trends.

While Figure 11 shows cross-national differences graphically over time (and Figure 12 shows patterns for a single year, 2017), Table 3 provides detailed data year by year. In 2017, there were 10 countries in which the level of IRC was higher than 60 %: six out of ten articles published had authors affiliated with at least two countries. The research internationalisation leaders include two very small systems (Cyprus and Luxembourg) in which limited national human resources make IRC more necessary than in bigger systems; and eight small- and medium-sized systems (Austria, Belgium, Denmark, Sweden, Netherlands, Estonia, Finland, and Ireland). Only one EU-13 country is represented in this group (Estonia, 63.3 %) and all EU-28 Nordic countries are represented among them. The largest European systems are internationalised in research in the range of 50-60 %, with France and United Kingdom at the top (58.8 % and 59.8 %, respectively), Germany in the middle (54.7 %) and Spain and Italy at the bottom of this range (49.5 % and 49.8 %, respectively. The two largest EU-13 systems of Poland and Romania are research internationalisation laggards, with slightly more than one third of their publications being internationally co-authored (34.7 % and 39.4 %, respectively). The only EU-28 countries with IRC levels significantly lower than 50 % are new EU member states, consistent with the results of research literature (see Kozak et al. 2015).

Although in this report standard input-output models of research and development evaluation are not used (Godin 2007; Payumo et al. 2017), just as neither GERD nor human capital in the research and development sector are referred to, it is clear that higher levels of IRC are strongly correlated with higher levels of R&D expenditures, especially R&D expenditures in higher education (Leydesdorff et al. 2018). The case of most EU-13 countries, with research underfunding as a dominant feature of their R&D systems, confirms this correlation.

Tables 22-24 in Data Appendices show the details of national and institutional collaboration, as well of no collaboration in the period studied. The average level of national collaboration for 2007-2017 exceeds 20 % for Italy and France as well as the USA and China and it stays at almost exactly the same levels in 2007 and in 2017 (2017: France 24.6 %, Italy 19.9 %, the USA 23.7 % and China 30.2 %, the highest share in all the countries studied). The above data strongly suggests that while IRC is on the rise, its increase occurs predominantly at the expense of institutional and no collaboration (single-authored) collaboration types.

National RC is strongly embedded, as it is through national funding, in national systems and seems to be resistant to medium-term changes. A decade of powerful changes in IRC is not reflected in changes in national RC, as the data for 2007 compared with 2017 clearly demonstrates. In several countries, national RC is increasing, including only two with substantial increases: Poland and Romania. From a longer term perspective, national RC is a small but very strong component of research collaboration, based on national scientific ties within national systems.

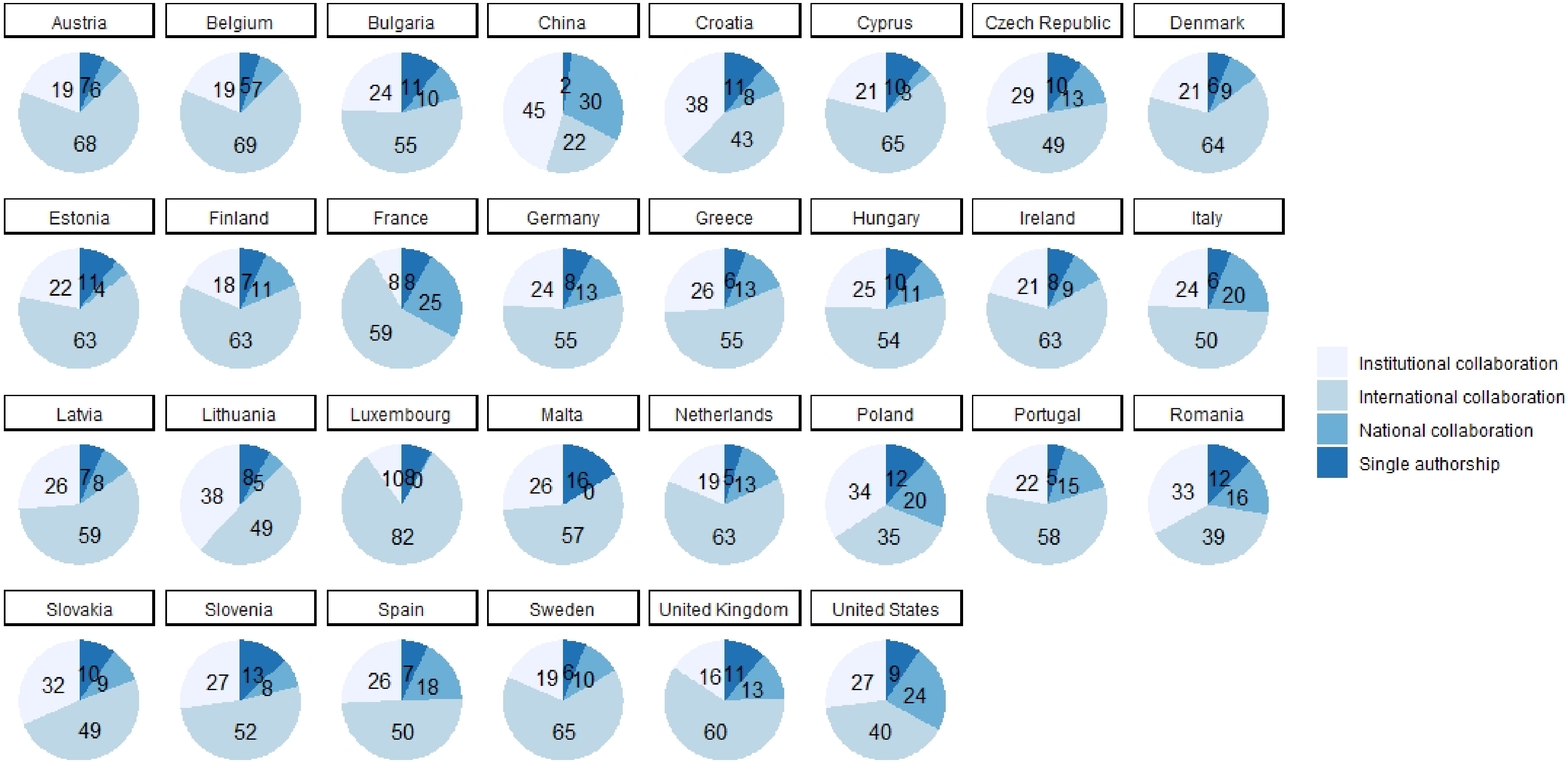
Institutional RC has been decreasing in all the countries studied. In ten EU-28 countries its average level for 2007-2017 exceeded 30 % (Lithuania, Croatia, Romania, Poland, Latvia, Greece, Slovakia, Slovenia, the Czech Republic and Spain, Table 23 in Data Appendices). In the case of the three aggregates, its average level was also relatively high (China 49.3 %, the nationally dominating collaboration type; EU-28 26.3 %, the second largest collaboration type, and the USA 26.7 %, also the second largest collaboration type). However, by 2017 only five of them represented a level higher than 30 %, and all of them were new EU member states (Lithuania Croatia, Romania Poland, and Slovakia). The dynamics of changes in RC is clearly away from institutional collaboration in which the co-authors come from the same institution, except that the process takes longer in generally research-underperforming and research-underfunded systems of EU-13.

Finally, a pronounced change in collaboration types across EU-28 countries and globally is away from single-authored articles (or away from the no-collaboration mode studied in this report). While in 2007 the no-collaboration share of publications was 3.7 % for China, 12.8 % for EU-28 and 14.6 % for the USA, in 2017 it was only 2.4 %, 10.3 % and 9.5 %, respectively, decreasing every year in the period studied. While at the beginning of the decade analysed the share was more than 10 % in 17 countries, at the end of the decade analysed it was more than 10% only in 10 countries. However, there are powerful cross-disciplinary differences, and both in 2007 and 2017 social sciences were the FOS with the highest shares of single-authored articles (compare the maps for 2007 and 2017, Figures 22-23 in Data Appendices; the differences at the more disaggregated level of ASJC (All Science Journal Classification used by Scopus) are even more pronounced, with some areas of humanities and social sciences keeping a very high and increasing percentage of single-authored papers in 2007-2017. At the same time, in this report, the issue of the changing coverage of journals from different FOS in Scopus, which influences overall percentages of collaboration types over time, is disregarded as our interest is in general trends rather than exact data).

Figure 11. RC trends: collaboration trends over time (the four collaboration types), EU-28, by country, 2007-2017 (in %).

Source: author's own calculations based on SciVal (2019) data

Figure 12. RC patterns: collaboration patterns (the four collaboration types), EU-28, by country, 2017 (in %).



Source: author's own calculations based on SciVal (2019) data

The trend of the increasing number of papers published in international collaboration in the EU-28 and the two comparator countries of China and the USA is shown in more detail in Table 2. While in China the number increased from 23,045 to 94,259 (and it was 409 % of the 2007 level) in the United States the number increased from 91,442 to 171,363 (187,4 % of the 2007 level), in the EU-28 the number increased from 138,822 to 262,110 (188,8 % of the 2007 level). The largest nominal increases in the number of internationally co-authored articles were noted in the five largest European systems of France, Germany, Italy, Spain and the United Kingdom (Figure 13). In the same timeframe of 2007-2017, total output per year or the total number of articles published in the four collaboration types combined has also been on the rise. Specifically, the changes in the number of all articles published in the four collaboration types combined, and in the number of articles written in international collaboration in 2007-2017 can be graphically observed in Figure 13 and Figure 14, respectively.

The levels of IRC in EU-28 countries differ substantially cross-nationally between the six FOS: in nominal terms, the largest numbers of internationally co-authored articles are published in the natural sciences and medical sciences; however, in terms of percentages, the largest increase is noted for the humanities and for social sciences (with low nominal bases in 2007). Across all EU-28 countries, in 2017 there were 175,150 papers in the natural sciences, followed by 84,325 papers in medical sciences, 61,600 papers in engineering and technologies, 30,624 papers in social sciences, 23,877 papers in agricultural sciences, and 5,480 papers in the humanities. The increases in the period studied were as follows: the two leaders in growth, social sciences (198.5 %) and the humanities (184.4 %), are followed by engineering and technologies (119.0 %) and agricultural sciences (103.9 %). The remaining two FOS were the two largest FOS in nominal terms, the natural sciences (70.9 % increase) and medical sciences (82.4 % increase) (Table 25 in Data Appendices).

Figure 13. Comparative research performance: the total number of articles published, EU-28 countries, 2007-2017.

Source: author's own calculations based on SciVal (2019) data

Figure 14. IRC trends: The number of articles written in international collaboration, EU-28 countries, 2007-2017.

Source: author's own calculations based on SciVal (2019) data

Table 3. IRC trends: *International* collaboration, EU 28 and comparator countries, 2007 to 2017, in descending order (in %).

	Average 2007-2017	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
LUX	78.1	77	72.6	76.9	77	72.2	78.6	77.5	77.5	80.5	79	81.6
CYP	66.6	64.6	65.6	62.5	69.5	65.9	68.2	64.1	65.2	69.8	69	65.4
AUT	62.9	55.9	57.1	58.1	60.5	60.7	62.8	63.7	64.3	65.7	67.4	68.2
BEL	62.3	55.5	56.4	57.7	59.3	60.6	60.9	61.6	63.9	66.3	67.6	68.6
DNK	58.9	53.8	54.3	55.5	56.3	55.9	57.3	58.3	59.1	61.5	63.7	64.4
SWE	58.6	51.7	52.7	53.7	55.5	56.6	58	58.5	59.5	62.1	64.2	64.9
NLD	56.1	48.6	49.5	50.6	52.1	52.9	55.5	56.2	58.3	60.2	62	63.5
EST	56	45.6	48.6	46.4	49.3	51.8	55.7	57.1	57.5	60.2	63.8	63.3
FIN	55.6	48.5	48.7	49.8	51.8	52.1	54.8	56.4	57.5	60.2	61.4	63.1
IRL	55.6	48.5	51.7	51.4	52.1	51	53.8	54.8	57.3	59.5	61.8	62.6
MLT	55.1	56.6	44.6	46.2	48.9	53.4	53.4	51.7	57.9	58.1	61.4	57.2
PRT	52.6	48.5	49.3	49.7	49.5	50.2	51.1	51.5	52.5	54	56.6	57.8
FRA	52.2	46.5	47.1	48.7	49.3	49.6	50.9	52	53.7	55.7	57.1	58.8
GBR	51.1	42.2	44.5	45.8	47	47.6	49.4	50.7	53.9	56	57.9	59.8
DEU	50.1	44.8	45.8	47.4	48.6	48.7	49.2	50.4	51.2	52.6	53.7	54.7
HUN	50.1	46.2	44.6	47	48.3	48.1	50.1	51.2	50.6	52.3	55.2	54.2
BGR	48.7	50	48.8	47.3	47.2	47.6	45.5	45.5	47.6	48.8	52.3	54.9
SVK	47	48.2	46.6	48.1	46.5	46.8	48	44.3	44.6	46.9	48	49.2
LVA	46.3	55.5	46.5	40.9	36.1	37	38.5	40.5	46.4	48	53.7	58.6
SVN	45.6	39.5	40.5	42	42.3	42.2	46.1	45.5	45.9	49.2	50.8	51.7
GRC	44.4	35.6	35.7	37.2	38.3	40.5	43.5	45.8	49.1	51.8	53.3	55.2
CZE	43.9	40	40.4	41.5	41.4	40.5	41.9	43	45.6	46.4	46.7	49
ITA	43.9	37.9	39	39.5	41.2	42.1	42.8	43.4	45.2	47	48.6	49.8
ESP	43.6	36.7	37.8	38.9	40.6	41.3	42.4	43.4	45.4	47.3	48.9	49.5
EU-15	41.0	35.4	36.5	37.4	38.3	38.8	39.8	40.9	42.4	44.3	45.7	47.1
EU-28	38.5	33.7	34.3	35.1	36	36.3	37.2	38.2	39.9	41.5	43	44.4
LTU	36.9	32.6	28.4	29.6	28.7	31.6	35	36.7	38.7	41.5	45	48.8
HRV	35.9	27.5	28.4	29.5	31.3	31.6	34.8	35.7	39.4	41.9	44.1	43.2
EU-13	34.8	34.7	32.8	33.2	32.7	32.2	32.8	33.9	35.2	36.1	37.8	39.2
USA	33.7	27.9	29	29.6	30.5	31.1	32.7	34	35.8	37.5	39.1	40
ROU	33.4	36.9	25.2	28.5	29.2	28.9	31	32.7	35.9	36	39.4	39.4
POL	30.3	30.1	28.2	29.4	28.9	28.2	28.5	29.3	30.4	30.7	32.6	34.7
CHN	18.2	13.1	13.9	14.9	15.9	16.9	17.3	17.9	18.8	20.1	21.1	22.2

Source: author's own calculations based on SciVal (2019) data

5.2. Research collaboration networks: partnership countries

EU-28 countries also differ significantly in terms of their IRC in terms of two other dimensions: their partner countries in collaboration in Europe and beyond, and the Field-Weighted Citation Impact (FWCI) of their internationally co-authored publications. FWCI is the ratio of citations received relative to the expected world average for the subject field, publication type and publication year.

The data on international collaboration patterns in each UE-28 country in Table 4 clearly indicate that there are common patterns across Europe: in the vast majority of countries, the three top collaborating partners are the USA, the UK and Germany; in several, there appear France and Italy. However, there are also collaboration patterns which indicate that geographical, linguistic and historical ties matter: for instance, Greece is a top collaboration partner for Cyprus, Spain for Portugal, Finland for Estonia, Germany for Austria and Czech Republic, France for Romania and Czech Republic for Slovakia; additionally, Lithuania and Russia are among top three collaborating countries for Latvia. For twelve EU-28 countries (including two EU-13: Poland and Hungary and the biggest knowledge producers – the UK, Germany, France, Italy and Spain), the USA is a top collaborating partner.

In Table 5 and Table 6 below, the data of collaboration partnerships within Europe (between EU-28 countries only) and within Europe plus the USA and China is shown in detail. Collaboration partnerships analysed are limited to Top 20 only in terms of co-authored publication counts. The left panel in Table 5 shows pairings of countries sorted by the count of co-authored publications and the right panel shows pairings of countries sorted by FWCI, both in descending order. So within the selected pool of top 20 collaboration partnerships, with the main global competitors of EU-28 and without them, collaboration partnerships are studied both in terms of numbers of co-authored publications and in terms of the strengths of their average impact in science as measured by FWCI. Certainly, all collaboration partnerships show FWCI higher than 1, or higher than the expected world average for the subject field, publication type, and publication year.

The two tables show the most prolific collaboration partner countries in Europe: first, ordered by the volume of research outputs co-authored between them (see column 'Publications 2013-2018' in the left panel, only 5-year windows being available from SciVal) and, second, ordered by the field-weighted citation impact of the same outputs (see column 'FWCI' in the right panel). The leaders in the pairs of internationally collaborating countries are the largest European knowledge producing nations: Germany, United Kingdom, France, and Italy (Spain from among the top 5 nations is lagging behind from this perspective, appearing only in rank 9). However, in terms of the citation impact, FWCI is the highest for the pairs of France and the Netherlands, Switzerland and the United Kingdom, Sweden and the United Kingdom, the Netherlands and the United Kingdom, and Italy and Switzerland (in the top five ranks). Internationally co-authored papers within the five top European collaborating pairs are 221-275 % more cited than the world average for similar publications. Internationally co-authored papers within the top 10 European collaborating pairs are 211-275 % more cited than the world average for similar publications, and those within the top 10 and top 20, 148 %-211 %.

Significantly, the most prolific collaboration partner countries across EU-28 countries do not include EU-13 countries. None of them appears in the lists below because of a very low number of internationally co-authored papers, including intra-European papers (see Table 2).

Table 4. IRC patterns: Top 3 collaboration partnerships for each EU-28 country (and USA, China) and the Field-Weighted Citation Impact (FWCI) of co-authored publications, 2013-2018.

Country	Three top collaborating countries	Co-authored publications 2013-2018	FWCI	Country	Three top collaborating countries	Co-authored publications 2013-2018	FWCI
AUT	DEU	37,420	2.5	**LVA**	DEU	1,182	4.39
	USA	24,026	3.13		LTU	935	4.12
	UK	17,605	3.52		RUS	922	3.97
BEL	USA	30,157	3.37	**LTU**	DEU	2,203	3.82
	FRA	27,105	3.05		USA	2,028	3.44
	UK	26,596	3.46		UK	1,949	4.31
BGR	DEU	3,614	3.31	**LUX**	DEU	2,146	4.02
	USA	2,914	3.44		FRA	2,042	3.61
	ITA	2,767	3.98		UK	1,360	5.98
CZE	DEU	12,943	2.94	**MLT**	UK	964	3.91
	USA	12,882	2.96		ITA	727	4.91
	UK	9,807	3.47		FRA	375	8
HRV	DEU	3,910	3.2	**NLD**	USA	60,055	3.27
	USA	3,808	2.87		UK	51,711	3.23
	ITA	3,662	3.31		DEU	48,573	3.15
CYP	GRC	3,194	2.93	**POL**	USA	19,909	2.98
	UK	2,715	3.76		DEU	19,189	3
	USA	2,255	3.61		UK	15,192	3.42
DNK	USA	27,920	3.32	**PRT**	ESP	18,477	2.35
	UK	22,546	3.62		UK	14,798	2.94
	DEU	19,886	3.59		USA	14,368	2.92
EST	FIN	2,908	4.68	**ROU**	FRA	7,013	2.95
	DEU	2,813	5.35		DEU	6,359	3.3
	UK	2,746	5.68		ITA	6,142	3.51
FIN	USA	18,262	3.26	**SVK**	CZE	7,297	1.82
	UK	14,922	3.54		DEU	3,525	3.99
	DEU	13,952	3.53		POL	3,273	3.46
FRA	USA	93,308	2.85	**SVN**	ITA	3,952	3.4
	UK	64,296	3.11		USA	3,906	2.89
	DEU	62,891	2.97		DEU	3,841	3.29
DEU	USA	141,195	2.68	**ESP**	USA	61,796	2.91
	UK	90,202	2.89		UK	50,124	2.95
	FRA	62,891	2.97		DEU	42,335	3.18
GRC	UK	17,805	2.92	**SWE**	USA	39,974	3.1
	USA	16,250	2.96		UK	31,418	3.34
	DEU	12,496	3.49		DEU	28,377	3.18
HUN	USA	9,133	3.28	**UK**	USA	172,887	2.77

	DEU	8,959	3.33		DEU	90,202	2.89
	UK	7,297	3.86		FRA	64,296	3.11
IRL	UK	17,610	2.82	**USA**	CHN	266,244	1.85
	USA	12,849	3.31		UK	172,887	2.77
	DEU	8,133	3.83		DEU	141,195	2.68
ITA	USA	89,800	2.82	**CHN**	USA	266,244	1.85
	UK	67,903	2.96		UK	63,625	2.21
	DEU	58,874	3.11		AUS	55,831	2.24

Source: author's own calculations based on SciVal (2019) data

When collaboration partnerships are examined with EU-28 countries, the USA and China, the analysis leads to different results. The biggest number of internationally co-authored papers emerges in this research to be between China and the United States, followed by the United Kingdom and the United States, Germany and the United States, as well as France and the United States (Table 5, the left panel). The dominant feature of IRC in Europe is its powerful collaboration with the United States: the United Kingdom, Germany, and France collaborate more intensively with the United States than with any other European country. In terms of sheer numbers of internationally co-authored publications in the study period of 2013-2018 (or the most recent timeframe available from SciVal), there are 172,887 papers written jointly by UK and US scientists, 141,195 papers written jointly by German and US scientists, and 93,308 papers written jointly by French and US scientists. In contrast, the highest number of papers written by intra-European collaborative partners is only 90,202, the number of papers co-authored by German and UK scientists in the period studied. While China is the most powerful global partner of US science (with the globally unbeatable number of 266,244 papers), only one country in Europe is collaborating widely with China, namely the United Kingdom (with 63,625 papers jointly written).

However, in terms of citation impact, papers published jointly by Chinese and UK scientists and Chinese and US scientists have the lowest citation impact among the collaborative pairs studied (see the right panel in Table 6). One of possible explanations could be that a significant proportion of collaborative papers between China and both the US and the UK is between Chinese-born scientists working in the two countries. The highest FWCI that emerges from this research is between scientists having affiliations between the Netherlands and the United States (3.27), the Netherlands and the United Kingdom (3.23), Germany and Spain (3.18), and Germany and the Netherlands (3.15). The articles written by these collaborating pairs are 227 %, 223 %, 218 % and 215 % more cited than the world average for similar publications.

The total number of internationally co-authored publications and their change in numbers and in percentages over time need to be viewed in the context of the total number of publications (as clearly seen in Figure 13 and Figure 15). In such countries as France, Germany, Italy, Spain, and the United Kingdom, or the largest producers of papers in Europe, the total number of papers is increasing substantially. Also in these five countries the number of international co-authored papers has been increasing substantially in the timeframe studied.

Beyond the top 20 pairs of partnership countries, all European countries are collaborating in science among themselves: for instance, the top 10 collaborating countries with the UK are shown in Table 28 in the Data Appendices. The top ten countries collaborating with the United Kingdom include six European (in descending order: Germany, France, Italy, the Netherlands, Spain and Switzerland) and four non-European countries (in descending order: USA, China, Australia, and Canada). The rate of growth in co-authoring papers with top 10 countries is the highest for China (79.2 % in 2013-2018), compared with 25 %-40 % for all other collaborative partners.

Further analysis conducted at more disaggregated levels of FOS clearly indicates far-reaching cross-disciplinary variations in all four collaboration types. There are still fields of science in EU-28 countries in which about 30 % of scientists produce their publications as single-authored, and there are variations both across world regions and across national systems. The move away from the no-collaboration publication type has been especially powerful in the social sciences in the last decade.

Table 5. IRC patterns: Top 20 collaboration partnerships within Europe (between EU-28 countries), most prolific pairs 2013-2018. Pairings sorted by the count of co-authored publications (left panel) and by the Field-Weighted Citation Impact (FWCI) of co-authored publications (right panel).

Rank	Partner Country 1	Partner Country 2	Publications 2013 - 2018	FWCI	Rank	Partner Country 1	Partner Country 2	Publications 2013 – 2018	FWCI
1	DEU	GBR	90,202	2.89	1	FRA	NLD	27,484	3.75
2	FRA	GBR	64,296	3.11	2	CHE	GBR	36,666	3.49
3	ITA	GBR	63,176	2.94	3	SWE	GBR	31,418	3.34
4	DEU	FRA	62,891	2.97	4	NLD	GBR	51,711	3.23
5	ITA	DEU	54,956	3.09	5	ITA	CHE	27,317	3.21
6	DEU	CHE	52,688	2.72	6	DEU	ESP	42,335	3.18
7	ITA	FRA	51,897	2.91	7	FRA	CHE	31,424	3.16
8	NLD	GBR	51,711	3.23	8	DEU	NLD	48,573	3.15
9	ESP	GBR	50,124	2.95	9	FRA	GBR	64,296	3.11
10	DEU	NLD	48,573	3.15	10	FRA	ESP	39,434	3.11
11	DEU	ESP	42,335	3.18	11	ESP	FRA	39,434	3.11
12	ITA	ESP	41,595	2.98	12	ITA	DEU	54,956	3.09
13	FRA	ESP	39,434	3.11	13	ITA	ESP	41,595	2.98
14	ESP	FRA	39,434	3.11	14	DEU	FRA	62,891	2.97
15	CHE	GBR	36,666	3.49	15	ESP	GBR	50,124	2.95
16	AUT	DEU	35,003	2.48	16	ITA	GBR	63,176	2.94
17	FRA	CHE	31,424	3.16	17	ITA	FRA	51,897	2.91
18	SWE	GBR	31,418	3.34	18	DEU	GBR	90,202	2.89
19	FRA	NLD	27,484	3.75	19	DEU	CHE	52,688	2.72
20	ITA	CHE	27,317	3.21	20	AUT	DEU	35,003	2.48

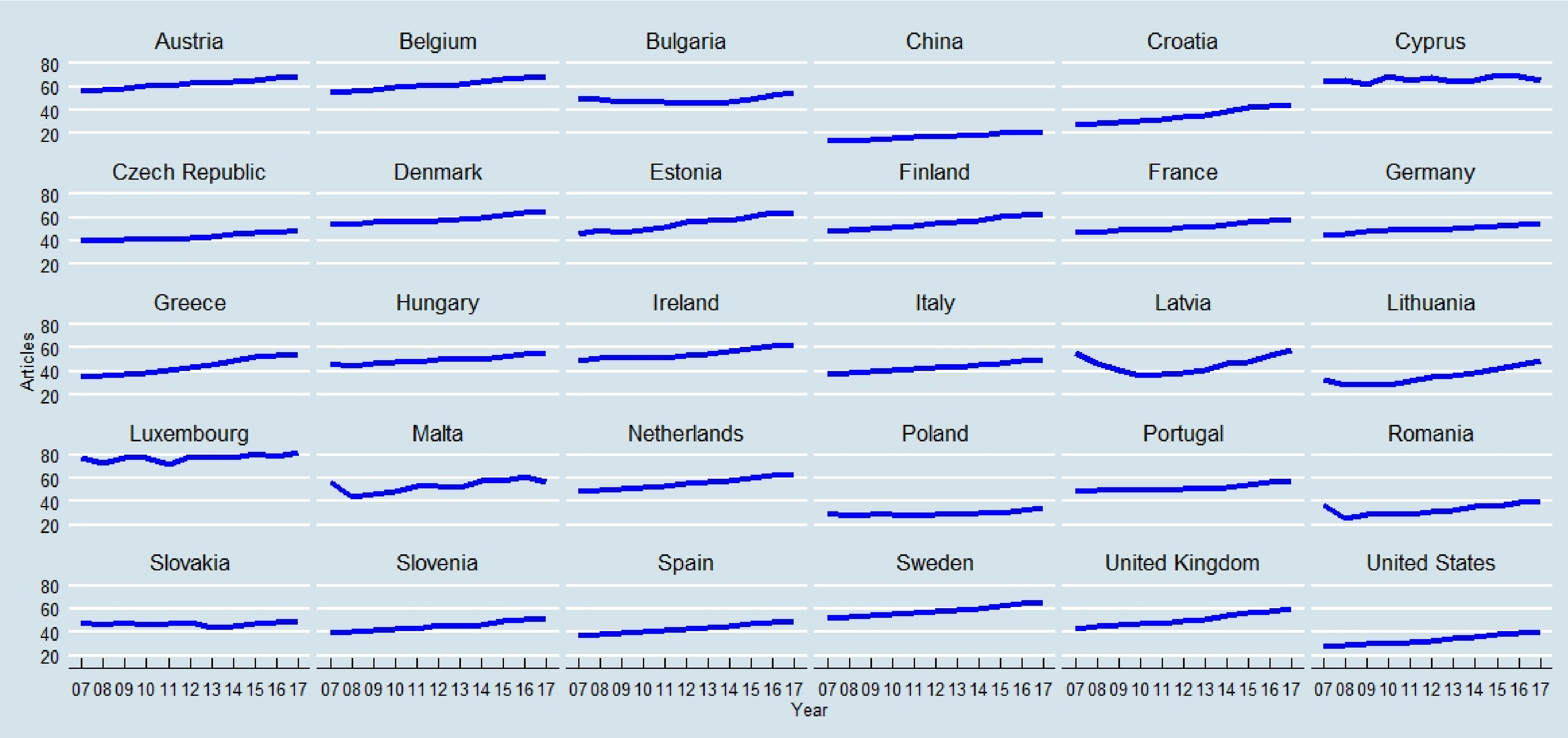
Source: author's own calculations based on SciVal (2019) data

Table 6. IRC patterns: Top 20 collaboration partnerships between of EU-28 countries (plus China and the USA), most prolific pairs 2013-2018. Pairings sorted by the count of co-authored publications (left panel) and by the Field-Weighted Citation Impact (FWCI) of co-authored publications.

Rank	**Partner Country 1**	**Partner Country 2**	**Publications 2013 - 2018**	**FWCI**	**Rank**	**Partner Country 1**	**Partner Country 2**	**Publications 2013 - 2018**	**FWCI**
1	CHN	USA	266,244	1.85	1	NLD	USA	60,055	3.27
2	GBR	USA	172,887	2.77	2	NLD	GBR	51,711	3.23
3	DEU	USA	141,195	2.68	3	DEU	ESP	42,335	3.18
4	FRA	USA	93,308	2.85	4	DEU	NLD	48,573	3.15
5	DEU	GBR	90,202	2.89	5	FRA	GBR	64,296	3.11
6	ITA	USA	84,107	2.8	6	USA	SWE	39,974	3.10
7	FRA	GBR	64,296	3.11	7	ITA	DEU	54,956	3.09
8	CHN	GBR	63,625	2.21	8	ITA	ESP	41,595	2.98
9	ITA	GBR	63,176	2.94	9	DEU	FRA	62,891	2.97
10	DEU	FRA	62,891	2.97	10	ESP	GBR	50,124	2.95
11	ESP	USA	61,796	2.91	11	ITA	GBR	63,176	2.94
12	NLD	USA	60,055	3.27	12	ESP	USA	61,796	2.91
13	ITA	DEU	54,956	3.09	13	ITA	FRA	51,897	2.91
14	ITA	FRA	51,897	2.91	14	DEU	GBR	90,202	2.89
15	NLD	GBR	51,711	3.23	15	FRA	USA	93,308	2.85
16	ESP	GBR	50,124	2.95	16	ITA	USA	84,107	2.80
17	DEU	NLD	48,573	3.15	17	GBR	USA	172,887	2.77
18	DEU	ESP	42,335	3.18	18	DEU	USA	141,195	2.68
19	ITA	ESP	41,595	2.98	19	CHN	GBR	63,625	2.21
20	USA	SWE	39,974	3.1	20	CHN	USA	266,244	1.85

Source: author's own calculations based on SciVal (2019) data

Figure 15. IRC trends: the percentage share of articles written in international collaboration, EU-28 countries, 2007-2017 (in %).



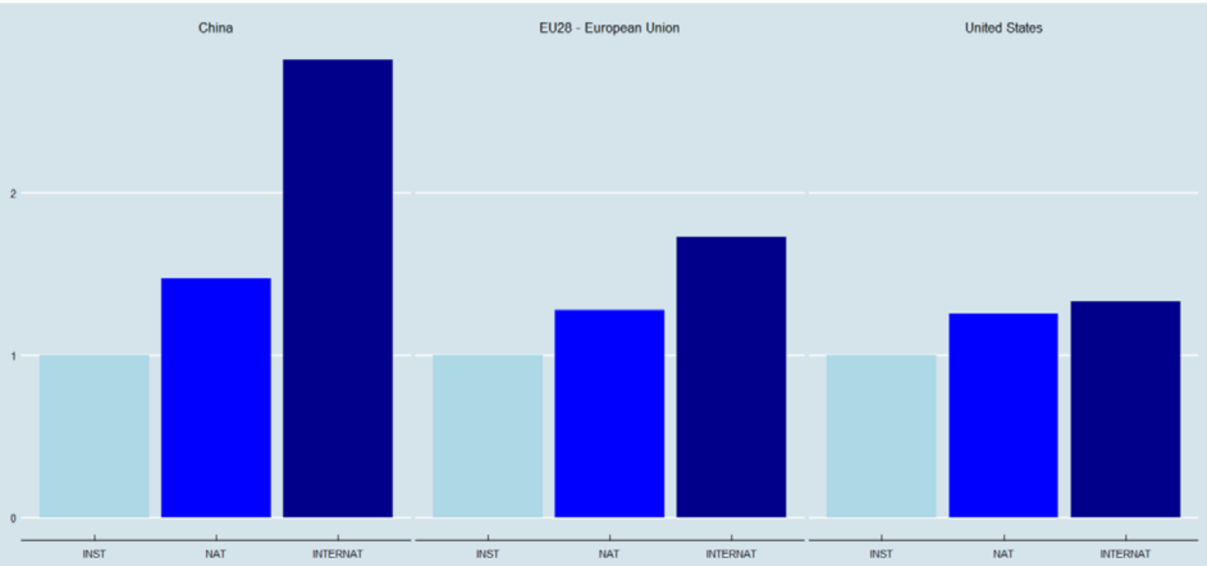
Source: author's own calculations based on SciVal (2019) data

5.3. Citation impact by collaboration type: the benchmark of institutional collaboration

The citation impact of different articles produced in different collaboration types (or the average number of citations received by publications that have international or national co-authorship, as well as single authorship) can be presented relative to the citation impact per institutional collaboration. In this case, citation impact per institutional collaboration is regarded as 1 (100 %, or the benchmark value; see Kamalski and Plume 2013). The patterns for EU-28 as a single entity, China and the USA indicate (Figure 16) that for the USA, the increases are considerable (by one-fourth in the case of national collaboration and by one-third in the case of international collaboration, 125.6 % and 133.5 %, respectively); for EU-28, the increases in the case of national collaboration are similar (127.8 %) and in the case of international collaboration, they are much higher (172.9 %). However, the biggest citation impact increase per national and international collaboration is observable for China (147.2 % in the case of national collaboration and a 181.9 % in the case of international collaboration).

From a regional perspective, IRC in EU-28 and China is a substantial factor increasing international visibility of published research as measured through a proxy of citation impact. For the USA as a global science centre, consistently with research literature, the citation impact per international collaboration does not differ much from the citation impact per national collaboration. In other words, IRC from this perspective pays off the most in China and pays off the least in the USA. However, the same analysis conducted for EU-28 countries separately shows a much more nuanced picture, with substantial cross-national differences. Table 7 shows citation impact per national and international collaboration in descending order.

Figure 16. IRC patterns: citation impact per collaboration type, regional approach (EU 28, China, and the USA), 2007-2017 (metrics: the 2007-2017 average). Fold increase over institutional collaboration (institutional collaboration = 1).



Source: author's own calculations based on SciVal (2019) data

Figure 17. IRC patterns: citation impact per collaboration type, 2007-2017 (metrics: the 2007-2017 average), by country. Fold increase over institutional collaboration (institutional collaboration = 1).

Source: author's own calculations based on SciVal (2019) data

Table 7. IRC patterns: citation impact per collaboration type, 2007-2017 (metrics: the 2007-2017 average), by country, in descending order. Fold increase over institutional collaboration (institutional collaboration = 100 %).

	Institutional collaboration - citation impact	National collaboration - citation impact	International collaboration - citation impact
LVA	100	128.6	466.7
BGR	100	109.3	451.2
HRV	100	145.1	423.5
ROU	100	145.0	420.0
LTU	100	103.6	364.3
MLT	100	87.7	357.9
SVK	100	140.8	357.1
POL	100	137.3	355.9
CZE	100	157.6	321.2
HUN	100	134.7	317.3
CHN	100	147.2	281.9
EST	100	128.0	276.6
SVN	100	142.2	243.3
CYP	100	107.2	228.9
FRA	100	146.6	222.4
ITA	100	125.4	205.4
ESP	100	128.6	205.0
GRC	100	114.3	194.4
AUT	100	130.7	194.2
DEU	100	131.9	188.2
PRT	100	114.5	186.3
IRL	100	105.9	182.4
FIN	100	117.1	180.9
BEL	100	121.8	180.1
DNK	100	115.8	178.4
EU-28	100	127.8	172.9
LUX	100	152.0	168.8
SWE	100	104.7	168.6
NLD	100	110.8	161.3
GBR	100	119.4	157.7
USA	100	125.6	133.5

Source: author's own calculations based on SciVal (2019) data

In a graphic form, cross-national differences can be clearly seen in Figure 17: the countries benefiting the most in terms of average citation rates from international collaboration are EU-13 countries, with increases reaching more than 300 % (in such countries as Latvia, Bulgaria, Croatia, and Romania) and more than 200 % (in such countries as Lithuania, Slovakia, Poland, the Czech Republic, and Hungary) compared with the institutional collaboration. The EU-15/EU-13 divide is striking but consistent with the idea of peripheries vs. centres in European science. For major EU-15 academic knowledge production systems, increases in the citation impact between papers published in institutional collaboration and those published in international collaboration generally reach the levels of about 50-120 %: the United Kingdom 57.7 %, Germany 88.2 %, France 122.4 %, Italy 105.4 %, and Spain 105.0 % (see Table 7).

One pattern is clear for all the countries studied, however: no matter what the citation impact in the case of institutional collaboration, the citation impact per international collaboration in the vast majority of cases exceeds 20 (in all countries except for Latvia, Bulgaria, Slovakia and Romania), and in the case of 11 EU-15 countries, it exceeds 25 (the European countries with the highest citation impact in the case of international collaboration include the Netherlands, Denmark, Sweden, Belgium, Ireland, the United Kingdom, Finland, Germany, Italy, Austria and France. The only EU-13 country in top 10 European countries is Estonia (29.6), see Table 29 in Data Appendices). The only EU-15 countries whose citation impact per international collaboration is similar to that of EU-13 countries are Portugal, as well as small systems of Cyprus, Luxembourg and Malta.

The citation impact of papers resulting from national collaboration is not much different across EU-28 countries and a similar EU-15/EU-13 divide for this collaboration type is not observable (Table 7). The increase in average citation impact between institutional collaboration and international collaboration remains in the range of 105-150 % (disregarding the case of a small system of Malta where it is negative). From a science policy perspective of increasing international visibility of national science systems in Europe, what really matters for new EU member states is internationally co-authored publications. IRC in EU-13 countries is associated with strikingly higher citation impact than citation impact in the case of national RC; and for EU-15 countries, IRC is associated with significantly higher citation impact.

One more dimension of analysis needs to be discussed: diversified citation impact per the six FOS. The citation impact rates used in the above analysis have been averaged for the whole of the academic science production (all FOS combined) in a given country. However, differentiated patterns emerge for different FOS (or even, at a more disaggregated level, for 41 All Science Journal Classification or ASJC categories used by Scopus). For each of the FOS (or for each of the 41 ASJC Scopus classification categories), separate patterns can be elaborated for citation impact by the four collaboration types. An example for the 2007-2017 average for all FOS for the specific case of international collaboration is presented in Table 8: different countries have different citation impact for internationally co-authored papers in different FOS. In all EU-28 countries, citation impact per international collaboration is the highest for the medical sciences (the only exception being a small system of Cyprus). The same pattern is observed for the aggregate of EU-28 and the USA; interestingly from a regional perspective, for China, this figure is the lowest of all the countries studied and equal to the citation impact for engineering and technologies and the natural sciences. The social sciences and humanities in EU-28 countries have the lowest citation impact.

Using the same methodology, the most and the least affected FOS by national collaboration and international collaboration in terms of generally increasing average citation impact can be shown, leading to a fine-grained cross-disciplinary analysis of trends over time and current patterns. From a science policy perspective, such detailed analysis at the level of collaboration types, individual countries, and FOS is especially useful for EU-13 countries which benefit most in terms of international visibility from international collaboration, as confirmed in the above analysis without reference to FOS. At a still lower level of disaggregation, used in the next section of the meso-level of institutions, the data on FOS can be combined with the institutional-level data on individual research organisations, including national flagship universities. Consequently, within these institutions, FOS in which IRC increases citation impact most (and those in which IRC does not change the average citation impact) can be determined, which can be particularly useful while adopting institutional-level internationalisation strategic plans.

Table 8. IRC patterns: citation impact per collaboration type: international collaboration, 2007-2017 (metrics: the 2007-2017 average), by country and FOS.

	Engineering and technologies	Agricultural sciences	Humanities	Natural sciences	Medical sciences	Social sciences
AUT	18.5	19.2	14.1	24.8	30.6	16.9
BEL	21.6	18.6	16.3	25.3	33.6	18.4
BGR	14.6	11.8	19.2	18.1	25.0	14.2
CHN	20.8	15.5	15.6	20.5	20.3	13.3
HRV	14.4	12.1	8.3	22.0	22.6	9.3
CYP	21.2	13.8	10.1	23.1	22.5	13.2
CZE	15.4	12.8	10.7	19.1	29.4	10.3
DNK	24.8	19.2	20.1	27.7	33.1	18.8
EST	15.3	18.5	11.3	27.4	36.2	14.3
EU-28	19.6	17.5	15.7	22.0	26.4	16.5
FIN	20.1	19.4	14.7	25.3	31.6	17.7
FRA	19	19.4	15.8	23.4	33.6	15.8
DEU	21.5	19.3	17.9	25.1	31.3	17.6
GRC	20.1	17.5	12.1	23.2	29.1	14.0
HUN	16.8	16.1	11.6	21.7	29.1	14.4
IRL	22.7	20.8	14.1	27.1	31.3	16.7
ITA	20.9	19.2	15.8	24.3	32.8	16.2
LVA	10.4	13.8	6.8	14.6	35.0	9.7
LTU	12.7	13.0	10.8	19.4	26.1	10.5
LUX	19.4	18.8	9.7	19.5	26.2	12.0
MLT	12.9	18.6	7.4	20.9	25.6	11.3
NLD	24.2	21.6	20.1	29.6	34.2	21.2
POL	14.2	13.3	10.8	18.3	31.6	12.4
PRT	19.5	16.7	11.5	21.3	24.3	13.4
ROU	13	11.2	12.7	15.6	24.6	10.0
SVK	12	10.7	7.0	16.9	23.0	8.5
SVN	17.6	18.3	12.2	22.1	26.4	11.6
ESP	20.7	17.7	14.6	22.9	30.0	14.3
SWE	21.6	19.9	18.0	26.4	31.5	17.8
GBR	21.5	20.7	18.3	26.4	31.0	18.1
USA	23.9	19.0	18.9	26.0	28.9	18.8

Source: author's own calculations based on SciVal (2019) data

5.4. Field-Weighted Citation Impact (FWCI) per collaboration type: international vs. national collaboration

Another method to study the influence of IRC on international research visibility is to compare Field-Weighted Citation Impact (FWCI) per collaboration type. The difference with the above analysis is that the country-level ratios of citations received are adjusted to the expected world average for the subject field, publication type and publication year. In short, cross-national comparisons are made between FWCI, rather than between citation impact as measured through the number of citations received. FWCI in SciVal is available for national and international collaboration types only so that both can be compared to national averages. The data for institutional collaboration cannot be used as benchmark values, and single-authored publications (no collaboration type) cannot be studied through this parameter. Consequently, the analysis in this subsection is complementary to that presented above.

In short: a Field-Weighted Citation Impact of 1.00 indicates that the country's publications have been cited exactly as would be expected based on the global average for similar publications (FWCI of 'World', or the entire Scopus database, is 1.00). A FWCI higher than 1.00 indicates that the country's publications have been cited more than would be expected based on the global average for similar publications (2.11 means 111 % more than the world average). A FWCI lower than 1.00 indicates that the country's publications have been cited less than would be expected based on the global average for similar publications (0.87 means 13 % less than the world average). 'Similar publications' are those publications in the Scopus database that have the same publication year, publication type, and discipline, as represented by the Scopus journal classification system. The FWCI parameter helps in understanding the prestige of a country's citation performance by observing the extent to which its FWCI is above or below the world average of 1.00.

This powerful indicator makes it possible to immediately observe whether the research performance and specifically for the purposes of this report, the research performance per various collaboration types, of EU-28 countries studied is significantly far below (indicator value < 0.5), below (indicator value between 0.5 and 0.8), about (between 0.8 and 1.2), above (between 1.2 and 1.5) or far above (> 1.5) the global average (following the distinctions proposed by van Raan 2004: 31).

While the analysis in the previous subsection refers to pure citation data (and compares citation levels per collaboration type), in this section the prestige of national citation performance can be compared cross-nationally.

Tables 9 through 11 show FWCI for all collaboration types combined (that is, for all publications, regardless of whether they were published in international, national, institutional collaboration or in no collaboration), FWCI per international collaboration and FWCI per national collaboration. While these tables show trends over time (2007-2017), our focus is on the average FWCI for the period studied (first column, 'Average 2007-2017'). In general, without reference to collaboration types (Table 9), FWCI for publications with authors affiliated with institutions in EU-13 countries (except for small systems of Cyprus and Malta) is lower than for those originating from EU-15 countries. For four EU-13 countries FWCI is about the world average: Bulgaria (6 % less), Poland (9 % less), Croatia (10 % less) and Romania (16 % less). From a regional perspective, FWCI for EU-28 is above and for USA is far above the world average (23 % and 51 % more, respectively), while for China it is about the world average (12 % less) and it is higher only than FWCI for Romania. The only EU-13 system with FWCI far above the global average is Estonia (1.83).

What is especially interesting in the context of large-scale data at our disposal is whether international collaboration increases FWCI, or increases the national visibility through citation levels. According to the research literature, papers written in international collaboration are expected to be more highly cited than those written in any other collaboration type. Table 10 shows that the average FWCI for internationally co-authored papers (for 2007-2017) for all but four EU-28 countries is higher than 1; these publications are cited more than the global average for similar publications. The four exceptions are the EU-13 countries of Croatia, Lithuania, Romania and Poland, with their FWCI ranging from 0.77 to 0.97), still about the global average. Interestingly, also the USA and China belong to this group of countries, with American internationally co-authored publications being cited 11 % less than the expected world average and Chinese publications significantly far below the world average; 52 % less. In contrast, in all EU-28 countries except for four (France, Italy, Portugal and Spain, with China and the USA belonging to this group), nationally co-authored publications are cited less than would be expected from the global average for similar publications (Table 11).

Taking into account the average FWCI for 2007-2017 (Table 12) for all publications, those written in international collaboration and those written in national collaboration, the emerging patterns are clear: in about half of EU-28 countries, FWCI for internationally co-authored publications is higher than FWCI for all publications. This group of countries includes all EU-13 countries except for Poland and Lithuania (for which FWCI for internationally co-authored publications is lower than for all publications). Poland is also the only EU-28 country which, together with the USA, has FWCI for this publication type lower than 1 (0.77, USA 0.89). In all EU-28 countries (except for France, accompanied by China), nationally co-authored publications have lower FWCI than those that are internationally co-authored. Nationally co-authored papers are more cited than would be expected for the global average in the case of a few countries only: apart from France and China, these include Italy, Portugal and Spain. (On top of this, different levels of FWCI per collaboration type apply to different FOS, with different speeds of change regarding international collaboration over time in different countries; however, this dimension of IRC is only mentioned due to the limitations of space in this report).

Table 9. RC trends: Field-Weighted Citation Impact (FWCI) (all publications – all collaboration types combined, articles only, self-citations included, by country, in descending order, 2007-2017.

	Average 2007-2017	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
LUX	1.89	1.17	1.43	1.45	1.54	1.43	1.47	1.71	1.54	1.74	2.85	2.68
DNK	1.88	1.81	1.89	1.81	1.8	1.83	1.97	1.81	1.87	1.98	2	1.83
NLD	1.85	1.79	1.81	1.81	1.86	1.86	1.9	1.83	1.79	1.89	1.91	1.87
EST	1.83	1.34	1.38	1.17	1.43	1.4	1.74	1.68	2.06	2.48	2.3	2.16
CYP	1.73	1.44	1.41	1.19	1.61	1.57	1.85	1.47	1.73	2.64	1.75	1.74
BEL	1.72	1.69	1.67	1.67	1.68	1.7	1.73	1.73	1.71	1.76	1.76	1.79
SWE	1.7	1.61	1.6	1.65	1.64	1.69	1.78	1.7	1.73	1.74	1.78	1.68
FIN	1.66	1.59	1.58	1.54	1.59	1.62	1.69	1.63	1.72	1.76	1.77	1.66
IRL	1.64	1.47	1.55	1.49	1.55	1.56	1.7	1.57	1.65	1.78	1.91	1.7
GBR	1.63	1.55	1.57	1.57	1.59	1.61	1.64	1.63	1.65	1.67	1.7	1.66
AUT	1.59	1.48	1.46	1.46	1.6	1.59	1.65	1.58	1.59	1.62	1.69	1.61
MLT	1.57	1.51	1.3	1.11	1.06	1.19	1	1.09	1.25	1.65	2.13	2.48
USA	1.51	1.55	1.54	1.53	1.53	1.53	1.52	1.52	1.52	1.51	1.48	1.44
DEU	1.44	1.39	1.41	1.41	1.44	1.46	1.44	1.45	1.44	1.46	1.44	1.43
ITA	1.44	1.34	1.35	1.31	1.38	1.4	1.47	1.44	1.47	1.51	1.51	1.54
FRA	1.37	1.36	1.35	1.33	1.35	1.38	1.37	1.4	1.36	1.42	1.4	1.37
GRC	1.35	1.2	1.2	1.16	1.23	1.22	1.42	1.39	1.44	1.54	1.51	1.49
PRT	1.33	1.29	1.29	1.3	1.21	1.27	1.33	1.31	1.31	1.35	1.39	1.43
ESP	1.3	1.24	1.24	1.23	1.27	1.3	1.32	1.3	1.32	1.33	1.36	1.31
EU-28	1.23	1.24	1.22	1.22	1.23	1.23	1.24	1.24	1.24	1.24	1.24	1.22
HUN	1.22	1.12	1.04	1.03	1.12	1.09	1.2	1.15	1.18	1.26	1.54	1.51
SVN	1.19	1.08	1.11	1.13	1.12	1.05	1.17	1.13	1.18	1.25	1.45	1.27
LVA	1.1	1.01	0.97	0.72	0.86	0.77	0.89	0.89	1.09	1.26	1.41	1.61
CZE	1.09	0.98	1.02	1	1.07	1.09	1.13	1.15	1.08	1.11	1.12	1.12
LTU	1.04	0.87	0.9	0.83	0.92	0.88	1.03	0.98	1.06	1.11	1.35	1.28
SVK	1	0.86	0.97	0.8	0.91	0.86	0.99	0.96	0.91	1.15	1.21	1.15
BGR	0.94	0.87	0.84	0.75	0.75	0.88	1	0.79	0.85	1.45	0.99	1.14
POL	0.91	0.85	0.74	0.76	0.76	0.85	0.87	0.9	0.94	0.98	1.03	1.07
HRV	0.9	0.72	0.73	0.74	0.89	0.78	0.85	0.87	0.94	1.01	1.06	1.12
CHN	0.88	0.65	0.69	0.71	0.76	0.82	0.87	0.88	0.92	0.97	1	1.05
ROU	0.84	0.8	0.76	0.59	0.65	0.72	0.77	0.82	0.91	0.91	1.04	1.12

Source: author's own calculations based on SciVal (2019) data

Table 10. IRC patterns: Field-Weighted Citation Impact (FWCI) per collaboration type: international collaboration, articles only, self-citations included, by country, in descending order, 2007-2017.

	Average 2007-2017	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
LUX	2.07	2.36	2.1	2.31	2.18	2.05	2.23	2.07	2.01	2	1.97	1.97
CYP	1.78	1.97	1.95	1.88	2.02	1.85	1.82	1.74	1.73	1.75	1.71	1.6
BEL	1.65	1.66	1.66	1.65	1.65	1.69	1.65	1.64	1.65	1.65	1.63	1.6
AUT	1.63	1.66	1.66	1.65	1.65	1.64	1.65	1.65	1.62	1.6	1.6	1.56
MLT	1.59	1.83	1.67	1.46	1.6	1.87	1.64	1.59	1.58	1.55	1.58	1.43
SWE	1.52	1.52	1.52	1.52	1.52	1.53	1.53	1.53	1.51	1.51	1.53	1.5
DNK	1.51	1.56	1.56	1.55	1.53	1.49	1.5	1.51	1.48	1.49	1.5	1.49
IRL	1.48	1.47	1.53	1.48	1.45	1.41	1.45	1.47	1.49	1.5	1.52	1.5
NLD	1.47	1.44	1.45	1.46	1.46	1.47	1.49	1.49	1.49	1.48	1.49	1.48
FIN	1.43	1.42	1.37	1.39	1.41	1.4	1.44	1.45	1.45	1.46	1.45	1.47
EST	1.41	1.3	1.37	1.33	1.33	1.35	1.41	1.45	1.43	1.46	1.47	1.42
GBR	1.35	1.25	1.3	1.31	1.31	1.32	1.33	1.35	1.38	1.39	1.4	1.41
PRT	1.34	1.4	1.39	1.38	1.34	1.35	1.33	1.34	1.31	1.31	1.36	1.35
FRA	1.31	1.29	1.29	1.31	1.3	1.3	1.29	1.31	1.31	1.32	1.32	1.33
DEU	1.27	1.29	1.29	1.3	1.29	1.28	1.26	1.28	1.26	1.25	1.24	1.23
HUN	1.27	1.33	1.25	1.31	1.31	1.27	1.29	1.3	1.25	1.24	1.27	1.22
BGR	1.22	1.4	1.33	1.29	1.25	1.24	1.13	1.12	1.16	1.15	1.17	1.22
SVK	1.21	1.38	1.31	1.33	1.26	1.25	1.25	1.14	1.14	1.15	1.15	1.16
LVA	1.2	1.56	1.35	1.18	1.01	1	1.08	1.11	1.2	1.2	1.29	1.34
SVN	1.2	1.14	1.16	1.21	1.18	1.18	1.24	1.23	1.19	1.21	1.21	1.2
GRC	1.18	1.08	1.08	1.09	1.08	1.12	1.16	1.21	1.26	1.27	1.27	1.29
ITA	1.12	1.07	1.09	1.09	1.11	1.12	1.11	1.11	1.13	1.13	1.15	1.15
CZE	1.11	1.14	1.12	1.13	1.1	1.07	1.08	1.1	1.13	1.11	1.08	1.11
ESP	1.1	1.03	1.06	1.07	1.08	1.09	1.09	1.11	1.13	1.13	1.14	1.14
EU-28	1.02	0.99	1	1.01	1.01	1	1	1.01	1.02	1.03	1.04	1.04
HRV	0.97	0.85	0.88	0.9	0.91	0.89	0.94	0.98	1.02	1.08	1.07	1.02
LTU	0.95	0.95	0.83	0.87	0.8	0.85	0.9	0.95	0.97	1.02	1.07	1.13
ROU	0.93	1.27	0.99	0.91	0.87	0.84	0.87	0.9	0.94	0.94	0.97	0.94
USA	0.89	0.83	0.85	0.85	0.86	0.86	0.88	0.9	0.91	0.92	0.93	0.93
POL	0.77	0.85	0.8	0.82	0.79	0.76	0.74	0.75	0.76	0.74	0.76	0.79
CHN	0.48	0.41	0.43	0.45	0.47	0.49	0.48	0.48	0.48	0.5	0.51	0.52

Source: author's own calculations based on SciVal (2019) data

Table 11. RC patterns: Field-Weighted Citation Impact (FWCI) per collaboration type: national collaboration, articles only, self-citations included, by country, in descending order 2007-2017.

	Average 2007-2017	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
FRA	1.51	1.51	1.52	1.52	1.52	1.52	1.52	1.52	1.51	1.5	1.48	1.46
USA	1.06	1.07	1.07	1.06	1.06	1.05	1.05	1.05	1.07	1.07	1.07	1.07
ITA	1.04	1.08	1.05	1.03	1.04	1.03	1.04	1.04	1.05	1.04	1.04	1.05
PRT	1.04	0.96	1.01	1.01	1.03	1.02	1.06	1.04	1.07	1.05	1.06	1.05
CHN	1.03	1.01	1.01	1.02	1.03	1.04	1.04	1.03	1.03	1.03	1.03	1.04
ESP	1.03	0.98	1.01	1.02	1.04	1.05	1.05	1.04	1.05	1.04	1.03	1.02
EU-28	1.02	1.01	1.02	1.02	1.02	1.02	1.03	1.03	1.03	1.03	1.03	1.03
NLD	0.96	0.93	0.94	0.95	0.96	0.98	0.98	0.97	0.96	0.97	0.98	0.97
GBR	0.95	0.95	0.94	0.94	0.93	0.94	0.94	0.95	0.96	0.97	0.98	0.98
FIN	0.91	0.95	0.97	0.93	0.94	0.91	0.9	0.9	0.85	0.87	0.87	0.87
POL	0.88	0.89	0.86	0.87	0.87	0.85	0.85	0.86	0.88	0.89	0.9	0.92
DEU	0.85	0.8	0.83	0.83	0.87	0.86	0.86	0.86	0.87	0.87	0.86	0.88
GRC	0.84	0.85	0.86	0.83	0.82	0.83	0.83	0.82	0.85	0.84	0.84	0.83
SWE	0.81	0.79	0.79	0.8	0.8	0.82	0.81	0.83	0.78	0.83	0.82	0.84
CZE	0.8	0.83	0.79	0.84	0.83	0.79	0.81	0.82	0.8	0.78	0.76	0.76
HUN	0.8	0.83	0.79	0.8	0.81	0.77	0.8	0.78	0.79	0.81	0.84	0.78
BEL	0.73	0.69	0.67	0.71	0.73	0.73	0.75	0.75	0.72	0.75	0.72	0.75
ROU	0.72	0.71	0.66	0.66	0.7	0.67	0.62	0.68	0.75	0.81	0.81	0.82
DNK	0.71	0.74	0.7	0.71	0.73	0.71	0.71	0.69	0.69	0.69	0.72	0.69
BGR	0.68	0.56	0.64	0.66	0.69	0.7	0.66	0.75	0.67	0.71	0.7	0.66
IRL	0.66	0.6	0.6	0.64	0.68	0.67	0.66	0.64	0.67	0.69	0.69	0.72
AUT	0.64	0.63	0.64	0.64	0.64	0.64	0.64	0.65	0.64	0.63	0.65	0.65
SVK	0.61	0.7	0.63	0.72	0.6	0.61	0.59	0.58	0.59	0.59	0.58	0.62
SVN	0.59	0.61	0.61	0.6	0.61	0.57	0.59	0.58	0.59	0.54	0.61	0.6
LVA	0.58	0.59	0.49	0.48	0.53	0.51	0.55	0.66	0.71	0.58	0.59	0.61
HRV	0.54	0.51	0.51	0.54	0.54	0.57	0.56	0.53	0.52	0.52	0.54	0.53
EST	0.49	0.44	0.51	0.45	0.47	0.44	0.54	0.52	0.58	0.46	0.48	0.44
LTU	0.49	0.4	0.49	0.52	0.48	0.5	0.46	0.52	0.52	0.46	0.45	0.53
CYP	0.38	0.12	0.21	0.23	0.32	0.39	0.46	0.41	0.53	0.36	0.39	0.42
LUX	0.13	0.32	0.14	0.06	0.15	0.05	0.12	0.06	0.13	0.12	0.22	0.1
MLT	0.02	0.14	0	0.2	0	0	0	0	0	0	0	0

Source: author's own calculations based on SciVal (2019) data

Table 12. RC patterns: Field-Weighted Citation Impact (FWCI), self-citations included, by publication type (all, international, national), average for 2007-2017.

	Average FWCI 2007-2017 (all publications)	Average FWCI 2007-2017 per international collaboration	Average FWCI 2007-2017 per national collaboration
AUT	1.59	1.63	0.64
BEL	1.72	1.65	0.73
BGR	0.94	1.22	0.68
CHN	0.88	0.48	1.03
HRV	0.9	0.97	0.54
CYP	1.73	1.78	0.38
CZE	1.09	1.11	0.8
DNK	1.88	1.51	0.71
EST	1.83	1.41	0.49
EU-28	1.23	1.02	1.02
FIN	1.66	1.43	0.91
FRA	1.37	1.31	1.51
DEU	1.44	1.27	0.85
GRC	1.35	1.18	0.84
HUN	1.22	1.27	0.8
IRL	1.64	1.48	0.66
ITA	1.44	1.12	1.04
LVA	1.1	1.2	0.58
LTU	1.04	0.95	0.49
LUX	1.89	2.07	0.13
MLT	1.57	1.59	0.02
NLD	1.85	1.47	0.96
POL	0.91	0.77	0.88
PRT	1.33	1.34	1.04
ROU	0.84	0.93	0.72
SVK	1	1.21	0.61
SVN	1.19	1.2	0.59
ESP	1.3	1.1	1.03
SWE	1.7	1.52	0.81
GBR	1.63	1.35	0.95
USA	1.51	0.89	1.06

Source: author's own calculations based on SciVal (2019) data

6. Empirical analysis – A meso-level of European institutions

The diversity of paths towards increased internationalisation in research (or towards increasing numbers and percentage shares of internationally co-authored publications in national research outputs) in EU-28 countries in the last decade has been accompanied by the diversity of these paths at the meso-level of individual academic institutions.

Following previous research literature, it is assumed here that patterns of IRC differ between national flagship universities and their local, peripheral counterparts within national higher education systems. IRC is expected to be higher in high-ranking, especially research-focused institutions, and lower in lower-ranking, especially teaching-focused institutions in all European systems studied.

In this section, an analysis of institutional-level IRC trends and patterns will be complementary to an analysis of national-level IRC trends and patterns presented above. The analyses at the macro-level of countries will be accompanied by the analyses at the meso-level of (selected, flagship) institutions. The selection of institutions has been described in the Data Sources and Methodology Section. The names of 22 flagship institutions are presented in Table 13.

Table 13. National flagship universities, 2017.

University	Country (ISO 3-character country code)	City
University of Luxembourg	LUX	Luxembourg
University of Vienna	AUT	Vienna
Karolinska Institutet	SWE	Stockholm
Katholieke *Universiteit* Leuven	BEL	Leuven
University of Oxford	GBR	Oxford
University of Copenhagen	DNK	Copenhagen
University of Helsinki	FIN	Helsinki
University of Tartu	EST	Tartu
Trinity College Dublin	IRL	Dublin
Comenius University	CZE	Bratislava
University of Lisbon	PRT	Lisbon
Eötvös Loránd University	HUN	Budapest
Ludwig Maximilian University	DEU	Munich
Utrecht University	NLD	Utrecht
University of Padova	ITA	Padova
University of Athens	GRC	Athens
University of Barcelona	ESP	Barcelona
Charles University	CZE	Prague
University of Ljubljana	SVN	Ljubljana
Babes-Bolyai University	ROU	Cluj-Napoca
Jagiellonian University	POL	Cracow
University of Zagreb	HRV	Zagreb

6.1. Collaboration trends and patterns: the four collaboration types

In most general terms, collaboration trends over time (2007-2017) and collaboration patterns for 2017 (according to the four collaboration types) are similar for EU-28 countries and for their flagship institutions; however, as could be expected, the internationalisation trends are more intense for flagship institutions than for countries, the country data being aggregated from the data of all national institutions, with vastly different internationalisation levels.

The percentage share of international collaboration is on average lower for flagship universities located in EU-13 countries than for those located in EU-15 countries, following the pattern known from the macro-level of countries (Table 14). While no flagship universities located in EU-13 countries exceeded the level of 60 % of international collaboration for the period 2007-2017 and only three exceeded that of 50 %, five flagship universities in EU-15 countries exceeded the level of 60 % of international collaboration (University of Luxembourg, University of Vienna, Karolinska Institutet, KU Leuven and University of Oxford, and only these institutions exceeded two-thirds in 2017). Only in four EU-28 flagship universities was the share of internationally co-authored publications in a single year of 2017 smaller than 50 % (all of them being located in Central and Eastern Europe). For all the universities studied, the share of internationally co-authored papers increased substantially between 2007-2017 (except for University of Luxembourg, the leader in both points in time, reaching the level of almost 80 %, perhaps a level of saturation, see Ponds 2009).

In almost all the universities studied, the percentage share of nationally co-authored publications slightly decreased in the same period, the only more than marginal exceptions being Jagiellonian University and Trinity College Dublin, both with about one-third of the publications being nationally co-authored in 2007 and 2017. (Table 15). Only for 2 universities the share of nationally co-authored publications in 2017 exceeded 30 %, for 9 it exceeded 20 %, and for 8 universities it was lower than 15 %.

Institutional collaboration (Table 16) has been low and declining in all universities, the only exception being the University of Zagreb, with more than a half of institutionally co-authored papers in 2007 and still almost 40 % of them in 2017.

So the level of national collaboration seems to be low and slightly decreasing over time and the level of international collaboration is very high and steadily increasing (see Figure 18 for each institution). As collaboration patterns for 2017 show (Figure 19), the percentage share of institutional collaboration reaches the highest levels in flagship institutions from EU-13 countries: in 2017, it was 39.4 % for the University of Zagreb, 29 % for the University of Ljubljana and 21.6 %-22.6 % for the University of Tartu, Charles University and Comenius University. The EU-15/EU-13 divide is not observable for institutionally co-authored publications: their share is the lowest in the case of the University of Oxford (9 %) and University of Barcelona (10.7 %) from the former group of countries and Jagiellonian University (11.4 %) and Eötvös Loránd University (11.2 %) from the latter group.

In all flagship universities, the total number of articles written in all four collaboration types and the total number of articles written in international collaboration has been increasing (Figure 20). However, the differences between institutions in terms of numbers rather than percentages are substantial and more properly describe their internationalisation potential and growth: the largest producer of internationally co-authored publications in the period studied, not surprisingly, is the University of Oxford (the total of 50,613 and 6,481 publications in 2017), followed by the University of Copenhagen (the total 39,542 and 5,103 publications in 2017). The biggest producer of internationally co-authored publications among EU-13 institutions is Charles University in Prague (the total of 17,562 and 2,227 publications in 2017, or about one third of the leader, University of Oxford). Flagship universities from Romania, Slovakia, Hungary, and Estonia had fewer than 1,000 internationally co-authored publications in the same year and their total in the period studied was in the range of 3,700-5,700 (Table 17).

Flagship universities have their networks of collaborating institutions. An example of the University of Helsinki (Table 30 in Data Appendices) shows the network of top 10 institutions (with a number of co-authored publications in decreasing order, co-authored publication growth in percent, the number of citations, the rate of citations per publication and field-weighted citation impact. Its five top ranks of collaborating institutions in 2013-2018 are five institutions from Finland, followed by CNRS in France and the Karolinska Institute in Sweden.

Table 14. IRC trends: international collaboration, selected European flagship institutions, by institution, in descending order, 2007 to 2017 (in %).

	Average 2007-2017	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
University of Luxembourg	73.7	78.2	67.6	76.5	74.5	60.7	76.9	73.2	74.2	75.4	72.4	76.9
University of Vienna	64.3	60.4	58.1	60.9	62.4	63.7	64.8	65.4	65.5	65.7	68.7	67
Karolinska Institutet	61.4	54.2	56.8	57.4	56.4	58.3	61.9	60.9	61.6	64.8	67.3	68
KU Leuven	61.4	55	55.7	55.7	58.3	59.3	61.2	61.2	62.8	64.7	67.2	66.9
University of Oxford	60.6	52.5	55.6	56.3	58.5	58.5	60.4	59.4	61.4	63.9	64.6	66.6
University of Copenhagen	57.1	51.4	51.1	53.3	54.2	53.7	55.4	56.5	58	60.8	61.2	62.5
University of Helsinki	56.9	50.1	50.6	51.8	53.2	54.5	55.1	57.4	58.7	60.8	62.4	64.7
University of Tartu	54.7	45.8	51	47.2	51.2	51.1	55	54.4	56.7	57.7	61.1	60.2
Trinity College Dublin	54.3	48.8	51.3	50.1	52.6	50	52	52.1	55.7	57.6	59.3	62
Comenius University	53.7	48.6	51.1	45.6	50.7	53.5	59.6	52.4	54.9	56.1	56.6	54.8
University of Lisbon	53	46.8	48.5	49.3	50.5	52.6	51.2	54.4	52.1	54.1	56.8	58.3
Eötvös Loránd University	52.1	47.9	42.5	49.4	52.4	50.9	51.2	49.8	50.7	51.6	58.5	61.5
L. Maximilian Uni. Munich	51.7	43.6	46.4	47.8	49.5	50.7	51.9	51.9	52.8	54.9	56.4	57.2
Utrecht University	50.8	43.2	42.8	44.4	46.8	48.1	50.1	50.3	52.5	55.9	56.8	58.9
University of Padova	48.1	43.2	41.6	43.5	47	44.6	47	47	48.2	50	54.4	54.6
University of Athens	45.7	34.9	34.4	36.8	37.1	41	47.1	47	50.1	53	56.3	58.7
University of Barcelona	45.7	39.8	40.1	42.4	41.6	42.6	43	45.7	46.7	49.2	51	53.5
Charles University	45.3	38.4	40.1	41.3	42	44.1	45.9	45	46.8	47.1	49	51.8
University of Ljubljana	43.1	37.7	38.4	37	39	39.2	44.5	44.2	43.8	46	48.1	49.3
Babes-Bolyai University	41.9	27	23.4	40.6	45.3	43.5	43.4	41.9	45.2	42.3	44.6	47.6
Jagiellonian University	40.7	38.5	38.2	41.4	41.5	38.8	40.9	38.7	41	40	43.5	43
University of Zagreb	33	24.7	26.4	26.9	28.5	27.8	30.7	33.2	36.6	39	42.1	40.8

Source: author's own calculations based on SciVal (2019) data

Table 15. RC trends: national collaboration, selected European flagship institutions, by institution, in descending order, 2007 to 2017 (in %).

	Average 2007-2017	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Jagiellonian University	36.7	34.1	35.5	36.4	36.5	34.5	35.6	37.7	36.6	38.3	38.7	36.9
University of Barcelona	33.9	32.6	33.8	33.4	34.2	36	36.2	34.2	34.5	33.6	32.9	31.3
Utrecht University	26.8	27.9	28.7	28.9	28.3	28.3	27.4	26.2	26	25.6	26.1	23.5
University of Padova	26	29.3	29.8	28.3	25.1	27.2	26.2	26.8	26.1	25	23.1	23.3
University of Athens	25.9	30.9	30.2	29.9	29.5	27.4	24.1	25.6	23.2	23.4	22.6	20.8
L. Maximilian Uni. Munich	22.6	23.1	23.2	21.7	22.7	23.7	23	23.2	22.8	22.1	22.2	21.5
University of Lisbon	22.1	23.6	23.1	23	21.7	21.8	22.2	21.9	23.7	22.2	21.1	20.4
Charles University	21.5	22.7	21.5	23.4	22.5	21.2	21.3	21.9	21.4	21	20.6	20.2
Eötvös Loránd University	21.5	22.9	23.5	21.3	20.2	21.1	22.9	22.7	20.9	21.9	21.1	18.7
University of Helsinki	21.5	26.1	26.1	24	25	23.3	21.9	20	19.9	18.5	18.8	17.1
Babes-Bolyai University	20	38.4	37.7	19.2	13.6	17.6	13.5	17	16.4	21.7	21.2	20.5
Karolinska Institutet	18.7	18.6	19.3	19.1	18.6	19.5	18.1	20.1	18.9	18.2	17.2	18.4
University of Oxford	17.7	21	19.3	19.7	18.6	17.7	17.4	18	17.6	16.6	16.4	15.8
Comenius University	17.4	19.3	16.6	19.4	18.5	17.4	12.9	17.1	17.3	17.8	18.1	18
University of Copenhagen	15.2	16.9	16.6	15	15.8	16.6	15.1	14.8	14.6	14.4	14.7	14.3
Trinity College Dublin	13.6	11.6	11.8	11.3	13.7	14.2	13.5	14.4	13.9	13.9	14.6	14.4
University of Zagreb	11.8	12.2	11.4	12.6	11.1	13	11.9	11.4	11.1	10.8	11.9	12.6
KU Leuven	11	10.6	10.8	12.1	11.6	10.7	10.8	11.2	10.9	11.2	10.8	10.9
University of Ljubljana	11	12.2	12	13.4	12.1	11	10.1	10.2	10.5	9.9	10.9	10.7
University of Vienna	10.5	12.5	13.4	10.4	11.5	10.7	10.3	9.9	9.3	9.8	8.7	10.5
University of Tartu	8.4	10.3	12.4	9.4	7.6	8.9	9.5	6.6	9.1	7.5	7.4	6.9
University of Luxembourg	1.2	3.8	0.9	0	1.6	0.4	0.8	0.7	1.2	1.3	2.4	0.7

Source: author's own calculations based on SciVal (2019) data

Table 16. RC trends: institutional collaboration by year, selected European flagship institutions, by institution, in descending order, 2007 to 2017 (in %).

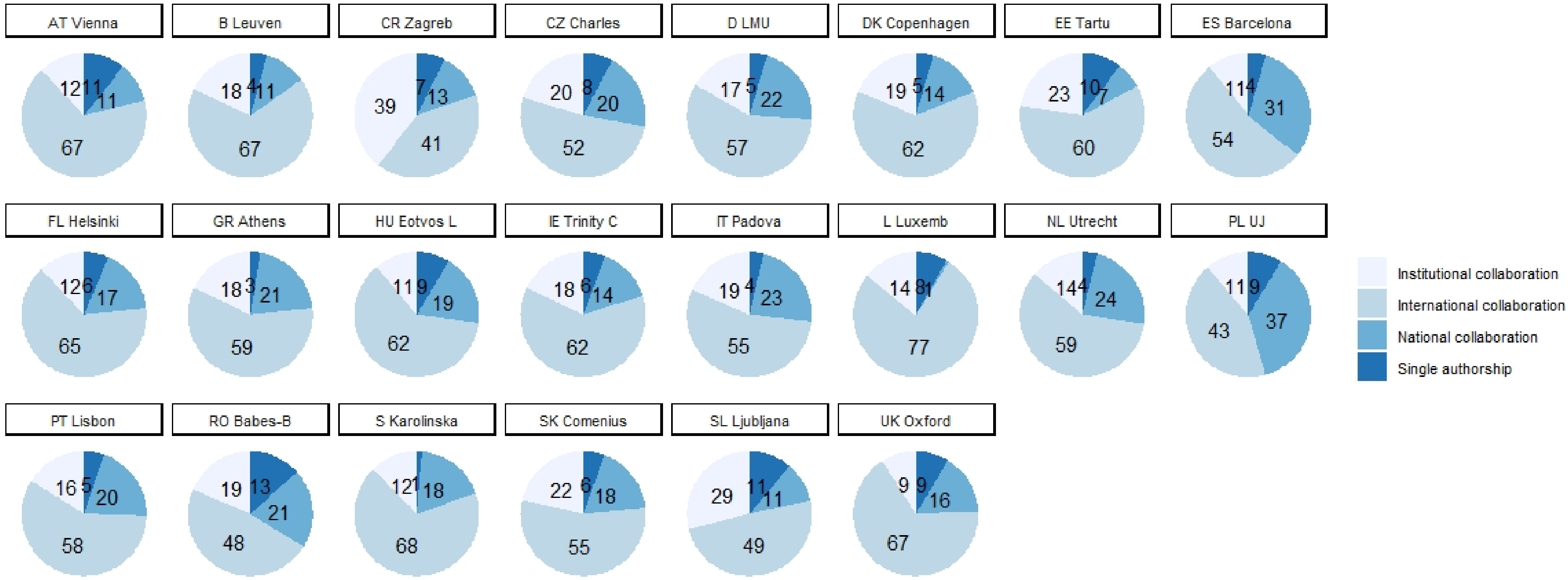
	Average 2007-2017	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
University of Zagreb	46.3	53.4	52	52.4	52.6	50.1	47	45.7	43.3	40.3	39.1	39.4
University of Ljubljana	35	37.4	39.1	39.5	39.3	38.8	34	34.4	33.9	33.2	31.6	29
University of Tartu	27.1	34	29.5	32.9	30.8	28.8	26.2	28.3	25.5	23.5	23	22.6
Charles University	25	31.1	30.3	28.1	27.5	25.6	24.3	24.2	22.8	23.2	22.8	20.4
Trinity College Dublin	24.8	30.7	27.5	29.7	27.3	26.8	28.1	26.2	23.3	21	19.9	17.9
University of Athens	24.5	29.4	31.3	29.5	29.4	26.9	23.9	23.6	21.9	20.6	18.5	17.9
Babes-Bolyai University	24.2	23	26.7	29.5	29.8	26.7	26.9	25.2	23.5	20.4	19.4	18.6
Comenius University	22.8	25.2	24.3	28.3	25	22.2	21.9	24.7	22.3	19.9	19.9	21.6
KU Leuven	22.6	29.3	28.1	27.4	25	23.7	22.1	22.1	21.2	20	18	18
University of Copenhagen	22.5	24.9	26.2	25	24.4	23.6	24	23.7	22.5	20.2	19.5	18.7
University of Padova	21.8	22.4	24.2	23.5	23.9	24.1	22.2	22.4	21.7	21.4	18.7	18.5
L. Maximilian Uni. Munich	20.2	26.8	23.8	24.6	23	20	19.5	19.3	18.6	17.4	16.8	16.7
University of Lisbon	19	22.2	21.3	20.4	21.4	19.5	20.4	18.6	19.3	17.8	16.5	16.1
Utrecht University	17.9	23.5	23.3	21.7	20.5	18.3	17.7	18.9	17.1	14.7	13.3	13.7
Karolinska Institutet	17.5	24.2	21.5	19.6	20.4	17.6	17.9	17.1	17.5	15.1	14.3	12.3
University of Barcelona	15.7	23.3	21.4	19.6	19.6	16.3	15.6	14.7	13.8	12.6	11.9	10.7
University of Helsinki	14.8	17.6	17.1	17.6	15.6	15	15.4	15.2	14	14	12.1	12
University of Luxembourg	14.4	12.8	19.4	13.4	11.2	21.4	11	13.1	13.2	14.1	16.6	14.2
University of Vienna	14.4	17.1	17.9	17.5	15.9	14.6	13.5	14.3	13.7	13.3	12.1	11.9
Eötvös Loránd University	13.5	14.2	16.3	13.2	13.9	12.8	13	16.4	13.8	14.1	11.2	11.2
Jagiellonian University	13.2	17.7	14.8	12.5	12.7	15.4	12.9	13.8	12.7	13.6	10.8	11.4
University of Oxford	11	13.5	13	12.8	11.8	11.8	11.1	10.8	10.6	10.1	9.8	9

Source: author's own calculations based on SciVal (2019) data

Figure 18. RC trends: collaboration trends over time (the four collaboration types), selected European flagship universities, by institution, 2007-2017 (in %).

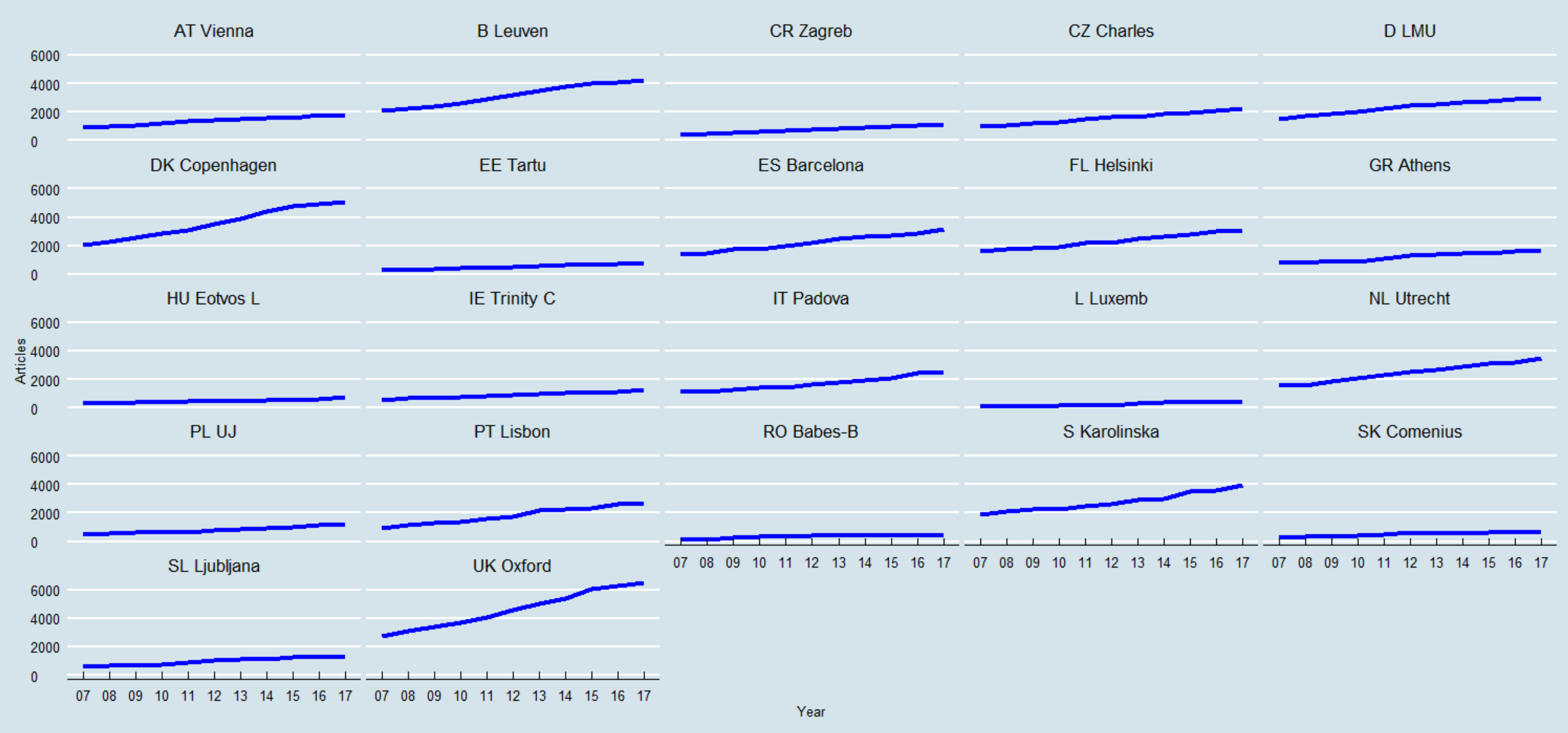
Source: author's own calculations based on SciVal (2019) data

Figure 19. RC patterns: Collaboration patterns (the four collaboration types), selected European flagship universities, by institution, 2017 (in %).



Source: author's own calculations based on SciVal (2019) data

Figure 20. IRC trends: the number of articles written in international collaboration, selected European flagship universities, by institution, 2007-2017.



Source: author's own calculations based on SciVal (2019) data

Table 17. IRC trends: the number of articles written in international collaboration selected European flagship universities, by institution, 2007 to 2017.

	Total 2007-2017	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
University of Oxford	50,613	2,691	3,068	3,392	3,706	4,034	4,567	5,044	5,352	6,042	6,236	6,481
University of Copenhagen	39,542	2,085	2,243	2,540	2,857	3,085	3,555	3,895	4,421	4,800	4,958	5,103
KU Leuven	35,154	2,067	2,278	2,421	2,604	2,908	3,218	3,505	3,812	4,043	4,100	4,198
Karolinska Institutet	30,484	1,873	2,090	2,231	2,241	2,451	2,617	2,934	3,026	3,508	3,589	3,924
Utrecht University	27,237	1,582	1,592	1,834	2,062	2,279	2,551	2,694	2,881	3,089	3,214	3,459
L. Maximilian Uni. Munich	25,583	1,494	1,707	1,906	1,998	2,208	2,433	2,562	2,665	2,793	2,934	2,883
University of Helsinki	25,489	1,641	1,722	1,837	1,877	2,174	2,236	2,480	2,632	2,770	3,007	3,113
University of Barcelona	24,224	1,354	1,473	1,726	1,724	1,995	2,169	2,463	2,616	2,724	2,847	3,133
University of Lisbon	20,188	955	1,156	1,302	1,382	1,597	1,767	2,154	2,245	2,356	2,603	2,671
University of Padova	18,775	1,104	1,094	1,297	1,442	1,442	1,668	1,794	1,918	2,089	2,418	2,509
Charles University	17,562	998	1,085	1,242	1,302	1,473	1,668	1,659	1,867	1,938	2,103	2,227
University of Vienna	15,148	938	982	1,076	1,193	1,334	1,415	1,528	1,569	1,604	1,767	1,742
University of Athens	13,433	794	831	920	910	1,092	1,337	1,354	1,484	1,471	1,601	1,639
University of Ljubljana	10,599	592	677	688	747	887	1,054	1,111	1,127	1,231	1,248	1,237
Trinity College Dublin	9,857	554	668	695	782	833	878	959	1,028	1,071	1,143	1,246
Jagiellonian University	8,781	500	549	626	641	654	783	862	911	996	1,126	1,133
University of Zagreb	8,394	416	468	571	639	718	793	812	899	967	1,068	1,043
University of Tartu	5,649	314	322	350	417	424	508	580	650	650	718	716
Comenius University	5,567	295	341	351	381	467	604	547	562	652	707	660
Eötvös Loránd University	5,272	347	333	387	399	441	506	454	505	512	638	750
Babes-Bolyai University	3,721	114	115	275	346	350	386	414	425	420	442	434
University of Luxembourg	2,550	61	73	114	140	139	203	297	366	358	367	432

Source: author's own calculations based on SciVal (2019) data

6.2. Citation impact by collaboration type: the benchmark of institutional collaboration

As in the case of a macro-level analysis at the level of EU-28 countries, at the institutional level the citation impact of articles produced in different collaboration types can also be examined relative to the citation impact per institutional collaboration. Citation impact per institutional collaboration is thus regarded as 100 % (1, or the benchmark value).

The patterns indicate (Table 18) that the biggest increase in citation impact per international collaboration is observable for institutions located in EU-13 countries: the top five includes institutions from Czech Republic, Slovakia, Croatia, Poland and Romania. The increase is as follows: Charles University (Prague) by 336.9 %, Comenius University (Bratislava) by 290 %, University of Zagreb by 266 %, Jagiellonian University (Cracow) by 184.1 % and Babes-Bolyai University (Cluj-Napca) by 166.7 %.

Thus IRC in EU-13 flagship institutions is a substantial factor increasing international visibility of published research as measured through a proxy of citation impact. For the majority of EU-15 flagship institutions, in contrast, the citation impact per international collaboration does not increase so much compared with the citation impact per institutional collaboration. IRC pays off the most in the former and pays off the least in the latter group of flagship institutions. For instance, in the case of the five institutions with the lowest increases, the increase in citation impact associated with international collaboration compared with institutional collaboration is in the range of 50 %-70 % (University of Oxford, University of Vienna, University of Luxembourg, KU Leuven and Utrecht University).

In the case of national RC, the fold increases are much less remarkable and only for five universities the increase is higher than 30 % and all of them are located in EU-13 countries (Charles University, University of Zagreb, Babes-Bolyai University and University of Ljubljana). In a graphic form, cross-institutional differences can be clearly seen in Figure 21: the flagship institutions benefiting the most in terms of average citation impact in 2007-2017 from international collaboration are all located in EU-13 countries. Again, as in the case of country-level analyses, the EU-15/EU-13 divide is striking but consistent with the idea of peripheries vs. centres in European science.

There is a clear pattern for all the flagship institutions studied: the citation impact per international collaboration in the vast majority of cases exceeds 20 (in all universities except for three: the University of Luxembourg, the University of Zagreb and Babes-Bolyai University) and in the case of EU-15 institutions, with some exceptions it, exceeds 30. The only EU-13 institution in this group is the University of Tartu (30.3) and the leader is University of Oxford (40.2).

The citation impact of papers resulting from national and institutional collaboration is different across EU-28 countries and a similar EU-15/EU-13 divide for these collaboration types is observable (Table 19). For EU-13 institutions, the citation impact per national collaboration is considerably lower (and remains in the 7.7-12.7 range) and for institutional collaboration is still lower (in the 5.3-9.6 range). The only collaboration type for which no EU-13/EU-15 divide is not observable is single authorship (or no collaboration type); however, the percentage shares and numbers of single-authored articles are small.

Certainly, differentiated patterns emerge for FOS (or for 41 ASJC categories). For each of the FOS, separate patterns can be elaborated for citation impact by the four collaboration types. Different flagship universities have different citation impacts for internationally co-authored papers in different FOS. However, citation impact per international collaboration is predominantly the highest for medical sciences. The most and the least affected FOS by IRC at the level of individual

EU-28 institutions in terms of their generally increasing average citation impact can be shown, leading to a fine-grained cross-disciplinary intra-institutional analysis.

Table 18. IRC patterns: citation impact per collaboration type, 2007-2017 (the 2007-2017 average), selected European flagship universities, by institution, in descending order. Fold increase over institutional collaboration (institutional collaboration = 100 %) (in %).

	Institutional collaboration - citation impact	National collaboration - citation impact	International collaboration - citation impact
Charles University	100	161.5	436.9
Comenius University	100	113.3	390.0
University of Zagreb	100	145.3	366.0
Jagiellonian University	100	88.6	284.1
Babes-Bolyai University	100	141.7	266.7
Eötvös Loránd University	100	105.2	251.0
University of Athens	100	115.1	248.7
University of Ljubljana	100	136.6	247.3
University of Tartu	100	98.4	244.4
University of Barcelona	100	119.4	238.8
L. Maximilian Uni. Munich	100	125.7	222.2
University of Padova	100	122.3	212.8
University of Copenhagen	100	120.2	209.5
University of Helsinki	100	114.8	198.8
Karolinska Institutet	100	102.1	189.1
Trinity College Dublin	100	90.9	186.0
University of Lisbon	100	109.7	173.4
Utrecht University	100	111.1	170.0
KU Leuven	100	112.0	167.4
University of Luxembourg	100	150.0	163.3
University of Vienna	100	108.9	160.8
University of Oxford	100	103.7	150.6

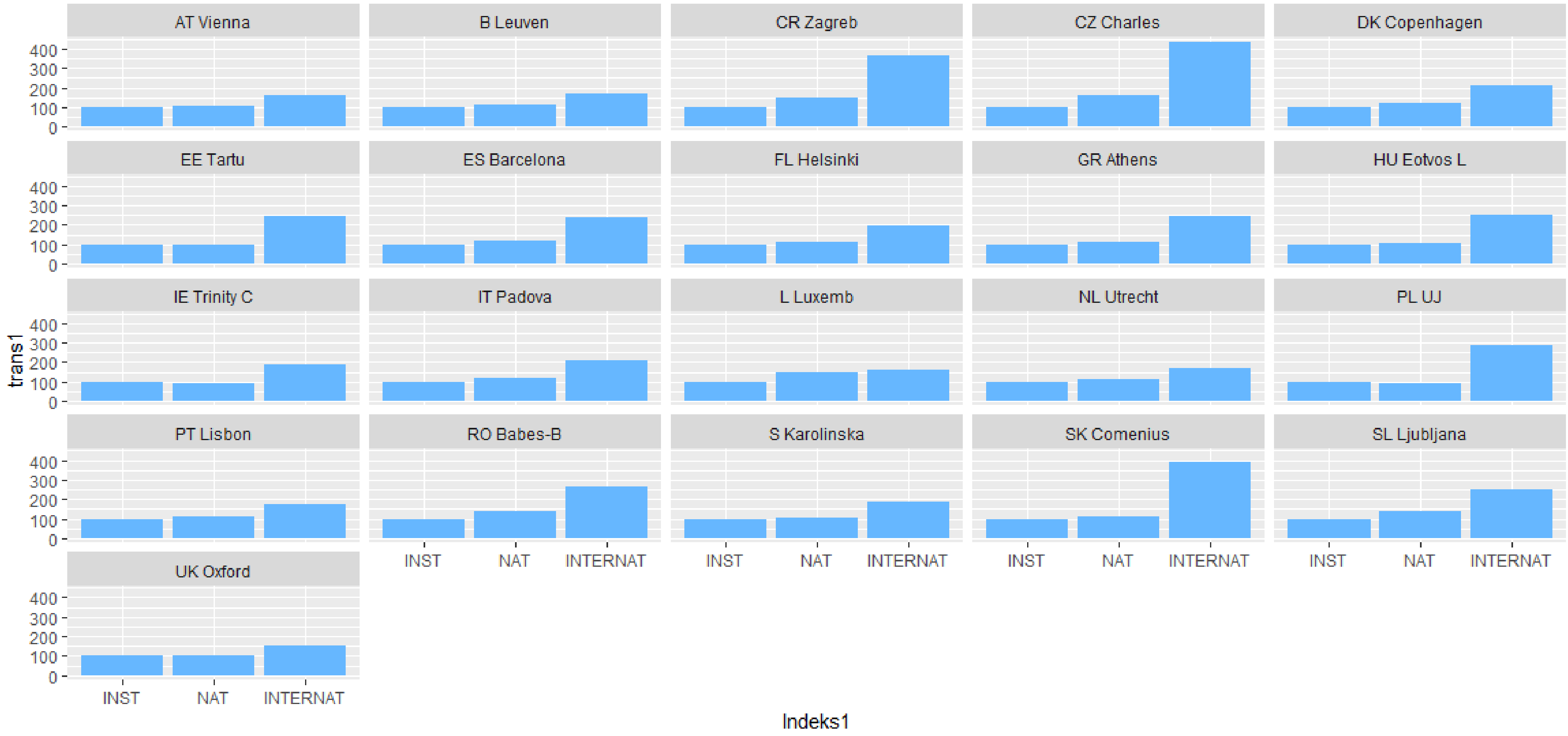
Source: author's own calculations based on SciVal (2019) data

Table 19. IRC patterns: citation impact per collaboration type, 2007-2017 (metrics: the 2007-2017 average), selected European flagship universities, by institution, in descending order.

	International collaboration	National collaboration	Institutional collaboration	Single authorship (no collaboration)
University of Oxford	40.2	27.7	26.7	7.8
L. Maximilian Uni. Munich	38	21.5	17.1	2.2
Karolinska Institutet	36.5	19.7	19.3	7.5
University of Copenhagen	35.2	20.2	16.8	7.3
Utrecht University	35.2	23	20.7	-
Trinity College Dublin	34.6	16.9	18.6	7.7
University of Helsinki	33.6	19.4	16.9	5.7
University of Barcelona	33.2	16.6	13.9	8.6
University of Padova	31.5	18.1	14.8	4.5
KU Leuven	30.8	20.6	18.4	9.2
University of Tartu	30.3	12.2	12.4	5.5
University of Athens	29.6	13.7	11.9	4.1
Charles University	28.4	10.5	6.5	3.5
University of Vienna	25.4	17.2	15.8	2.2
Jagiellonian University	25	7.8	8.8	7.8
Eötvös Loránd University	24.1	10.1	9.6	8.4
Comenius University	23.4	6.8	6	4.2
University of Ljubljana	23	12.7	9.3	5.8
University of Lisbon	21.5	13.6	12.4	4.4
University of Luxembourg	19.6	18	12	10.9
University of Zagreb	19.4	7.7	5.3	17
Babes-Bolyai University	16	8.5	6	3.3

Source: author's own calculations based on SciVal (2019) data

Figure 21. IRC patterns: citation impact per collaboration type, 2007-2017 (metrics: the 2007-2017 average), selected European flagship universities, by institution. Fold increase over institutional collaboration (institutional collaboration = 100 %) (in %)



Source: author's own calculations based on SciVal (2019) data

6.3. Field-Weighted Citation Impact (FWCI) per collaboration type: international vs. national collaboration

The influence of IRC on international research visibility at the institutional level can be studied by comparing Field-Weighted Citation Impact (FWCI) per collaboration type. As in the case of country-level analyses, the difference with the above analysis is that the institutional-level ratios of citations received are adjusted to the expected world average for the subject field, publication type and publication year. Cross-instituitional comparisons are made between FWCI, rather than between citation impact as measured through the number of citations received.

A FWCI of 1.00 indicates that the institution's publications have been cited exactly as would be expected based on the global average for similar publications (the FWCI of 'World' is 1.00). A FWCI higher than 1.00 indicates that the institution's publications have been cited more than would be expected based on the global average for similar publications; a FWCI lower than 1.00 indicates that the institution's publications have been cited less than would be expected based on the global average for similar publications, as explained in more detail in the section on country differences (significantly far below: indicator value < 0.5, below: indicator value between 0.5-0.8, about: 0.8-1.2, above: 1.2-1.5 or far above: > 1.5 the global average). In this way, the prestige of citation performance can be compared across institutions.

Table 20 shows FWCI for all collaboration types combined (that is, for all publications, regardless of whether they were published in international, national, institutional collaboration or in no collaboration). While the trend over time (2007-2017) shows that for almost all institutions studied, FWCI increased, our focus is on the average FWCI for the period studied (first column, 'Average 2007-2017'). In general, FWCI for publications with authors affiliated with institutions located in EU-13 countries is lower than for those originating from EU-15 countries. However, only for two EU-13 flagship universities the average FWCI for 2007-2017 is about the world average: Babes-Bolyai University (5 % less) and University of Zagreb (19 % less); for the rest it is higher. The flagship institutions studied are strengthening their global positions; while in 2007 for 11 of them FWCI was far above the global average (or more than 1.5), in 2017 their number increased to 17.

A particularly important question is whether international collaboration increases FWCI of flagship institutions: are papers written in international collaboration more highly cited than those written in any other collaboration types (compared to the world average)? The average FWCI for internationally co-authored papers (for 2007-2017) for all but two institutions (Jagiellonian University and University of Zagreb) is higher than 1; these publications are cited more than the global average for similar publications (Table 21).

Comparing the average FWCI for 2007-2017 for all publications, those written in international collaboration and those written in national collaboration, the emergent patterns for selected flagship institutions are clearer than in the case of countries; in all but three institutions, FWCI for internationally co-authored publications is higher than FWCI for all publications. Nationally co-authored papers are more cited than would be expected for the global average in the case of only one university (Jagiellonian University), for all other institutions these papers are about the global average (in 9 cases, 20 %-7 % less cited). A relatively low influence of IRC on the average FWCI of all publications combined may mean the powerful role of publications written in institutional collaboration in the case of flagship universities, differently than in the case of countries as units of analysis. However, FWCI for this collaboration type is not currently available from Scopus.

Table 20. Comparative research performance: Field-Weighted Citation Impact (FWCI) (all publications – all collaboration types combined), articles only, self-citations included, by institution 2007 to 2017, in descending order, selected European flagship universities.

	Average 2007-2017	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
University of Oxford	2.38	2.09	2.32	2.21	2.36	2.32	2.55	2.39	2.51	2.5	2.52	2.26
Karolinska Institutet	2.08	1.85	1.83	1.85	1.8	1.91	2.35	1.98	2.34	2.2	2.32	2.15
University of Copenhagen	2.04	1.96	2.05	1.88	1.89	1.93	2.2	1.93	2.04	2.14	2.19	2.05
Utrecht University	2.02	1.81	2.1	2.07	2.03	2.05	2.03	2.03	1.94	2.14	2.04	1.97
L. Maximilian Uni. Munich	1.94	1.97	1.98	1.84	1.87	1.82	2.07	1.9	1.92	1.91	2.21	1.85
University of Helsinki	1.92	1.83	1.8	1.69	1.86	1.87	1.99	1.85	1.87	2.1	2.2	1.87
KU Leuven	1.91	1.86	1.82	1.83	1.89	1.93	1.9	2.01	1.88	1.92	1.98	1.96
Trinity College Dublin	1.79	1.73	1.8	2.08	1.77	1.69	1.76	1.85	1.7	1.71	2.1	1.55
University of Padova	1.76	1.62	1.58	1.56	1.71	1.65	1.72	1.63	1.83	1.68	2.09	2
University of Barcelona	1.7	1.53	1.66	1.61	1.52	1.56	1.84	1.7	1.53	1.93	1.88	1.81
University of Luxembourg	1.68	1.07	1.32	1.46	1.71	1.46	1.8	1.77	1.55	2.01	1.69	1.66
University of Tartu	1.66	1.49	1.26	1.25	1.46	1.32	1.64	1.42	1.79	1.91	1.78	2.3
University of Athens	1.55	1.12	1.35	1.14	1.33	1.39	1.64	1.53	1.63	1.79	2.02	1.89
University of Vienna	1.48	1.52	1.39	1.26	1.42	1.68	1.41	1.38	1.58	1.46	1.61	1.47
Charles University	1.38	1.17	1.26	1.09	1.23	1.51	1.53	1.47	1.31	1.47	1.39	1.6
Eötvös Loránd University	1.37	1.13	0.9	1.12	1.05	1.21	1.17	1.12	1.17	1.27	2.25	2.08
University of Lisbon	1.35	1.29	1.29	1.32	1.27	1.3	1.35	1.36	1.28	1.35	1.4	1.51
Jagiellonian University	1.27	0.98	1.14	1.11	1.06	1.02	1.19	1.14	1.21	1.2	1.72	1.71
Comenius University	1.25	0.99	1.25	0.88	1.29	1.21	1.57	1.45	1.14	1.15	1.25	1.37
University of Ljubljana	1.23	1.16	1.21	1.08	1.1	1.04	1.21	1.12	1.22	1.28	1.53	1.4
Babes-Bolyai University	0.95	0.87	0.93	0.91	0.91	0.95	0.95	0.87	1.16	0.9	0.88	1.06
University of Zagreb	0.81	0.69	0.74	0.68	0.82	0.67	0.74	0.78	0.91	0.92	0.93	0.99

Source: author's own calculations based on SciVal (2019) data

Table 21. RC patterns: Field-Weighted Citation Impact (FWCI), self-citations included, by publication type (all, international, national), average for 2007-2017 in descending order (FWCI – international).

	Average FWCI 2007-2017 (all publications)	Average FWCI 2007-2017 per international collaboration	Average FWCI 2007-2017 per national collaboration
University of Luxembourg	1.68	1.99	0.09
KU Leuven	1.91	1.64	0.53
Karolinska Institutet	2.08	1.62	0.8
University of Vienna	1.48	1.57	0.55
University of Oxford	2.38	1.5	0.83
Trinity College Dublin	1.79	1.44	0.52
University of Helsinki	1.92	1.41	0.86
University of Copenhagen	2.04	1.4	0.59
University of Lisbon	1.35	1.3	0.87
Utrecht University	2.02	1.3	0.93
L. Maximilian University	1.94	1.28	0.79
Comenius University	1.25	1.24	0.65
Babes-Bolyai University	0.95	1.2	0.56
Eötvös Loránd University	1.37	1.17	0.82
University of Athens	1.55	1.15	0.81
University of Padova	1.76	1.14	0.84
University of Barcelona	1.7	1.13	1.06
Charles University	1.38	1.11	0.69
University of Ljubljana	1.23	1.11	0.37
Jagiellonian University	1.27	0.94	1.08
University of Zagreb	0.81	0.91	0.35

Source: author's own calculations based on SciVal (2019) data

6.4. Limitations of the present study

The results at the macro-level of countries and meso-level of flagship institutions can be summarised as follows:

UE-28 countries	Flagship institutions in EU-28 countries
IRC less intense	IRC more intense
Lower percentage shares of internationally co-authored publications	Higher percentage shares of internationally co-authored
Weaker internationalisation trends over time	Stronger internationalisation trends over time
Weaker national collaboration	Stronger national collaboration
Slower increase in total output	Faster increase in total output
Medium-intensity institutional collaboration	Low-intensity institutional collaboration
Bigger increase in citation impact per international collaboration in EU-13	Bigger increase in citation impact per international collaboration in flagships in EU-13
IRC pays off more in EU-13 than in EU-15	IRC pays off more in flagships in EU-13 than in flagships in EU-15
Higher FWCI for internationally co-authored publications	Much higher FWCI for internationally co-authored publications
Stronger role of publications written in institutional collaboration	Weaker role of publications written in institutional collaboration
Stronger role of single-authored publications, especially in EU-13	Weaker role of single-authored publications, in both EU-15 and EU-13 flagships

This study has several limitations. Collaboration in science can be studied both between individual scientists and their groups, departments, institutions, sectors, and countries/regions. Measuring the scope of IRC at the above levels requires reliable data about the institutional location (that is, unambiguous affiliations) of publications' authors. Authors from the same institution may use different forms of their institutional affiliation; however, in Scopus database, publication data on authors with similar affiliations are merged (for instance, publications of the present author are merged despite the author being affiliated with 'University of Poznan', 'Adam Mickiewicz University' and 'Poznan University'). In bibliometric studies of IRC, the geolocation in institutional, national, and international collaborative publications is crucial (Jiang et al. 2018). Quantitative approaches to IRC rely on bibliometrics and its tools; more qualitative approaches rely on survey data and interviews with scientists. The present study uses quantitative tools, methods and data sets. Both quantitative and qualitative approaches to IRC have their own drawbacks. Most importantly, bibliometrics relies exclusively on a single domain of research collaboration, that is, research collaboration leading to joint publications, preferably indexed in international indexing datasets (Scopus or WoS). The major drawbacks of surveys and interviews as tools to study IRC are very high costs of data, their limited cross-national and cross-institutional comparability and, generally, their predominantly cross-sectional rather than longitudinal character. Studying trends in time, the focus of this report, without year-by-year data covering at least a decade, is barely possible through qualitative approaches.

Generally, trends over time in IRC are most extensively studied on the basis of the information collected from publications; this type of information, as opposed to information derived from surveys or interviews, is widely available, cross-nationally comparative and of relatively low cost. Consequently, in this report, the unit of analysis is the individual indexed publication rather than the individual academic scientist.

In this perspective, 'international collaboration' universally means 'internationally co-authored publications'. By the same token, 'national collaboration' means 'nationally co-authored publications', and 'institutional collaboration' means 'institutionally co-authored publications'. Finally, 'no collaboration' as one of the four collaboration types used in this report means 'single-authored publications'.

An important methodological limitation of all IRC studies is that the patterns of collaboration examined depend on the data used; different levels of data disaggregation (for instance, international collaboration disaggregated further into intra-European, transatlantic within EU-15 and within EU-13 collaboration etc; various classifications of fields of science: FOS or ASJC; or different publication types, other than journal article used in this report) may lead to slightly different results.

In this study, the tension resulting from different levels of analysis is shown specifically between patterns of collaboration with and without reference to FOS and patterns of collaboration between countries as units of analysis and selected national flagship universities as units of analysis. A single publication type, journal article, is studied in the report (and subsequently the other types for which full data in Scopus and SciVal are available, such as reviews, conference papers, editorials, short surveys, book chapters and books, are not examined). All publication and citation data have been aggregated to six major FOS: engineering and technologies, the agricultural sciences, the humanities, the natural sciences, the medical sciences and the social sciences; for specific purposes, an aggregation to all fields of science combined has also been used. Consequently, this report did not use a more granular analytical scheme to study cross-national and cross-institutional differences encompassing more than 300 subjects or 41 fields (ASJC, All Science Journal Classification codes) available from Scopus and SciVal, as the results would be too detailed and beyond the scope of this cursory study.

Thus, first, internationalisation in research in this report is measured through internationally co-authored publications and their citations (that is, the report uses a narrow definition of research internationalisation); second, internationalisation in research is measured through predominantly English-language publications; third, the universe of all publications used as a reference base for measuring cross-national and cross-institutional differences in publishing and citing, is the Scopus database, the biggest database available today but still the database not covering the vast majority of national-language publications.

Bibliographic records in the two major global indexing datasets include details about the authors' affiliations, making it possible to determine their international, national, and institutional collaborative links. Both collaboration in research and its dominating subtype, international collaboration in research, are generally difficult to define. However, clear definitions have been adopted: IRC means publications co-authored by scientists institutionally affiliated with institutions located in different countries. In this way, the definition adopted in the study was fully compatible with the definition used the in the global dataset from which it collected data.

7. Policy options

Policy option 1: IRC should be at the centre of national research policies.

National higher education systems focused on increasing the international visibility of their academic knowledge production need to install the internationalisation of research at the centre of their national research policies (Norway being a prime positive example, see Gornitzka and Langfeldt 2008). European countries have been transforming governance and funding modes in their higher education systems and internationalising their research policies to increase their global competitiveness (Horta and Yudkevich 2016; Shin et al. 2014; Kwiek 2013; Kwiek 2015b).

At the same time, global and intra-European competition in research is reflected on several planes:

- *human resources*, or the competition for talent (including scientific prize winners and Highly Cited Researchers)
- *funding*, or the competition for EU research funds (including highly competitive individual research funding from ERC; see Bloch and Schneider 2016)
- *research performance*, or the competition for highly-cited publications and publications in highly-cited journals (for instance, publications in the top 1 % or 10 % citation percentile and publications in the top 1 % or 10 % journal percentiles; see Bornmann et al. 2013; Bornmann et al. 2014; and Didegah and Thewall 2013)
- *international academic rankings* (and especially those fully research-based like Leiden Ranking based on WoS data).

If IRC should move to the centre of national research policies, English should also be acknowledged as the language of global science today because, increasingly, 'non-native English speakers face challenges when trying to publish' (Powell 2012). Academic and scientific English holds the key to success on the international scale.

Installing the internationalisation of research at the centre of national research policies refers to all levels of operation of HE systems, from national to institutional to departmental to individual. In most general terms, internationalisation-supportive research policies should promote top international publications in academic employment, rather than merely top national publications and should promote international, rather than merely national, collaboration in research. They should promote international publication channels both in direct block funding to their institutions and in indirect, individual-level competitive research funding in their national research councils (or their equivalents). They should also promote the internationalisation of research in their award and reward systems in science at the level of individual scientists.

Consequently, national models of successful universities, departments, research teams and individual scientists need to be clear: no academic success is possible and no large funding is awarded at any level to those units and individuals that are not internationalised in research. No professorships are available (or renewable) to scientists whose research performance profile is predominantly national – rather than international. In some national systems, detailed guidance is needed (numbers or percentages, percentiles of publications or journals, or national journal ranking lists); in others, general guidance suffices for the research internationalisation agenda to be implemented.

However, as this report strongly emphasises, IRC depends to a large extent on individual approaches of scientists as 'calculating individuals': scientists collaborate internationally in research, including top-level international publishing, because it is profitable to them in terms of academic prestige, scientific recognition and access to academic rewards and research funding. Consequently, the convergence between individual-level drivers for internationalisation and departmental-, institutional-, and national-level research policies is needed.

For the research internationalisation agenda to be successful, highly internationalised institutions, departments, research teams and scientists need to be better off than local ones; the international needs to be promoted over the local in research in the different variants of national research assessment exercises, usually leading to different intra-national rankings of institutions or their organisational units (Ponomariov and Boardman 2010). IRC should matter more for funding and academic prestige and it needs to be consistently promoted at all levels of academic organisation. Usually, major opponents to national assessment exercises and rankings of institutional units or institutions come from the humanities and their major supporters come from the natural sciences; consequently, national and institutional systems need to guarantee cross-disciplinary flexibility so that the whole idea of systematic promotion of research internationalisation is not in jeopardy; in each system, there is a limited number of local academic disciplines, usually linked to national languages, literatures and history.

Policy option 2: Large-scale funding should be provided for IRC.

Increasingly, top scientists globally opt for collaborative, networked science that is locally rooted through training and institutions and nationally funded. European countries should consider supporting their academic faculty to become more internationalised in research and providing large-scale funding for IRC to avoid creeping isolation at a global level.

Internationalisation costs are increasing across all national systems in Europe: suffice to compare institutional and national budgets for research, including budgets for new ministerial programmes or programmes of national research councils directed at IRC. Internationalisation costs include both such traditional items as travel and subsistence costs for hundreds of thousands of travelling scientists and such new items as subscriptions to global indexing data sets and global academic journals. Doctoral students, postdocs, junior and senior scientists travel for academic business increasingly frequently, and use access to global knowledge bases (publications and data provided by Clarivate Analytics, Elsevier and other commercial providers) to an unprecedented degree. Journal and book subscription and ICT infrastructural costs are critical to the success of IRC and they are also increasing, both globally and in EU-28 countries. As international academic travel, global academic journals and books and ICT infrastructure are at the core of internationalisation, the rise of internationalisation-related costs needs to be noted and reflected in both budget size and its internal distribution. IRC costs – and it costs a lot.

Consequently, national systems seeking to increase the international visibility of their knowledge production need not only to install international research at the centre of national research policies but also to consider substantial public investments in research internationalisation. One option is to increase public investments, and another is to choose spending priorities differently, with internationalisation in research in focus. In different systems, different options are possible; however, disregarding both options may lead to gradual international isolation of national science systems across Europe, and especially in EU-13 countries, traditionally heavily underfunded in research in the last three decades in almost all cases and almost all academic disciplines.

Policy option 3: Individual scientists should be at the centre of national internationalisation agendas.

National systems determine conditions in which academic institutions operate, thriving or fighting for survival; however, in IRC the critical node is the individual scientist who will (or will not) collaborate internationally in research, will (or will not) publish in international collaboration and will (or will not) publish in top academic journals.

The national aggregate of individual-level research performance determines national research performance, and the aggregate of individual-level collaboration patterns in research determines dominating national collaboration patterns, as different as they have been discussed in the two sections on empirical findings in this report. In IRC, the abstract levels of 'countries' (Section 5) and 'institutions' (Section 6) are ultimately aggregates of individual scientists collaborating and publishing, more (or less) internationally. Understanding this individual-level determination of successes or failures of IRC is critical in understanding the future of IRC. 'It's the individual scientist, stupid!', to paraphrase Bill Clinton (in the multi-layered context of IRC which includes institutional and national award and reward structures in science, systems of academic promotion, levels of research funding and modes of its distribution etc.)

The individual scientist matters so much for IRC today because the modalities of IRC depend almost entirely on scientists themselves. They decide whether and with whom to collaborate, institutionally, nationally and internationally, and the decision to internationalise in research depends on individual choices based on reputation, resources, research interests, and the attractiveness of the potential research partner (Wagner 2018; Da Fonseca Pachi et al. 2012). In the empirical section of this report, different national (28 countries) and different institutional (22 flagship universities) collaboration patterns have been shown in detail, with different levels of IRC between systems and within systems. However, the data used are merely aggregates of individual-level data derived from publications. And publications are only (co-)published by (more or less heavily) internationally collaborating individuals.

At this basic, individual level of particular collaborating scientists affiliated to particular institutions, there is always a trade-off between the time and energy spent on IRC and research and publishing outcomes of this collaboration. If a given collaboration in research is beneficial individually, it will occur; but if it is not, it will not occur.

Therefore the crucial point is to create sufficiently attractive internationalisation-supportive research policies at various levels, from institutional to national (and international), to make sure that scientists are increasingly involved in IRC. A bottom-up approach, with maximum flexibility as to how, with whom and on which topic to collaborate internationally in research, unreservedly combined with the hard line of research excellence as defined through top publications alone, should always work better than any other set of recommendations for IRC programmes.

If the global network of science emerges because scientists 'connect with each other on a peer-to-peer basis, and a process of preferential attachment selects specific individuals into an increasingly elite circle' (Wagner 2018: x), then scientists *not* collaborating internationally in every country (with the possible exception of the USA) are gradually being excluded from the ongoing global scientific conversation.

Across Europe, internationalists compete directly with locals, or scientists collaborating internationally in research compete directly with scientists not collaborating internationally (in sharp contrast to the United States, see Goodwin and Nacht 1991; Finkelstein and Sethi 2014), and locals increasingly stand to lose out. As the rules governing academic prestige, incentives, and awards become increasingly homogeneous across the continent, individual evaluations based on prestigious international publications become ever more important for individual academic careers. Across Europe, academic institutions (competing for public funding and high international rankings) tend to use the same research-based metrics because their aggregated institutional success hinges on the disaggregated individual research successes of the academics they employ.

The international visibility of national research output hinges on prevailing patterns of collaboration (international, national) and of publication (international channels, national channels). These can be changed over time by means of careful policy measures that promote advantageous patterns while discouraging others.

What is important in increasing the international visibility of individual scientists, institutions, or countries is not only IRC; it is also the changes in the publication behaviour of scientists and the increasing role of the academic journal stratification in which all journals have their clear positions in global science systems, with all disciplines having their own top-tier journals (van Raan 1998). As part of their IRC policies, faculties, institutions, and nations should no longer be focused on merely the international publications of their scientists; they should be increasingly focused on *highly-cited publications in highly-ranked academic journals*. Only these publications can increase their position in global rankings and guarantee stable public funding. This is particularly true in the context of widespread national 'research excellence' initiatives additionally supporting financially only selected parts of higher education systems. Generally, understanding that IRC rests on individual scientists and their individual decisions to internationalise their own research should be installed in the centre of national internationalisation agendas. European international collaboration trends in research are merely aggregates of individual research decisions taken by millions of scientists involved in the global academic enterprise, day by day, year by year.

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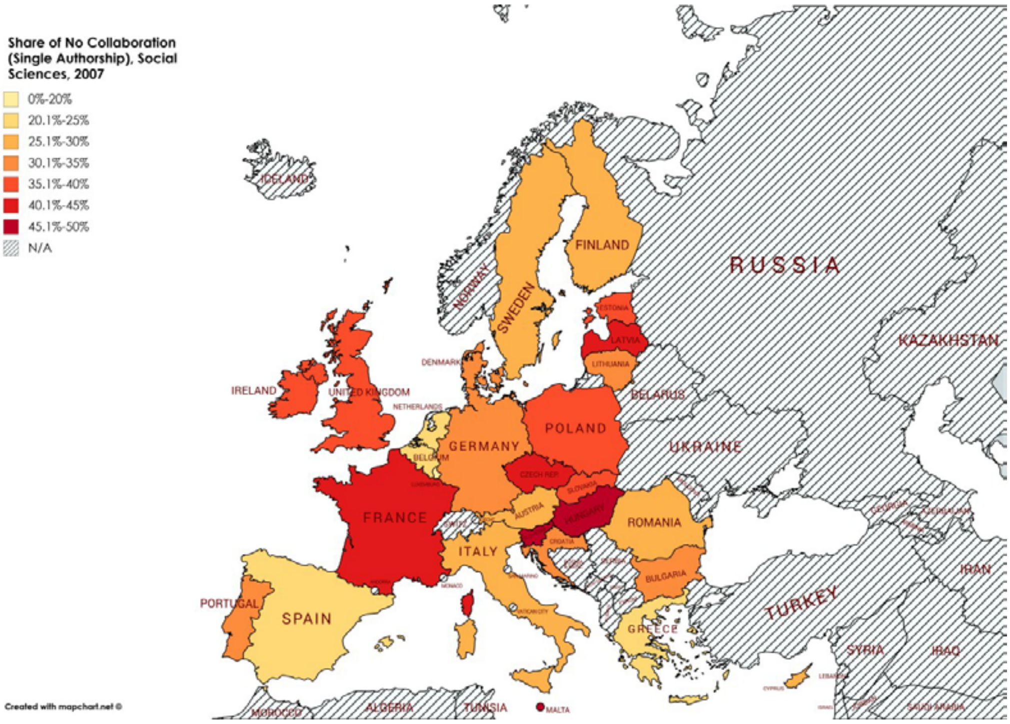
Data appendices

Figure 22. Disciplinary example: Social sciences. Percentage share of no collaboration (single authorship), EU-28 countries, 2007 (in %)



Source: author's own calculations based on SciVal (2019) data

Figure 23. Disciplinary example: Social sciences. Percentage share of no collaboration (single authorship), EU-28 countries, 2017 (in %)

Source: author's own calculations based on SciVal (2019) data

Table 22. RC trends: national collaboration, EU-28 and comparator countries, by country, in descending order, 2007 to 2017 (in %).

	Average 2007-2017	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
CHN	29.4	28.2	28.4	28.4	28.5	29.4	29.6	29.6	29.6	29.5	30	30.2
FRA	26.2	26.6	27.4	26.2	26.6	26.8	26.9	26.6	25.9	25.8	25.2	24.6
USA	23.6	23.8	24	23.4	23.2	23.4	23.4	23.3	23.8	23.7	23.7	23.7
ITA	20.6	22.4	21.3	20.3	20.5	20.5	20.7	20.7	20.6	20.3	19.8	19.9
EU-15	19.7	19.8	20	19.6	19.9	20.1	20.2	19.9	19.7	19.5	19.3	19.2
EU-28	19.2	19.4	19.4	19	19.2	19.4	19.5	19.4	19.2	19.2	19	18.9
ESP	19	19.3	19.7	19.3	19.6	20.1	19.8	19.2	18.7	18.2	17.7	17.7
POL	17.4	16.4	16	15.8	16	16	16.7	17.1	17.9	18.8	19.1	19.6
PRT	16.3	15.4	16.3	16.3	16.4	16	17.1	16.6	17.1	16.3	15.8	15.3
GRC	14.6	16.7	16.6	15.4	15	15.1	14.5	14.2	14.1	13.5	13.3	13
EU-13	14.5	13.7	13.7	13.9	14.1	13.9	14.1	14.4	14.7	15.2	15.3	15.3
NLD	14.3	15.1	15.2	14.9	14.6	15.2	14.7	14.3	14	13.8	13.5	13
GBR	14.3	15.9	15.4	14.8	14.4	14.5	14.5	14.4	13.9	13.8	13.7	13.2
CZE	13.6	14.4	14.1	15.3	14.7	14	13.9	14.3	13.1	12.6	12.6	12.5
FIN	13.6	16	16.6	15.3	15.4	14.6	14.1	13.2	12.1	11.8	12	11.3
ROU	13.5	13	12	11.9	13.6	12.7	11.1	12.3	13.4	15.6	15.3	15.6
DEU	13.1	12.4	13	12.6	13.3	13.4	13.5	13.3	13.3	13.2	12.9	13.2
HUN	11.5	12.1	12.4	11.4	11.6	11	11.7	10.9	11.3	11.6	11.7	10.9
SWE	10.8	11.6	11.4	11.1	10.9	11.2	10.8	11.2	10.3	10.4	9.9	10.4
BGR	10.6	7.9	9.5	10.1	10.9	10.9	10.3	12.5	11.1	11.6	10.9	9.9
DNK	9.6	10.8	10.2	9.8	10.3	10.3	9.9	9.4	9.3	9.1	9.2	8.7
LVA	9.3	7.2	7.9	7.4	9.6	9.3	10	11.6	11.8	9	8.6	8.5
IRL	9	8.7	8.3	8.8	9.5	9.6	9.1	8.9	8.8	8.8	8.6	9.2
SVK	9	10.2	8.9	10.2	8.6	8.9	8.4	8.9	8.7	9.2	8.6	9.4
SVN	8.4	9	9.5	9.4	8.8	8.5	8	8.2	8.4	7.3	8.1	7.9
HRV	8.1	8.5	8.6	8.6	8.4	9.1	8.5	7.9	7.4	7.2	7.8	7.6
BEL	7.7	8.1	7.9	8.1	8.1	7.9	8.1	7.7	7.3	7.3	7	7.2
AUT	6.3	7.2	7.1	6.7	6.5	6.7	6.3	6.4	6.1	5.9	5.8	5.8
LTU	5.8	5.1	6.7	7.9	7.2	6.8	5.2	5.8	5.9	5	4.5	4.8
EST	5.7	7.5	8.5	6.7	5.5	6.1	6	5.1	6.1	5	4.7	4.3
CYP	2.8	0.8	1.3	1.8	2	2.5	3.4	3.2	4.7	2.6	2.8	3.4
LUX	0.5	1.1	0.3	0.2	0.6	0.3	0.5	0.3	0.6	0.5	1.1	0.3
MLT	0.1	0.9	0	0.6	0	0	0	0	0	0	0	0

Source: author's own calculations based on SciVal (2019) data

Table 23. RC trends: institutional collaboration, EU-28 and comparator countries, by country, in descending order, 2007 to 2017 (in %).

	Average 2007-2017	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
CHN	49.7	55.1	54.3	53.5	52.5	50.7	50	49.6	49	48.3	46.9	45.4
LTU	45	46.1	47.6	47.6	49.6	48.9	46.8	46.2	43.1	43.1	41.3	38.3
HRV	44.3	51.8	49.8	50.4	49.9	48	44.9	43.8	41.2	38.6	37.7	37.8
ROU	37.8	35.7	44.9	41.6	42.2	41.3	40.2	37.6	35.8	34.8	33.9	32.9
POL	37.7	38.5	38.9	39.1	39.3	39.2	39.3	38.5	37.1	37.2	36	34.1
EU-13	36.8	37.5	38	38.1	38.9	38.6	38.3	37.2	36.3	35.8	34.8	33.5
LVA	34.1	27.2	33.5	39.1	38.7	40.5	40.9	39.1	31.8	34.7	27.3	26.2
GRC	33.9	40.5	39.9	40	38.6	36.9	34	32.9	30.1	28.7	27.5	26
SVK	33	29.4	30.8	29.8	33.7	32.2	32.8	34.9	36.8	34.5	33.1	31.5
SVN	32.8	36.6	37.2	36.1	36.6	36.4	32.3	31.6	32	31.3	28.8	27.1
CZE	31.9	34	33.6	32.7	33.3	34.5	33	32	31.2	30.9	30.6	28.8
EU-28	30.6	34.3	33.6	33.4	32.7	31.9	31.1	30.3	29.4	28.5	27.6	26.5
USA	30.6	33.7	33	33	32.7	32.2	31.5	30.6	29.3	28.5	27.5	26.9
ESP	30.3	37.5	35.4	34.9	33.3	31.4	30.2	29.2	28.3	27.2	26.5	25.7
BGR	29.3	31	29.9	30.2	30.4	29.5	31.4	30.7	31.1	28.2	26	24.3
ITA	28.7	32.4	32.6	32.6	31.4	30	29.1	28.7	27.3	26.2	25.2	24.2
MLT	28.2	20.8	37.6	32.7	28.7	29.4	26.9	29.7	27.2	26.5	28.5	26.5
EU-15	28.2	32.6	31.6	31.2	30.3	29.3	28.6	27.9	27	26	25.1	24.1
DEU	27.9	32	31	30.2	29	28.9	28.4	27.6	26.7	25.9	25.3	24.2
EST	27.6	35.9	32.9	34.5	33.2	29.9	27.8	26.7	26.4	24.2	22.2	21.8
IRL	26.7	32.2	29.9	30	29.5	29.8	28.4	27.5	25.3	23.7	21.6	20.7
HUN	25.6	27.3	27.4	26.1	26	25.8	25.6	25.6	26.2	24.8	23.3	24.5
PRT	25.4	29	27.6	27.3	27.6	27.2	25.7	26.4	24.8	24.5	22.4	22.1
DNK	24.2	26.8	26.9	26.1	25.6	25.2	25.2	25.3	24.7	22.7	21.4	20.9
BEL	23.5	29.3	28.5	27.4	26.1	24.4	23.8	23.2	22.1	20.8	19.8	18.8
NLD	23.4	28.7	28.2	27.5	26.6	25	23.5	23	21.5	20.5	19.3	18.6
AUT	23	28	26.9	26.2	24.6	24.7	22.9	22.2	22.1	21.4	19.7	19.3
SWE	22.7	27.8	27	25.6	24.2	23.2	23.1	22.6	22.7	20.6	19.5	18.6
FIN	22.6	27.1	25.9	25.8	24.4	23.8	22.7	22.3	22.3	20.7	19.4	18.5
GBR	20.5	25.5	24.3	23.8	23.5	22.3	21.3	20.1	18.7	17.6	16.5	15.6
CYP	18.3	21.4	18.5	21.4	14.6	17.3	16.5	18.6	18	16.5	18.3	21
LUX	13	14.1	17.8	15.5	12.7	17	12.7	14.2	12.6	11.7	12	9.9
FRA	11.8	15.8	14.7	14.3	13.4	12.8	11.7	11.1	10.6	9.8	9.3	8.4

Source: author's own calculations based on SciVal (2019) data

Table 24. RC trends: no collaboration (single-authored articles), EU-28 and comparator countries, by country, in descending order, 2007 to 2017 (in %).

	Average 2007-2017	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
MLT	16.6	22.2	17.7	20.1	22.2	16.7	20.3	18.7	14.7	15.4	10	16.3
ROU	15	12.2	15.6	17.4	14.8	16.8	17.5	17.2	14.8	13.5	11.4	12.3
POL	14.6	14.9	16.9	15.6	15.9	16.7	15.6	15.2	14.6	13.4	12.4	11.8
GBR	14.2	16.6	16	15.8	15.2	15.6	14.9	14.9	13.5	12.7	12	11.5
EU-13	13.9	14.1	15.5	14.9	14.4	15.2	14.9	14.6	13.7	12.9	12.1	12.1
SLV	13.3	15	12.8	12.5	12.2	12.9	13.5	14.7	13.6	12.4	12.5	13.7
HUN	12.8	14.3	15.7	15.5	14	15.1	12.6	12.3	12	11.3	9.8	10.5
LTU	12.6	16.4	17.4	15.3	14.8	13	13.2	11.5	12.6	10.6	9.2	8.2
CYP	12.4	13.1	14.9	14.2	14	14.2	12.2	14.2	12.5	11.5	10.1	10.2
USA	12.2	14.6	14.2	14	13.6	13.3	12.5	12.2	11.2	10.5	9.8	9.5
HRV	11.8	12.4	13.3	11.6	10.4	11.4	12	12.8	12.3	12.4	10.6	11.4
EU-28	11.8	12.8	12.7	12.5	12.1	12.5	12.2	12.1	11.6	10.9	10.5	10.3
BGR	11.4	11.1	11.8	12.3	11.4	12	12.8	11.1	10.3	11.3	10.8	10.8
EU-15	11.1	12.2	11.9	11.8	11.5	11.7	11.5	11.4	10.9	10.2	9.8	9.7
SVK	11	12.1	13.7	11.8	11.2	12.1	10.7	12	9.9	9.3	10.3	9.9
EST	10.9	10.9	10	12.4	11.9	12.2	10.8	11.1	10.4	10.7	9.2	10.6
CZE	10.6	11.6	11.8	10.5	10.5	11.1	11.2	10.7	10.2	10.1	10.2	9.7
LVA	10.3	10.1	12.1	12.6	15.8	13.1	10.6	8.8	10	8.3	10	6.7
FRA	10	11.1	10.8	10.8	10.7	10.9	10.5	10.3	9.8	8.8	8.4	8.3
DEU	9	10.7	10.3	9.8	9.2	9	9	8.7	8.9	8.3	8.1	8
IRL	8.9	10.6	10.2	9.9	8.9	9.6	8.9	8.8	8.6	8	8	7.6
LUX	8.4	8.1	9.4	7.6	9.9	10.5	8.2	8.3	9	7.2	8	8.1
FIN	8	8.3	8.8	9.1	8.3	9.2	8.2	8	8	7.1	7.1	7.1
SWE	7.9	8.9	8.9	9.6	9.4	9.1	8.1	7.7	7.5	7	6.4	6.2
AUT	7.8	9	9	9.1	8.4	7.8	8	7.7	7.6	7.1	7	6.8
DNK	7.3	8.4	8.6	8.6	7.8	8.5	7.7	7	6.8	6.8	5.8	6.1
ESP	7.3	6.8	7.1	6.9	6.7	7.4	7.8	8.2	7.6	7.4	7	7.2
GRC	7	7.3	7.8	7.5	8.2	7.6	8	7	6.7	6	5.8	5.8
ITA	7	7.3	7.2	7.6	7	7.5	7.3	7.3	7	6.6	6.4	6.1
BEL	6.6	7.1	7.3	6.9	6.5	7.2	7.3	7.5	6.8	5.5	5.6	5.6
NLD	6.3	7.6	7.1	7	6.7	6.9	6.3	6.4	6.1	5.6	5.2	5
PRT	5.9	7.2	6.9	6.7	6.4	6.5	6.3	5.5	5.6	5.3	5.3	5
CHN	2.9	3.7	3.5	3.4	3.3	3.2	3.2	3.2	2.8	2.3	2.3	2.4

Source: author's own calculations based on SciVal (2019) data

Table 25. IRC trends: articles published in international collaboration by Fields of Science, by country, 2007 to 2017.

	Engineering and technologies		Humanities		Medical sciences		Natural sciences		Social sciences		Agricultural sciences	
	2007	2017	2007	2017	2007	2017	2007	2017	2007	2017	2007	2017
AUT	1,048	2,155	54	186	2,175	4,171	4,035	7,686	345	1,139	431	1,004
BEL	1,450	2,983	132	373	3,277	6,519	5,694	10,021	693	1,871	743	1,592
BGR	359	431	13	15	234	431	1,061	1,254	38	92	61	152
CHN	7,747	38,536	156	712	5,173	19,388	18,672	73,656	1,026	6,538	1,533	6,539
HRV	183	427	12	45	215	656	594	1,386	40	203	84	264
CYP	86	219	6	42	51	383	237	710	63	215	9	84
CZE	849	1,986	20	93	925	2,074	2,946	6,138	85	590	274	847
DNK	694	2,189	80	223	2,450	5,459	3,767	7,814	360	1,378	646	1,358
EST	76	237	9	46	172	396	385	1,009	38	163	54	160
EU 28	28,134	61,600	1,927	5,480	46,224	84,325	102,490	175,150	10,260	30,624	11,710	23,877
FIN	857	1,961	56	186	1,749	3,106	3,372	5,916	354	1,171	410	848
FRA	6,299	11,710	284	800	7,509	13,301	22,169	35,138	1,255	3748	2,300	4,037
DEU	7,865	13,970	347	1,122	11,975	20,532	28,635	45,659	1,850	5,853	2,484	5,007
GRC	828	1,466	36	130	1,289	2,328	2,571	4,100	246	673	244	534
HUN	518	768	21	58	851	1,425	2,066	3,092	123	363	217	392
IRL	485	1,189	50	142	970	2,308	1,829	3,471	264	751	296	573
ITA	3,323	8,050	176	589	6,303	13,001	13,442	23,919	936	3,472	1,223	3,103
LVA	72	174	0	12	61	150	193	447	12	54	14	69

	Engineering and technologies		Humanities		Medical sciences		Natural sciences		Social sciences		Agricultural sciences	
LTU	117	355	4	16	167	338	370	874	43	222	45	133
LUX	32	239	1	30	79	328	140	634	35	182	14	54
MLT	7	36	0	11	32	150	30	136	11	36	6	22
NLD	1,983	4,129	262	668	5,498	11,467	8,416	14,957	1,413	4,152	1,144	2,242
POL	1,561	3,049	39	172	1,291	2,845	4,779	8,496	171	768	367	939
PRT	872	2,365	44	197	936	2,819	2,760	6,629	212	1,203	462	1,159
ROU	252	966	10	67	120	827	652	2,674	28	315	28	210
SVK	359	816	8	59	357	593	1,145	2,004	52	323	128	309
SVN	284	653	9	38	249	644	913	1,712	68	256	87	247
ESP	3,154	7,571	170	645	4,138	10,078	11,573	23,171	920	3,649	1,471	3,692
SWE	1,620	3,906	97	314	4,253	7,944	6,582	12,193	611	2,101	775	1,573
GBR	6,218	15,544	872	2,095	14,556	28,723	26,436	47,327	4,415	10,987	3,268	5,993
USA	15,845	35,568	1,273	2,880	34,520	64,029	63,525	109,624	8,114	18,773	7,144	14,539

Source: author's own calculations based on SciVal (2019) data

Table 26. IRC trends: disciplinary example, medical sciences, articles published in international collaboration, EU-28 and comparator countries, by country, in descending order, 2007 to 2017.

	Total 2007-2017	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
EU-28	727,858	46,228	49,673	53,500	57,384	61,330	65,088	71,844	76,876	80,146	82,075	83,714
EU-15	703,440	44,786	48,096	51,788	55,562	59,319	62,867	69,301	74,010	77,334	79,303	81,074
USA	545,090	34,485	36,892	39,666	42,905	45,961	48,396	53,622	57,658	60,203	61,843	63,459
UK	235,847	14,507	15,750	16,615	18,161	19,397	20,471	23,050	24,932	26,952	27,525	28,487
DEU	183,393	11,975	12,636	13,854	14,749	15,582	16,805	18,221	19,228	19,768	20,199	20,376
CHN	131,730	5,172	6,328	7,474	8,784	10,265	11,292	13,212	15,232	16,832	17,860	19,279
FRA	116,343	7,502	8,068	8,877	9,252	9,897	10,510	11,413	12,150	12,481	12,963	13,230
ITA	107,576	6,312	6,952	7,533	8,194	8,961	9,509	10,756	11,505	12,180	12,747	12,927
NLD	95,882	5,499	5,934	6,641	7,324	7,981	8,949	9,617	10,337	10,972	11,254	11,374
ESP	78,505	4,138	4,719	5,109	5,842	6,515	6,960	7,923	8,716	9,234	9,347	10,002
EU-13	71,669	4,255	4,543	4,970	5,296	5,846	6,304	7,178	7,689	8,148	8,634	8,806
SWE	65,954	4,244	4,387	4,785	5,124	5,396	5,937	6,461	6,879	7,329	7,539	7,873
BEL	55,066	3,264	3,518	3,847	4,193	4,627	4,948	5,509	6,029	6,270	6,416	6,445
DNK	42,070	2,442	2,558	2,813	3,143	3,332	3,645	4,075	4568	4,933	5,129	5,432
AUT	36,080	2,172	2,380	2,501	2,714	3,071	3,369	3,627	3,870	4,056	4,170	4,150
FIN	25,752	1,754	1,807	1,932	2,063	2,081	2,297	2,368	2,631	2,892	2,851	3,076
POL	21,951	1,292	1,348	1,467	1,568	1,756	1,973	2,142	2,344	2,536	2,688	2,837
GRC	20,362	1,290	1,363	1,529	1,545	1,720	1,842	2,042	2,271	2,225	2,222	2,313
PRT	20,220	938	1,127	1,235	1,291	1,507	1,801	2,088	2,325	2,478	2,631	2,799
IRL	18,551	971	1,238	1,358	1,526	1,533	1,611	1,802	2,019	2,022	2,188	2,283
CZE	15,861	929	975	1,056	1,167	1,208	1,325	1,476	1,728	1,903	2,030	2,064
HUN	12,834	850	917	962	1,036	1,112	1,184	1,284	1,323	1,339	1,409	1,418
ROU	6,447	236	305	351	432	489	518	746	822	864	847	837
SVK	5,324	353	371	415	415	426	481	444	566	604	657	592
SVN	5,146	248	319	335	365	431	497	562	548	584	622	635
HRV	4,921	214	231	324	380	426	476	487	530	587	615	651
BGR	3,465	235	310	285	237	260	268	331	327	376	400	436
EST	3,096	172	181	210	214	252	252	308	337	388	382	400
LTU	2,528	168	162	149	168	196	194	230	278	306	337	340
CYP	2,244	52	82	109	145	148	190	246	256	280	350	386
LUX	2,145	79	108	115	132	161	183	184	274	292	287	330
LVA	1,191	59	68	72	73	98	95	140	131	135	173	147
MLT	875	32	35	42	43	55	92	71	101	120	135	149

Source: author's own calculations based on SciVal (2019) data

Table 27. IRC trends: disciplinary example, medical sciences, articles published in international collaboration, EU-28 and comparator countries, by country, in descending order, 2007 to 2017 (in %).

	Average 2007-2017	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
LUX	81.3	73.8	72	75.2	74.2	74.9	79.9	75.4	82.8	88.2	86.2	90.2
CYP	74	72.2	78.1	66.9	78	68.8	73.1	74.3	72.5	74.7	77.4	74.4
EST	66.8	61	61.1	62.5	58.8	64.3	63.6	65.5	67.3	71.5	73.5	74.8
LVA	65.4	63.4	68	69.9	66.4	57.6	57.2	66	58.5	66.5	74.6	70.3
BEL	61.6	52.4	53.7	55.4	57.4	59.3	60.3	62.5	64.4	66.1	68.4	69.1
AUT	61.5	51.9	54.9	56.2	57.9	58.1	61	62.1	63.4	65.5	67.2	70.2
SWE	56.8	49.5	50.5	50.8	52.7	54.1	57.1	57.3	58.2	61	63.2	63.8
MLT	55.4	57.1	38.9	48.3	43.9	53.9	56.4	50.4	58	57.1	60	63.7
FIN	54.3	46.5	46.4	47.4	50	50.7	53.2	55.5	57.9	60.8	60.3	64
DNK	53.9	50.6	49.7	51.5	51.8	51.1	51.8	52.8	53	56.4	58.4	59.9
IRL	51.6	43.3	49.2	48	48.3	45.8	48.6	51	53.4	54.9	58.9	59.3
NLD	51.2	42.5	43.9	44.8	46.5	47.7	50.7	51.6	54.1	56	57.8	59.2
LTU	50.3	43.4	47.1	46.7	44.2	47.2	45.4	49.5	55.4	52.1	56.4	55.9
HUN	48.8	39.8	42	46.4	48.2	46.2	49.3	51.6	48.9	51.9	53.6	55.8
GBR	48.3	38.3	40.7	41.6	44	45.2	46.4	48.2	51.6	54.4	56.2	58.8
PRT	48.2	46.1	47.2	45.3	43.2	42.3	46.4	47.1	48.3	50.2	52.1	54.3
SVN	46.9	40.5	42.5	39.8	39.3	43.4	48.1	50.1	47.9	49.5	51.8	54
EU-15	35.5	29,4	30,6	31,4	32,6	33,2	34,2	35,9	37,5	39,2	40,5	42,1
BGR	44.2	37.1	45.1	43.1	41.1	42.1	39.5	42.7	45.1	44.5	46.9	55.3
SVK	44.2	41.3	39.7	42.8	41	42.1	44.7	41.7	47	47.4	49	45.1
DEU	44.1	38.4	39.8	41.7	42.7	42.2	42.9	44.5	45.6	46.7	47.7	49.1
FRA	42.7	36.3	37.6	38.6	39.2	39.9	41.3	43.6	45.2	46.8	47.6	49.3
GRC	40.4	30.4	31.1	32.5	33.1	35	39.4	42.7	46.9	49.3	51	53.9
ITA	38.2	30.7	31.8	33.1	35	36.2	36.5	38.6	39.8	42.5	44.8	45.9
CZE	37.1	29.2	30.3	33.2	32.9	32.3	34.5	36.5	39.4	41.2	44.1	46.4
ESP	35.5	26.6	28.1	29.3	31.2	32.9	34.4	37	39	40.3	40.8	43.1
EU-28	33.6	27.8	28.9	29.8	30.9	31.3	32.3	33.9	35.5	37.1	38.5	40.1
EU-13	31,4	25,5	26,7	27,8	28	28,6	29,8	31,6	33	34,1	36,6	38,5
HRV	31.4	19.7	21.9	25.1	27.7	26.4	29	30.7	34.1	38.6	42.4	42.5
ROU	30.3	27.6	24.9	23.5	22.6	24.1	25.4	30.5	33.5	33.9	36.6	42.4
USA	29.7	24.8	25.6	26.4	27.5	27.4	28.5	29.9	31.4	32.9	34.2	35.2
POL	24.4	18.4	19.8	20.3	21.5	22.6	23.6	24	26.1	27.1	29.1	31.7
CHN	18	13.6	14.5	15.4	16.9	17.9	18	18.2	18.4	19.5	19.4	20.1

Source: author's own calculations based on SciVal (2019) data

Table 28. IRC pattern: country example. Countries collaborating with the United Kingdom, in descending order, 2013-2018 (Top 10).

No.	Country	Co-authored publications	Co-authored publications (growth %)	Co-authors in the UK	Co-authors in the UK (growth %)	Co-authors in the other country	Co-authors in the other country (growth %)	Citations	Citations per publication	Field-Weighted Citation Impact	Institutions
1	United States	172,887	25.9	163,384	32.3	281,042	33.1	3,120,197	18	2.77	1,330
2	Germany	90,202	29.4	100,533	33	104,757	28.6	1,749,257	19.4	2.89	524
3	France	64,296	25.8	79,170	26.3	72,933	29.5	1,354,688	21.1	3.11	393
4	China	63,625	79.2	55,883	57.8	101,394	103.5	825,259	13	2.21	699
5	Italy	63,176	40.2	72,795	40	76,553	40	1,190,199	18.8	2.94	241
6	Australia	59,830	37.5	74,991	34.4	52,684	48.8	1,096,412	18.3	2.98	175
7	Netherlands	51,711	27.6	67,921	31.4	45,235	32.4	1,100,658	21.3	3.23	137
8	Spain	50,124	31	64,631	34.5	56,138	42.2	980,580	19.6	2.95	242
9	Canada	44,195	30.1	61,355	33.7	45,017	39.6	984,051	22.3	3.5	148
10	Switzerland	36,666	38	55,493	44.8	36,888	-5.2	855,015	23.3	3.49	73

Source: author's own calculations based on SciVal (2019) data

Table 29. RC patterns: citation impact per collaboration type, by country, in descending order, 2007-2017 (metrics: the 2007-2017 average).

	Institutional collaboration - citation impact	National collaboration - citation impact	International collaboration - citation impact
NLD	19.4	21.5	31.3
DNK	17.1	19.8	30.5
EST	10.7	13.7	29.6
SWE	16.9	17.7	28.5
BEL	15.6	19	28.1
IRL	15.3	16.2	27.9
GBR	17.5	20.9	27.6
FIN	15.2	17.8	27.5
DEU	14.4	19	27.1
USA	20.3	25.5	27.1
ITA	13	16.3	26.7
AUT	13.7	17.9	26.6
FRA	11.6	17	25.8
GRC	12.6	14.4	24.5
HUN	7.5	10.1	23.8
EU-28	13.3	17	23
CYP	9.7	10.4	22.2
SVN	9	12.8	21.9
PRT	11.7	13.4	21.8
HRV	5.1	7.4	21.6
CZE	6.6	10.4	21.2
LUX	12.5	19	21.1
POL	5.9	8.1	21
LTU	5.6	5.8	20.4
MLT	5.7	5	20.4
CHN	7.2	10.6	20.3
LVA	4.2	5.4	19.6
BGR	4.3	4.7	19.4
SVK	4.9	6.9	17.5
ROU	4	5.8	16.8

Source: author's own calculations based on SciVal (2019) data

Table 30. IRC pattern: institutional example, institutions collaborating with the University of Helsinki, in descending order, 2013 to 2018. (Top 10 only).

	Institution	Country	Co-authored publications	Co-authored publications (growth %)	Co-authors at the University of Helsinki	Co-authors at the University of Helsinki (growth %)	Co-authors at the other Institution	Co-authors at the other Institution (growth %)	Citations	Citations per Publication	Field-Weighted Citation Impact
1	University of Turku	Finland	2,739	5.1	2,896	8	2007	18.6	45,513	16.6	2.26
2	University of Eastern Finland	Finland	2,196	28.9	2,526	36.1	1409	28.7	43,046	19.6	2.48
3	National Institute for Health and Welfare	Finland	2,024	-0.3	1,790	12.5	869	-10.6	41,965	20.7	2.65
4	University of Tampere	Finland	2,003	20.2	2,042	29.6	1198	17.4	38,380	19.2	2.84
5	University of Oulu	Finland	1,898	23.2	2,017	36.9	1338	21.7	35,696	18.8	2.38
6	CNRS	France	1,836	34.7	1,229	54.9	2444	59.8	70,880	38.6	4.41
7	Karolinska Institutet	Sweden	1,800	110.6	1,791	115.6	1548	87	59,517	33.1	5.16
8	Aalto University	Finland	1,723	3.9	1,626	19.2	1413	21.2	29,347	17	2.24
9	Universite Paris-Saclay	France	1,598	33.8	891	34.1	1335	12.5	67,487	42.2	5.16
10	ComUE Paris-Saclay	France	1,566	32.4	838	30	1393	0.3	63,922	40.8	4.87

Source: author's own calculations based on SciVal (2019) data

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International research collaboration (IRC) is at the core of contemporary higher education and science systems, and the percentage of internationally co-authored publications globally and across Europe is on the rise. The aim of this study is to analyse, based on large-scale data on publication and citation trends over time (within the last decade), the changing nature of academic knowledge production in all European Union Member States (EU-28) and the trend towards a radically increasing internationalisation.

The study combines theoretical knowledge about IRC with the most up-to-date empirical data and their analysis. This quantitative study analyses the macro-level of countries and the meso-level of flagship institutions to assess the cross-national and cross-institutional differentiation in the pace of these changes, and their depth. The report uses Scopus and SciVal data for 2007-2017, and the analysis of collaboration in research is based on bibliometric data on publications and citations.

The empirical analysis is preceded by a section on the motivations, and another on the major barriers connected with the processes of research internationalisation. The study suggests policy options for improving collaboration at the European level.

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