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The Impact of Collaboration on Europe's Scientific and Technological Performance

Final Report

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0 Executive Summary

Literature review

- The literature review showed that co-publications and co-patents are relevant proxies for international collaboration. Though publications are more frequently used than patents, not at least because private research collaborations and technological R&D may have additional outputs than only patents.
- A number of motives for international collaboration was identified from the literature. The most important ones are geographical proximity, historical ties, common language, common problems, economic factors, availability of expertise, availability of specific research equipment, databases and laboratories, political factors. These motives were also largely affirmed in the survey.

Feasibility study

- The feasibility study revealed that the tight definitions of DG-RTD were not optimal for the research questions addressed here.
- For future analyses and a permanent monitoring system a more open definition of intra-EU collaborations – also including additional partners from non-member countries is recommended.
- For publications, the alternative to the SCI named SCOPUS should be taken into account in addition or instead. For patents are more internationally relevant perspective is recommended, focusing on special kinds of patent families. The analysis of USPTO patent data is not appropriate for the research question of international collaborations.

Scientific publications

- The absolute numbers as well as the shares in relation to the totals of international co-publications have considerably increased since the 1990s. Though, extra-EU co-publications increased even faster than intra-EU collaborations.
- Smaller countries tend to collaborate more often and New Member States reach higher shares of collaborative articles. However, the absolute numbers of the 12 New Member States are low. This is why a focus on relevant “science” countries instead of EU-27 is recommended
- Obviously, the collaboration intensities are higher in more basic research fields. Publications in fields of traditional European strengths seem to be less frequently co-authored than fields of relative weakness – at least from a very general perspective. This finding gives back-up to the finding in the literature that collaborations are knowledge- and resource-seeking driven.

Patent applications

- Increasing international collaboration in technology since the 1990s both for the EU and most EU countries can be found. Though, higher increases in extra-EU collaborations than intra-EU are obvious.
- Country size (economic or technological) is one factor in explaining inter-country differences but not the only one, whereas innovation leadership is not particularly related to a higher propensity to collaborate.
- The most important external partners for the EU are US and Switzerland but the biggest increases have been with China and India, albeit from a very small base.
- The largest share of EU international collaborations is in the field of Chemistry – an area of traditional European strength.

Survey results

- Co-publications are broadly validated by survey respondents as an appropriate indicator (76%), while the opinions on co-inventoried patents are more divided. 30% of respondents considers the latter to be an inappropriate measure for international collaboration, while the majority refers to other indicators as well.
- The concept of ERA is not known to all respondents but seems to play an important role in international cooperation (as also suggested by the network analysis).
- According to the survey, ERA stimulates international cooperation, which in turn leads to improved coordination of national research activities and policies, better allocation of resources by streamlining of research and increasing the mobility of researchers, the expansion of researcher's networks and knowledge sharing.
- Funding is mentioned as the most important driving factor of international collaboration. Differences exist for motives, barriers and value added between intra- and extra-EU research collaboration. Moreover, intra-EU collaboration is also most intensive as compared to domestic or extra-EU collaboration, which indicates that the funding possibilities existing within the EU play a facilitating role for collaborations.

The policy conclusions of this study are:

- Especially publications, but also patents can be used to measure collaborations and also as proxies to monitor the development of the ERA.
- However, geographical as well as cultural (especially language) proximities matter.
- New Member States – being less integrated so far – might be more integrated by using these findings.
- In addition, access to resources – knowledge, funding or infrastructure – foster international collaborations. In this respect, the European Union plays an important role by funding of projects and infrastructures.

1 Introduction

Modern high-technology and frontier research are complex, knowledge and resource intensive, and often boundary-spanning. Public research is nationally and internationally linked and parts of huge knowledge networks. Research in multinational companies is often decentralised with project members at different locations within the same country but also very often at locations in different countries. The locations of knowledge, competences and resources steer the knowledge flows. In consequence, the international collaboration of public research and companies plays an increasing role, both for the national competitiveness as well as for new knowledge creation in general.

Over the past about 20 years globalisation and internationalisation have accelerated, and while economic integration is perceived as its dominant feature, other dimensions including R&D but also the social, cultural, political and institutional realms are highly relevant too (OECD 2005). Knowledge production and R&D are seen as key components of this development (European Commission 2007). Thus, the understanding of the process of internationalization of R&D is indispensable for policy making and taking strategic decisions. This is also true in the context of the „European Research Area" (ERA), which was launched in the year 2000, aiming at further integration of the European research system and achieving a higher degree of coordination and cooperation among the various players at all policy levels aiming at improved efficiency and effectiveness of still fragmented research efforts (European Commission 2007) in order to strengthen Europe’s international competitiveness. And even though milestones have been reached towards the ERA, progress is mixed and a lot still remains to be done. Decisions concerning required actions and measures need to be taken based on reliable and valid information. Thus, it is crucial to have adequate tools for analysing the internationalisation process and its impact.

Internationalisation of S&T can take various forms such as the mobility of researchers, collaboration between partners from different countries, research activities from institutions abroad, informal knowledge exchange, and systematic exploitation and application of foreign knowledge e.g. by being present in other countries for know-how acquisition and networking (Edler et al. 2007). Thus, a variety of approaches and methodologies are required to capture and analyse internationalisation in order to arrive at a comprehensive description of the processes and trends. So far the internationalisation of industrial R&D is a major issue being discussed in the scientific literature. Indicators applied to measure globalization are R&D expenditures or R&D personnel of foreign firms. Other studies focussed on the analysis of researcher’s mobility (OECD 2002). Very few studies attempted to draw a rather comprehensive picture of R&D internationalisation by combining complementary methods of analysis.

This report concentrates on S&T collaboration and its measurement by indicators. The intention is to analyse the feasibility to regularly monitor developments concerning the evolving degree of integration of ERA. S&T collaboration in this project will be specifically reflected by co-authorships (co-publishing) and co-patenting – knowing that these indicators cannot cover all aspects and all types of S&T collaboration.

The motivations behind the internationally collaborative projects are manifold and range from personal networks to resource accesses. The output of these collaborations can also be manifold ranging from informal exchanges of ideas and knowledge to codified output for example in the form of co-patents or co-publications. This latter codification can be measured and quantified. Next to a quantification and a structural analysis, a detailed examination of the driving forces is necessary to allow an overall assessment of the developments, of the trends as well as to derive adequate policy measures to foster international knowledge flows and create tailor-made environments and framework conditions for international research collaborations, especially against the background of the development of the European Research Area (ERA). Both aspects – the quantitative and the qualitative – of international research co-operations are taken into account in the course of this report.

This documentation starts in chapter two – after this introduction – with a literature review on collaborations and the ERA in general as well as the use of co-publications and co-patents as indications of international collaboration. The third chapter presents the methodology and the obstacles to measure collaboration by co-patents and co-publications. Furthermore, the data sources are introduced, which are analysed in the fourth chapter. The results of an analysis of co-publications and co-patents are discussed against the background of EU-15 and EU-27 cross-border research collaborations. Structures within the EU and with non-EU partners are examined. A network analysis complements this part of the report. As the motivations and driving forces behind the collaborations – measured and quantified by the data base analyses – cannot directly be derived from the quantitative sources, the results of a qualitative survey are introduced in chapter five, before the report concludes with some summarising remarks.

2 Literature Review

2.1 Importance and characteristics of RESEARCH collaboration

2.1.1 Collaboration from a policy perspective

2.1.1.1 Increasing interest from policy-makers

The 'history' of the interest of European policy-makers for (international) collaboration in Science and Technology goes back to the period shortly after World War II. Indeed, the first initiatives in this regard were taken in the early 1950s with the creation of European intergovernmental research organisations such as CERN in 1954 (later on followed by ILL in 1967, EMBL in 1974, ESRF in 1996 etc). The rationale underlying the creation of large-scale, co-funded research organisations was that in some scientific or technological fields requiring large investments and complex infrastructures (typically 'Big Science fields'), operating research activities at world-class level would be too costly and too complex to be hosted by one single country. Creating intergovernmental organisations with co-funding from member countries was thus necessary to keep developing scientific and technological research in specific fields of strategic importance and according to the highest quality standards. These intergovernmental organisations were in a way the very first attempts to joint and to integrate European research activities, with the main aim to reach the higher critical mass required. They were also made possible by the more general trend towards European integration that finds its origin in the immediate aftermath of World War II.

These first initiatives were reinforced by the development of a true EU-wide research policy from the early 1980s on. The Founding Treaties of the European Community did not initially provide the Community with an extensive responsibility in the field of Research. Until the late 1970s, European research policy mainly consisted of sectoral initiatives in areas such as nuclear energy, coal and steel and agriculture. A true Community research policy, shifting from an ad hoc approach without an explicit legal base, towards an integrated vision for research only started in the 1980s, with the first EC Research Framework Programme (1984). On the basis of the positive experiences with this first pilot FP, a separate chapter on research and technology development was included in the Single European Act in 1986.

Articles 163 to 173 of the Treaty establishing the European Union describe the objectives of EU RTD and define the Framework Programme as the basic mechanism for implementing this policy. The text of the Treaty is of course the basis, but not the sole justification for EU intervention. The essential rationale for the FP is that it finances activities in areas that will benefit from public sector support, and, crucially, that these activities can be more effectively carried out at a European level. In other words, the FP should target funding on those actions that can produce a value over and above that which could be achieved through regional or national programmes. European added value is in reality a complex concept which has been the subject of much discussion. Nevertheless, there is broad agreement on a number of particular cases where EU intervention is justified. These can be regrouped in three main categories: a) *Pooling and leveraging of resources (critical mass, Big Science);* b) *Fostering human capacity and excellence in S&T through training, mobility, career development*, *and competition at European level*, and c) *Better integration of European R&D (pan-European research agenda's, coordination of national policies) – (EC COM 2005)*. These three types of policy intervention were obviously tightly intertwined with an improvement of cross-border collaboration patterns between scientists and/or research organisations.

Since the launch of these first Framework Programmes in the 1980s, the context, however, has evolved considerably. A number of trends, which were already apparent in the 1990s, have further intensified and have forced policy-makers to pay increased attention to international (European) collaboration in R&D. Three trends can be distinguished in this regard:

- Globalisation has accelerated, with knowledge production and R&D acting as key components of this new global dynamic. As a result, a new 'division of labour' has appeared in Science and Technology, leading to adjustments in coordination, co-operation, networking, partnerships etc.
- Awareness has grown of various socio-economic challenges – such as increased socioeconomic disparities within the EU, climate change, ageing, and risks of infectious diseases – and there is a consensus that more and stronger concerted action is needed at EU and global level, notably in science and technology. These global challenges need to be more than ever tackled via global (international) research agenda's.
- The European research landscape has evolved in the last few years, notably with the launching of new measures such as the European Research Council and the European Institute of Technology, but also through various ERA specific measures, as well as the wider diversity of scientific cultures that have come with the expanded EU. Within this changing context, the ERA concept itself has also been subject to gradual changes. Its initial focus was on how to improve the efficiency and effectiveness of fragmented research efforts and systems in Europe, and how to get a better return on investment. Gradually, its scope was broadened to include the need for more public and private investment in research, and later to encompass the neces-

sity for improving coherence and synergies between research and other EU policies in order to achieve the renewed Lisbon strategy.

2.1.1.2 Collaboration in the light of the European Research Area

Since 2000, the European Research Area has become the mantra for European and Member State research policies. The underlying idea of ERA was not new (André 2006). The European Research Area idea is a rediscovery of a concept dating back to the 1970s. It was reanimated several times, but was never actually implemented. ERA, as perceived since the 1970s, is a vision about coordinating national research activities and policies and creating an internal market for research with the free circulation of researchers, ideas and technology. However, it was only in 2000 that the concept was put on the political agenda and gained visibility. The Commission Communication 'Towards a European Research Area' generated the necessary momentum while the political context played a major role, creating a threefold awareness: firstly of the major challenges facing Europe, secondly of the potential of science and technology (S&T) to deliver solutions to these challenges and, finally, of the weaknesses of the European S&T system which needed to be overcome to realise this potential (EC 2000).

The Lisbon European Council in March 2000, which urged Europe to turn itself into a knowledge-based economy through more and better investment in the knowledge triangle of research, education and innovation, recognised ERA as an objective of the EU and paved the way for its implementation[1].

The ERA was launched in response to three perceived S&T weaknesses: insufficient funding; lack of an environment to stimulate research and exploit results; and the fragmented nature of activities and dispersal of resources. Improved (cross-border) cooperation and co-ordination among key players in the EU was seen as one key ingredient to remove these deficiencies. Indeed, according to the EC's Communication of 2002, the ERA aimed for:

- the creation of an "internal market" in research, an area of free movement of knowledge, researchers and technology, with the aim of increasing cooperation, stimulating competition and achieving a better allocation of resources;
- a restructuring of the European research fabric, in particular by improved coordination of national research activities and policies, which account for most of the research carried out and financed in Europe;

1 Presidency Conclusions Lisbon European Council 23 and 24 March 2000.

- the development of a European research policy which not only addresses the funding of research activities, but also takes account of all relevant aspects of other EU and national policies (EC 2002).

In the last few years, and particularly with the measures implemented in the 6th Framework Programme (2002-2006), ERA has been transformed from a theoretical concept to a practical policy approach embodying many different dimensions. EU-wide, cross-border collaboration among scientists, research organisations (including universities) and enterprises is at the heart of the strategies and instruments implemented in the ERA context. In the following paragraphs we review the main instruments put in place under the ERA initiatives and with (expected) impact on collaboration activities).

2.1.1.3 ERA Policy instrument in support of collaboration

ERA concerns both the Community and the Member States (including their regions) and the response has been significant at both levels. At EU level a number of actions have been launched since 2000 in support of ERA, notably through the 6th Framework Programme. Progress on some of these actions has been good though somewhat restrained at times, while for others it has been more limited, pointing to the limits of what can be achieved at Community level alone.

One of the notable developments has been the ERA-NET instrument which has made a start at addressing the inefficiency and fragmentation inherent in a system comprising numerous research funding schemes, spread across policy levels. The ERA-Net scheme was launched in 2002 as part of FP6. It aims at stimulating the cooperation and coordination between national (regional) research programmes, including their mutual opening and the development of joint calls. It typically targets research programmes owners or managers (ministries, government agencies or research councils) and invites them to submit proposals in self-nominated topic areas (bottom-up principle). The ERA-Net scheme is one of the flagship instruments of the European Commission for the further development of an integrated 'European Research Area' (ERA). Though the interest it provoked suggests that it responded to existing needs, the volume of funding involved in the resulting joint activities is still marginal. Moreover, national and regional 'programme-owners' are reluctant to restructure their programmes in a way which would enable the development of genuine joint programmes.

Another area where good progress has been made is research infrastructures. A first major milestone was reached with the adoption of the European Strategy Forum for Research Infrastructures (ESFRI) Roadmap. However, the Roadmap will only be a success if the proposed projects are realised. For this to happen there is still a long way to go: New approaches are required - new legal, institutional and financial tools need to be developed.

In the area of international cooperation, ITER[2] has been a very visible success, and has demonstrated that Europe has the will and the capacity for leadership to address global challenges with partners around the world. However, while Europe is increasingly engaged in global science, research and infrastructure initiatives, these initiatives are far from systematic and often poorly coordinated with those of the Member States.

Despite the success of important measures aimed at better exploiting human resources (such as the Marie Curie scheme, the European Charter for Researchers and the scientific visa package), Europe still lacks an open, competitive and attractive labour market for researchers. Some bright researchers and S&T graduates are still leaving Europe, others do not enter a research career in Europe or exit early, others miss opportunities to move into positions where their capacities could be better used and developed.

At national level too, Member States have been involved in implementing actions which can help achieve ERA, for example:

Some convergence in national policy making is materialising, driven in part by discussion and interaction between Member States and the Community level, such as through the Open Method of Coordination (OMC - launched in the context of the 3% Action Plan and overseen by CREST since 2003) or as a follow-up to Commission Communications.

Trans-national and international cooperation are elements of most Member State research policies but, with some exceptions, still remain marginal in regard to the overall policy mix. In general, there is little evidence that national policy makers have taken ownership of the ERA concept, or have advanced far in their practical reflections on how national policy can contribute to constructing ERA, by building policy coherence across borders and across policy levels. Thus, progress at national level has also been mixed.

As a result of these mixed outcomes, the EC has launched in the Spring 2007 a broad-based public consultation on the future of the ERA. The basic piece of evidence underlying this consultation in the (2007) Green paper on the ERA, which has emphasised once again the importance of improved collaboration and co-operation with / between

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2 International Thermonuclear Experimental Reactor.

the key actors of Europe's research systems. According to the Green Paper, *"the ERA that scientists, companies and citizens need should have the following 6 key features":*

1. **An adequate flow of competent researchers** with high levels of mobility between institutions, disciplines, sectors and countries;
2. **World-class research infrastructures**, integrated, networked and accessible to research teams from across Europe and the world, notably thanks to new generations of electronic communication infrastructures;
3. **Excellent research institutions** engaged in effective public-private cooperation and partnerships, forming the core of research and innovation 'clusters' including 'virtual research communities', mostly specialised in interdisciplinary areas and attracting a critical mass of human and financial resources;
4. **Effective knowledge-sharing** notably between public research and industry, as well as with the public at large;
5. **Well-coordinated research programmes and priorities**, including a significant volume of jointly-programmed public research investment at European level involving common priorities, coordinated implementation and joint evaluation; and
6. **A wide opening of the European Research Area to the world** with special emphasis on neighbouring countries and a strong commitment to addressing global challenges with Europe's partners[3].

Improved coordination and cooperation with / between the key actors of the ERA are not only instrumental to increase the flows of people (pt 1) or knowledge (pt 4), or to achieve economies of scale (pt 2), they are also a mean to step up the quality of research towards world-class excellence through *"effective participation in innovation clusters including virtual research communities"* (pt 3).

As we will see below, this increasing interest in collaboration from the policy side has influenced the patterns and intensities of national and international collaboration.

2.1.2 What does collaboration entail?

2.1.2.1 What is (research) collaboration?

Collaboration in research and/or development is assumed to be 'a good thing' and thus it should be encouraged (Katz/Martin 1997). However, the interpretation of 'collaboration' is not an easy task. In an attempt to define 'research collaboration' on the level of

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[3] European Commission, *The European Research Area: New Perspectives*, Green Paper, Presented by the Commission (SEC(2007) 412), COM(2007) 161 final, Brussels, 4 April 2007, p. 2-3.

the collaborator, two definitions, each one of which represents an extreme, can be given (many other scholars have provided similar definitions). The first definition is based on what a collaborator is:

> "A collaborator is anyone providing input to a particular piece of research"

The second definition:

> "Only those scientists who contributed directly to all the main research tasks over the duration of the project would be counted as collaborators"

Both definitions have some drawbacks, therefore as Katz and Martin (ibid) state, "the definition of a research collaboration lies somewhere between those extremes" and "exactly where the border is drawn is a matter of social convention and is open to negotiation". The 'boundaries' of collaboration vary across institutions, fields, sectors and countries as well as over time (see also Miotti/Sachwald 2003). So instead of attempting to define collaboration, several putative criteria can be given for distinguishing collaborators from other researchers.

'Collaborators' will normally include the following:

- Those who work together on the research project throughout its duration or for a large part of it, or who make frequent or substantial contribution.
- Those whose names or posts appear in the original research proposal.
- Those responsible for one or more of the main elements of the research (e.g. the experimental design, construction of research equipment, execution of the experiment, analysis and interpretation of the data, etc.).

Collaboration and competition both in industrial and academic environments seem to be two sides of the same coin. Forms of co-operation between firms and research organisations have greatly expanded the last couple of decades, partly due to the increased funding possibilities offered. Collaborations are often based on contractual agreements and can be mainly found at the front end of the R&D chain. There seems to be co-operation during the research phases, while there is competition in the market introduction phases, i.e. innovation (EC 1997; Hagedoorn et al. 2000).

2.1.2.2 Forms and types of collaboration

Research partnerships can be characterized in terms of the members of the relationship or in terms of the structure of the relationship (see below). The two dimensions are not necessarily independent. Looking at the type partners involved in collaboration, one may distinguish between public and private actors. In our search for taxonomy of research partnerships and collaboration, Katz and Martin (1997) offer a very good starting point by looking at the different levels of collaboration, thereby distinguishing among individual, group, departmental, institutional and national levels.

Table 2-1: Different levels of and forms of collaboration

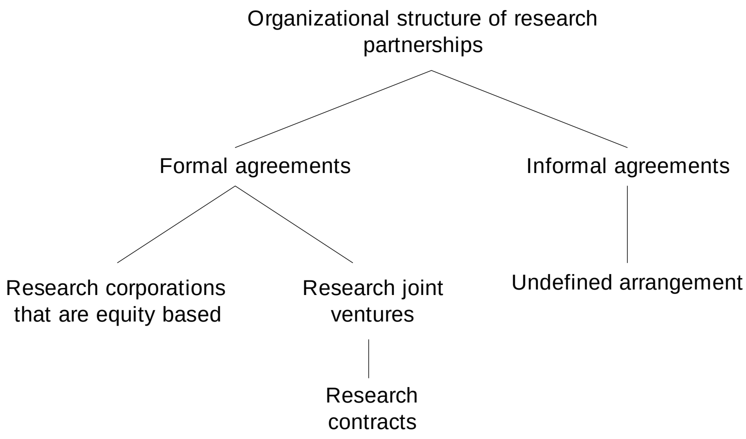
Level	***Intra***	***Inter***
Individual	-	Between individuals
Group	Between individuals in the same groups	Between groups (e.g. in the same department)
Department	Between individuals or groups in the same department	Between departments (in the same institution)
Institution	Between individuals or departments in the same institution	Between institutions
Sector	Between institutions in the same sector	Between institutions in different sectors
Nation	Between institutions in the same country	Between institutions in different countries

Source: Katz/Martin (1997)

Interesting to note is that most policies are primarily aiming to foster collaboration and the higher levels, thereby assuming that the lower levels (researchers) will indirectly benefit as well. Following these levels, if we then consider the collaborating partners, we may than distinguish between intra (within) and inter (between) types of collaboration. This distinction however is not unambiguous if we consider the case where two different researchers, from different organisations and from different countries collaborate with each other. As we will see, this ambiguity translates further into difficulties of actually measuring collaboration intensity and patterns.

Hagedoorn and his colleagues (2000) have synthesized and categorized academic, professional, and policy literature with respect to the intrinsic structure of the partnership (see Figure 2-1). They provide a different taxonomy, also applicable to company's collaborative efforts, that clarifies some of the epistemological differences between concepts like collaboration and outsourcing, which is again another 'thin line' when trying to grasp what collaboration is.

Figure 2-1: Taxonomy of research partnerships by organizational structure



Source: Hagedoorn et al. (2000)

According to Hagedoorn et al. little is known about informal partnerships, except the fact that a lot of companies are involved with one another in short term research endeavours[4]. Firms team-up with other firms and/or universities in many various ways. Informal arrangements in this respect are mostly undefined and thus difficult to measure.

Two types of formal agreements are distinguished: equity joint ventures that focus on R&D (research corporations) and research joint ventures (RJV) which are mainly contractual arrangements (see also Hagedoorn 1990). Research joint ventures, such as joint R&D pacts or consortia to cover non-equity agreements, are created so that firms can undertake joint R&D activities. Although the success of such arrangements depends on the commitment of the partners, the collaboration can be terminated with only a relatively small loss compared to equity based arrangements. A specific subgroup of RJV are research contracts that concern R&D cooperation in which one firm contracts another firm to perform a particular research project. These types of collaboration may well lead to joint publications and/or patents, but their interpretation should be different.

4 As a result, the effect of informal research partnerships on the innovation performance of firms and in the end the financial performance of firms has not been studied in detail. This is largely caused by the difficulties of collecting data on informal partnerships.

2.1.2.3 Drivers of collaboration

2.1.2.3.1 The changing nature of research

The current complexity in knowledge production and diffusion has proven the relatively older models of innovation, like the 'linear or chain-linked' model to be rather simplistic (see e.g. Kline/Rosenberg 1986). A reciprocal model (or network model) of knowledge production and diffusion is more appropriate in that sense (Gibbons et al. 1994). In the latter, the very nature of knowledge is evolving to a more network-oriented structure, with greater emphasis on strategic alliances, knowledge demand and supply chains and a growing transdisciplinarity and heterogeneity. Knowledge is not discrete and coherent, and the production of it is not defined by clear rules and governed by settled routines. Instead, it is based on a mix of theory and practice, of abstraction and aggregation, coupling ideas and data from different origins and sources. The combination of these different origins and sources lead to further cross-fertilization and creation of new opportunities and becomes visible through intensified science – industry interactions.

Two elements herein are important. Firstly, one of the drivers for increasing collaboration is the dynamic evolution of knowledge and knowledge creation itself (cfr. supra) that makes knowledge generation and thus research, a social process in which many different actors (academia, industry, policy, etc.) play a role. This has lead to the increasing awareness of research entities of their network embeddedness and to a boost in the search for partners (Mansfield 1991; Howells 2000).

Secondly, over the last decade we have observed an increasing interwoveness between science and technology. In many technological domains, and also sectors of industry we find an increasing proximity and interwoveness between science (i.e. creation, discovery, examination, classification, reorganization and dissemination of knowledge on physical, biological or social subjects) and technology (i.e. the creation and use of artefacts, crafts and items of knowledge as well as various forms of social organization). Modern technological areas have become highly scientific (Toynbee 1963; De Solla Price 1965; Narin and his colleagues at CHI; Schmoch 1997) thereby stimulating scientists to collaborate with one another. As a result, the classical distinction between industry and academia has faded, and increasing collaboration between the two has been observed.

2.1.2.3.2 Motives for collaboration

As the above elaboration and explanation is of a more exogenous nature, there are also more endogenous factors that stimulate collaboration. Scientists are likely to collaborate for reasons that go beyond scientific compatibility and complementarity. Among these factors are the following (Wagner et al. 2001; Katz/Martin 1997):

- Geographic proximity: neighbouring countries often have similar research or complementary interests and common publication profiles.
- History: Ties that form human, linguistic or other ties, as a result 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. Moreover, the costs of collaboration (travel, communication) have decreased strongly.
- Expertise: Collaborations can be driven by the need for the best, or most appropriate, expertise to pursue the objectives of the scientific query. Many developing countries have institutions and individuals with world-class expertise.
- Research equipment, databases, and laboratories: 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. (see section 2.1.1).

Hagedoorn et al. (2000) have further elaborated on these motives from a company perspective, thereby distinguishing among five approaches towards collaboration (see also Miotti/Sachwald 2003): 1) competitive force approach (strengthening positions), 2) strategic network approach (influencing agenda setting), 3) resource based view of the firm (scarce and unique capabilities), 4) dynamic capabilities (access and development of skills and capabilities), 5) strategic options to new technologies (forward looking).

2.1.3 Measuring 'collaboration'

2.1.3.1 Introduction

As illustrated in the previous sections, collaboration is of particular interest for policy makers, in view of the various policy initiatives targeting the promotion and enhancement of scientific collaboration among researchers and research institutions. Also, inter-sectoral or interdisciplinary research collaboration is promoted by bringing together researchers from different disciplines or promoting collaboration among researchers and technologists serving different market segments. In this context and as scientific collaboration gains a prominent position in the prioritisation of the research policy agenda, it is essential to investigate the ways in which scientific collaboration can be measured as well as the effects of collaboration, and its sources and the implications for research policy. These elements are of importance when collaboration patterns and intensities are 'evaluated' or when research policies need to 'refocus' their policy mix towards the enhancement of collaboration in science.

In the following section we present a concise overview of the most frequently used methods for measuring collaboration.

2.1.3.2 Measuring collaboration

In the first section of this report, we indicated the importance of understanding patterns of internationalisation in science, technology and innovation. Approaching this by studying patterns of collaboration (between both research institutes and enterprises) has proven to be very valuable. However, many challenges remain like the availability of internationally comparable data and the interpretational difficulties related to several indicators. Frequently used indicators to grasp collaboration patterns are co-publishing, co-patenting and co-operative R&D agreements. In this report we focus on the first two.

The area of research utilising the information contained in research publications is labelled "bibliometrics". The term "bibliometrics" is assigned to Pritchard (1969), who defined it as: "… the application of mathematics and statistical methods to books and other media of communication." According to van Raan (1997), scientometrics should be interpreted much broader. He considers it research devoted to be "…quantitative studies of science and technology with the aim of advancing the knowledge on the development of science and technology, also in relation to societal and to policy questions." Similarly, "techometrics" is the area of research dealing with the measurement of technical progress based on among other information contained in patent documents (Grupp 1994).

Since the late 50s, multiple-author publications or co-authored publications have been used as a basic measure of collaborative activity (for example in Smith 1968). Scientific papers can be assigned in different categories reflecting different types of collaboration (Moed et al. 1995). On the basis of the addresses of the authors papers were assigned to the "no collaboration" category, in the case they were single-authored or published by more than one author from the same research group. Remaining papers were assigned to the category "collaboration type *within the Netherlands*," in case the co-author(s) participated from other groups within the Netherlands, or "collaboration type

International," when scientists from groups outside the Netherlands were involved. This is an example of how multi-authored papers can be analysed in terms of collaboration.

Based on the previous discussion, it should have become clear that collaboration is a multifaceted concept which should be approached by various indicators. Co-publications and co-patents are two of these indicators. But they are imperfect. As Katz and Martin (1997) have argued, collaboration cannot be synonymous to co-authorship; nor to co-inventorship. Co-inventions are often based on a formal contractual agreement that stipulates the modalities under which intellectual property will be shared. Co-authorship is a result of values and day-to-day practices. Both reflect to some extent collaborative efforts and engagements and thus both are imperfect or partial indicators of research collaboration on various levels.

2.2 Co-publications

Even though co-authorship[5] is by no means a perfect indicator it is meanwhile frequently used and widely accepted for the analysis of research collaboration. Nowadays basic statistics on patterns of international collaboration and its dynamics are published by various national and international reports on science and technology indicators e.g. the NSF's Science and Engineering Indicators (see for instance National Science Board 2000, 2002, 2006, 2008). Similar data was also used in the European Commission's Report on S&T Indicators (European Commission 2003: 304), the European Commissions Key Figures reports (European Commission 2001, 2002, 2004, 2005, 2007) and also more recently to inform an ERA expert group which was set up in order to identify potential measures to strengthen the ERA (see European Commission 2008b: 20f.).

Research collaboration can be dealt with at different levels of aggregation. Katz and Martin (1997) distinguished between collaboration at the individual, group, departmental, institutional, sectoral and national level. In addition, at each level (with the exception of the individual level) an "intra" and an "inter" form of collaboration can be found. A large number of analysis focuses on collaboration between institutions at the national or regional level. However, the focus of the present study is on international collaboration only. Furthermore, it focuses only on international collaboration in bibliometric terms which is reflected by scientific publications with author-addresses from at least two different countries.

5 Both terms co-authorship and co-publication are used to express the same content.

Katz and Martin (1997) argue that co-authorship should only be seen as a "partial indicator" to measure research collaboration because only those activities, which eventually lead to jointly authored papers, are reflected. Not all collaborations, however, result in publications and conversely, a joint paper does not always mean that the results presented are based on research collaboration. Glänzel and Schubert (2004) on the other hand outline that this is in particular the case as far as intramural[6] collaboration is concerned while in the case of international collaboration the parties involved are, as a rule, well acknowledged. They conclude that even taken into consideration those problems as well as the phenomena of multi-institutional authors,[7] co-authorship "seems to reflect research collaboration between institutions, regions, and countries in an adequate manner" (Glänzel/Schubert 2004: 259) and thus may be used as an analytical tool.

Since the end of the 1970s a growing number of papers dealt with the issue of international research collaboration. This increasing interest in the topic is to be seen in the context of the significant increase of the extent of international research collaboration during the past decades (see chapter: Trends in scientific trans-national co-publishing).

Among the first to have dealt with the topic of international collaboration in research are de Beaver and Rosen (1978, 1979). According to their findings until World War II international collaboration grew rather slowly while afterwards a more rapid increase was observed. Apart from dealing with the degree or the intensity of international research collaboration its consequences for productivity is an interesting question that is being dealt with. Again already de Beaver and Rosen (1978, 1979) analysed this relationship (see section: Trends in scientific trans-national co-publishing). Based on their findings they concluded that collaboration results in higher publication activity.

Another interesting and relevant issue is the question for what reason international collaboration is engaged in. What are the motive and drivers that might explain this phenomenon? This issue will be dealt with in a specific chapter at the end (see section: Motives and drivers). Intra-scientific factors are to a large extent motivating international collaboration. In particular the desire to enhance the scientific knowledge, exchanging skills and data and to enhance professionality (de Beaver/Rosen 1979; Luukkonen et al. 1993) is relevant but other factors are of relevance too.

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6 Intramural collaboration = collaboration within a research group, a department or an institute.

7 Multi-institutional authors are authors involved with two or even more institutions.

The analysis of patterns of collaboration in the sense of identifying networks between actors (here: countries) and the rule certain actors play within those networks is of increasing interest in the context of analysing international collaboration. Meanwhile also here a growing number of publications can be found, often focussing on specific fields of science or on specific countries or regions.

2.2.1 Methodologies to analyse trans-national co-publishing

The analysis of international collaboration is primarily done by using co-authorship data gathered from the Science Citation Index (SCI) so far. The SCI is an international multidisciplinary data base produced by Thomson Reuter. The data base can be accessed via the internet. Alternatively commercial hosts such as STN also offer access to the data base, which is furthermore also available on CD Rom. The SCI for a long time had, compared to other bibliographic data bases, the advantage that affiliation information for all authors of a scientific publication was covered. Only this information enabled the analysis of co-authorships at various levels of aggregation (e.g. inter-institutional or international co-authorships).

From a technical point of view co-publication data can be dealt with in different ways. Publications can be assigned to a country using (1) fractional counting or (2) whole counting[8]. Fractional counting assumes that all authors named, contributed equally to the publication and thus, each author or institution is assigned the same fraction. Thus, a paper is accounted to a country proportionally to the number of addresses given from each country. However, the underlying assumption of equal contributions is not proven and thus, the integer counting method, which assigns a paper fully to each participating country can be used as an alternative too. This method leads to the fact that, if publication shares of all countries are added up, the sum exceeds 100 per cent. Thus, it favours those countries with a high propensity to collaborate internationally. However, both methods are applied in recent studies analysing international research collaboration. Results and interpretations gained from the analyses may differ depending on the counting method used. Based on data from the NSF's Science and Engineering Indicators Report 2002 (National Science Board 2002), where a 10 per cent decline of the US publication output was found for the period 1992-1999, it was stated that the fractional counting method is "biased against growth, and highlighted the possible effect of displacement of papers from 'established' countries, particularly the USA, by those from developing ones. In addition, it was observed that the absolute – wholly counted – number – of US papers did show growth, and seemed at least to suggest that this pat-

8 For a more detailed discussion of the use of fractional versus whole counting see for instance Persson and Danell (2004).

tern may reflect more properly the trend in the US science system's performance than the fractional counting method" (Moed 2005: 274). Consequently, in order to allow for an informed assessment of the data presented it is important to always state precisely which method was used.

Luukkonen et al. (1993) outline problems occurring when calculating indicators reflecting patterns and degree of international collaboration. Often analyses are based on simple shares of joint papers. As a relevant factor influencing a country's collaboration propensity and intensity they identified its size. Already Frame and Carpenter (1979) stated that the size of a country influences its propensity to collaborate internationally. As a consequence, in order to derive a picture adequately reflecting collaboration between countries, absolute as well as relative measures should be taken into account and indicators reflecting international collaboration need to be normalized taking into account the size of the countries under investigation. Often used to normalize collaboration data are the Salton's or Jaccard Index.

However, somewhat contradictory to the above mentioned relationship are findings by the same authors. Luukkonen et al. (1992: 123) found, based on a macro-level analysis of international collaboration, that the relationship between the size of scientific output and the rate of international collaboration is relatively weak. Their analysis, carried out for 30 countries, is based on SCI data for 1981 to 1986. In the paper it is attempted to explain country-to-country differences in the rates of international collaboration. In order to do so geopolitical, historical factors and language as well as the relevance of social, intellectual, cognitive and economic factors were taken into consideration. Similarly also Narin et al. (1991) stated the relatively weak relationship between the size of a country and the degree of international co-authorship. However also in the Narin et al. paper conflicting statements may be found. While on page 317 they argue that "first, international coauthorship is increasing steadily, and second, it is higher for scientifically smaller countries", they also attempt to explain this phenomenon. "The second point is, of course, a direct consequence of scientific size. Scientists in countries such as Italy have far more scientists outside their country to cooperate with, and far fewer inside, than scientists of much larger countries such as the United States or the United Kingdom." (Narin et al. 1991: 317). This result is based on the analysis of only five major EU countries. Using a larger country set, including non-EU countries, they state that "total coauthorship seems to be determined by factors other than size" (Narin et al. 1991: 319). Schubert and Braun (1990) again conclude, based on an analysis of SCI data for the years 1981-1985, on the contrary that the "general tendency is that scientifically small countries have more foreign co-authorships than scientifically large countries. Their explanation is similar to that given by Narin et al. (1991) cited above.

Melin (1999) outlines in the context of the contradictory findings presented by different authors that "This indicates a complexity of the impact of national scientific size on research collaboration which is not well captured in the simplified conclusion that scientists from large countries more easily can find their partners within their own national borders, while scientists from smaller countries need to cross borders, more often to find partners" (p. 163). Consequently he concludes that "national size seems to matter, but the picture is somewhat blurred and further studies are needed in order to clarify the circumstances in general and the causality between national size and international collaboration in particular" (p. 163).

Frietsch (2004) and also Schmoch (2005, 2006) conclude that not only size and the number of potential partners in a country drive the collaboration structure, but also strategic aspects. Explicitly not collaborating with a national partner can be sought. The necessity to collaborate internationally (e.g. in EU projects or to get access to certain data or research facilities) might also build an incentive.

As already outlined findings and interpretation often depend on the specific indicators selected for an analysis. This is not only the case if international research collaboration is analysed. In this context Moed (2005: 272f) insistently argues that the data used and the methodologies applied to calculate indicators are accurately described and explained.

Intra-scientific factors motivating international collaboration are the desire to enhance the scientific knowledge, exchanging skills and data and to enhance professionality (de Beaver/Rosen 1979; Luukkonen et al. 1993). Frame and Carpenter (1979) identified non-science factors influencing the degree of international collaboration and who is collaborating with whom. The factors they mention include geographic location, linguistic, cultural and political factors. In addition they state that differences occur between fields. According to their findings basic disciplines express a higher propensity to collaborate internationally than applied disciplines.

Similar factors are mentioned by Glänzel and Schubert (2004). While Katz (1994) outlined – concerning intra-national collaboration – the intensity of collaboration decreases with increasing distance between partners, they argue that in relation to international collaboration other factors such as country size, political and economic factors, aspects of mobility and migration are relevant too (Glänzel/Schubert 2004: 264)

De Beaver (2001: 373) presents the following rather comprehensive list of 18 purposes for research collaboration:

- Access to expertise;
- Access to equipment, resources, or retool, learn new skills or techniques, usually to break into a new field, subfield, or problem;

"stuff" one doesn't have;

- Improve access to funds;
- obtain prestige or visibility; for professional advancement;
- Efficiency: multiplies hands and minds; easier to learn the tacit knowledge that goes with a technique;
- make progress more rapidly;
- tackle "bigger" problems (more important, more comprehensive, more difficult, global);
- enhance productivity;
- get to know people, to create a network, like an "invisible college";
- satisfy curiosity, intellectual interest;
- share the excitement of an area with other people;
- find flaws more efficiently, reduce errors and mistakes;
- keep one more focussed on research, because others are counting on one to do so;
- reduce isolation, and to recharge one's energy and excitement;
- educate (a student, graduate student, or oneself);
- advance knowledge and learning;
- for fun, amusement, and pleasure.

Katz and Martin (1997: 14-15) outlined five different types of benefits of research collaboration:

- Sharing of knowledge, skills and techniques;
- Transfer of knowledge or skills;
- Stimulating effects and source of creativity;
- Networking effects;
- Enhancing the potential visibility.

Mattson et al. (2008) based on the above mentioned motives introduced four categories: financial reasons (e.g. access too funding, sharing facilities), social factors (networking, acknowledgements from the scientific community, preference to work in teams), improving knowledge (technical, analytical, theoretical), and political factors (including framework programmes and others to facilitate collaboration).

2.2.2 Trends in scientific trans-national co-publishing

Meanwhile various studies have shown that international collaboration has grown significantly during the last two decades. A trend which holds true for most countries (see for instance Schubert/Braun 1990; de Lange/Glänzel 1997; Glänzel 2001; Wagner-Döbler 2001; Sun 2006; Hinze et al. 2007). The number of internationally co-authored papers grows more rapidly than it is the case for the total of all papers. In the period 1986 to 1996 the total number of scientific publications covered by Thomson Reuter data bases grew by 12%. In the same period the increase of internationally co-authored papers amounted to 115% (National Science Board 2000). The following table exhibits the general trends on co-authorship data for the period 1988 to 2005. While in 1988 the rate of internationally co-authored papers was slightly above 8% it meanwhile grew to more than 20%.

Table 2-2: Share of worldwide S&E articles co-authored domestically and internationally: 1988-2005 (National Science Board 2008: 5.42)

	All coauthorship	Domestic coauthorship only	International coauthorship
1988	40,0	31,7	8,3
1989	41,1	32,2	8,9
1990	42,2	32,7	9,5
1991	44,1	33,4	10,6
1992	45,1	33,7	11,4
1993	46,4	34,0	12,4
1994	47,5	34,4	13,1
1995	49,1	35,2	13,9
1996	50,4	35,7	14,7
1997	51,9	36,3	15,6
1998	52,9	36,6	16,3
1999	54,2	37,1	17,1
2000	55,1	37,4	17,7
2001	56,8	38,1	18,6
2002	57,8	38,6	19,2
2003	59,1	39,3	19,8
2004	60,2	40,1	20,1
2005	61,2	40,7	20,4

NOTES: Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles are classified by year they entered database, rather than year of publication, and assigned to region/country/economy on basis of institutional address(es) listed on article. Articles on whole-count basis, i.e., each collaborating institution or country credited one count. Internationally coauthored articles may also have multiple domestic coauthors.

SOURCES: Thomson Scientific, SCI and SSCI, http://scientific.thomson.com/products/categories/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

Hinze et al. (2007) specifically look at the developments in Germany and for the EU-27 countries. According to their findings the share of internationally co-authored papers for Germany grew from about 19% in 1990 to about 44% in 2006. Within this period the share of the EU-27 countries increased from about 11% to about 23%. Differences concerning the share of internationally co-authored papers can be found for individual countries, which can also be seen from the following table which is drawn from Moed (2005).

Table 2-3: International collaboration for 15 major countries (Moed 2005: 298)

Country	International coauthorship (in %)
USA	14,6
UK	22,6
Japan	13,6
Germany	28,8
France	30,2
Canada	26,2
Italy	30,8
Australia	23,6
India	12,2
China	23,5
Netherlands	31,9
Russia	26,4
Spain	28,4
Sweden	33,8
Switzerland	42,1

According to his data international co-authorship is highest in Switzerland and lowest in India and Japan, but also for the USA the share is comparably low. Hinze et al. (2007) found similar results even though at higher absolute levels, which can be partly explained by the fact that data for a different time period was used. In addition Hinze et al. analysed a slightly different set of countries which includes the Scandinavian countries. The latter expressing similarly high levels of internationally co-authored papers as it was found for Switzerland. According to Hinze et al. the share of internationally co-authored papers for Switzerland recently amounts to about 58%, following are Denmark (about 56%), Austria (about 55%), Norway (about 52%) and Sweden (about 50%). Similar levels as identified for Germany can be found for France (43%), the UK and Canada (42%). Also here the USA are at the lower end with about 25% and thus, at a level comparable to that of Korea and slightly above Japan. For the latter two countries their geographic locations as well as language problems were assumed to impede stronger inclusion into international networks.

Frietsch et al. (2008) identified a kind of cultural effect as the Asian countries – they used data for Japan, Korea, China and India in comparison to other OECD countries – collaborate internationally on a much lower level. And this level seems to be persistent and similar over time, even given the strong increase of absolute numbers of scientific publications emerging out of these countries.

Also Narin et al. (1991) highlight the steady increase of internationally co-authored papers. They furthermore found out that this holds true for either inside as well as outside the EU. They found some evidence that the intra-EU increase was slightly higher in areas specifically targeted by the Commission (Narin et al. 1991: 323).

As already shown by the data presented above, variations can be found among countries but also among fields of research (Moed 2005: 285; Luukkonen et al. 1992; Hinze et al. 2007). Drawing on data gathered within the context of the recently performed exercise within the EU-27 countries the comparison between research fields shows that the share is highest in Multidisciplinary Research (51%) and Physics and Geosciences (49%) and lowest in Chemical Engineering (22%) and Basic Chemistry (23%). Similar results were found by Moed (2005).

Hinze et al. (2007) specifically analysed patterns of collaboration for Germany. While they found increasing international collaboration with all countries analysed[9], the increase differed between countries. For instance, it was highest for Korea, which might at least partly be explained by the still comparably low degree of collaboration between both countries in total (p. 19). Differences exist also if fields of science are compared. Comparing data for 1996 and 2006 for four segments of science – engineering, natural sciences, life sciences and medicine – increasing shares of international co-publication activities were found for all those segments. The share of international co-authorship is, however, highest in the natural sciences. It grew from about 36% in 1996 to about 53% in 2006. Second are the life sciences. Here the respective values are 34% in 1996 and 48% in 2006. In engineering in 1996 about 28% of all publications were internationally co-authored, while in 2006 this share came up to 42%. Lowest are the respective rates for Medicine with about 21% in 1996 and 36% in 2006. Still, if normalised for the general growth of the individual segments the annual increase was found to be highest in Medicine (5.5%) and lowest for the life sciences (3.3%). For the social sciences and / or humanities no data was presented, as they are much more nationally oriented. Furthermore, country comparisons are hardly possible based in this data set as non-English speaking countries are underrepresented for the reason that arts and humanities are also much more frequently published in national languages.

In addition, for Germany it was also found that international collaboration is growing more rapidly with other EU countries that for instance with the US (Hinze et al. 2007: 19/20). A finding confirming what was stated by Narin et al. (1991) more generally for intra-EU collaboration before. These are first findings which may indeed point towards the development or emergence of a European Research Area.

Other studies focussing on international collaboration for particular countries exist such as for Korea (Kim 2005), China (Zhou/Leydesdorf 2006), and Turkey (Uzun 2006).

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9 In their study they analysed co-authorships between German authors and authors from 15 mainly European but also other countries e.g. USA, Japan, Korea.

According to Glänzel and Schubert (2004) international collaboration is not necessarily a symmetric relationship between countries but expresses rather an asymmetric pattern. In some cases this is due to historic relationships, e.g. "neo-colonial ties" between the countries concerned (see also Nagtegaal/de Bruin 1994). The findings by Glänzel and Schubert (2004) may underline this argument. They found for instance "strong stable links both between Algeria and France, and Morocco and France" (p. 270).

Glänzel in his 2001 paper also analysed country profiles and compared domestic and internationally co-authored papers. He found that countries follow different strategies. While for some there are hardly any differences between both profiles others seem to "compensate relatively weak domestic activities through international collaboration" (p. 101). According to his findings there seems to be no relationship between these patterns and the size of a country or its economic or scientific development. However, small, less developed countries seem to be more likely to follow a strategy where the profiles of domestic and international activities differ completely from each other (Glänzel 2001: 102).

Apart from analysing intensities of international collaboration and its dynamics various studies deal with the analysis of structures of collaboration networks (Schubert/Braun 1990; Glänzel 2001; Glänzel/Schubert 2004; Hinze et al. 2007; Mattsson et al. 2008). Glänzel and Schubert (2004) visualise changing intensities and structural changes in collaboration networks. For creating the respective maps the Salton index was used to measure strength of bi-lateral co-authorship links. The authors identified clusters varying in size – a big cluster including Western Europe, the USA and Canada and two smaller clusters, one including the Scandinavian countries and one which includes the Eastern European countries. In addition three small clusters covering Australia and New Zealand, Egypt and Saudi-Arabia, and Brazil and Argentina were found. From the perspective of Eastern European Countries Germany and the USA are the most important collaborators in the early 1990s. They call Germany the "gateway to the west for Economies in Transition in Eastern Europe" (Glänzel/Schubert 2004: 266). In this context findings presented by Hinze et al. (2007) are of interest. Apart from analysing international collaboration from the German perspective they also focussed on the question whether any indications can be found pointing to the emergence of the European Research Area. Co-authorship data was used to calculate a matrix reflecting relationships between pairs of countries. Included were the EU-27 countries as well as the USA and Switzerland, as those are important partners for German scientists too. Covered were the periods 1994-1996 and 2004-2006. In addition to calculating the countries' share within the German co-authorship profile also the respective change was calculated, which enables statements about which country is becoming increasingly important as a partner. The analysis confirmed the above statement that co-operations among EU member countries are increasingly important while the USA and also Switzerland are loosing ground – which is, however, not the case if the US-American or Swiss perspective is taken. Within their collaboration portfolio Germany's position is strengthening. But back to the statement by Glänzel and Schubert (2004) that Germany plays a specific rule for Eastern European countries. In the ERA context, based on the recent findings, it appears that the collaboration between Germany and the new member states, is from a German perspective, decreasing. The only exceptions being Romania and Lithuania, with whom, however, collaboration activities are still rather low in total. Interestingly, also from the perspective of the new member states Germany's rule within their collaboration portfolio seems to be decreasing. At the same time it seems that those countries broaden their collaboration portfolio and increasingly collaborate with other EU countries. Thus, from an ERA point of view the changing pattern seems to point to increasing collaboration among EU-27 countries in general. However, the analysis by Hinze et al. (2007) can only be seen as a starting point. More detailed analyses are required to shed light on the recent processes.

Patterns of extra- and intra-EU co-authorships were also studied recently by Mattsson et al. (2008). They dealt with the following research questions: the extent to which EU countries collaborate either within or beyond the EU; the characteristics that determine patterns of collaboration and whether field specific differences can be observed. Eighteen EU countries, contributing 99% of the EU publication output, were analysed. The results confirm the findings by Narin et al. (1991) and Hinze et al. (2007) that intra-EU collaboration has increased stronger than extra-EU collaboration. According to their findings – as far as intra-EU collaboration is concerned – size seems to matter concerning the extent of collaboration – small countries tend to collaborate more intensely. More scattered is the picture they found for extra-EU collaborations. Here size does not seem to influence the collaboration intensity. Difference between fields were observed, while in clinical medicine and engineering, computing & technology no size difference was found, in agriculture, biology & environmental sciences a significant difference was found between large and small countries. In addition, in order analyse EU interactions networking activities were analysed. Network size was determined by the number of countries involved in a publication. Here the analysis yielded significant differences between intra- and extra-EU networks for all fields. Intra-EU networks were found to be larger than extra-EU networks. Thus, the authors conclude that the results point to an Europeanization than a general internationalization.

Both studies dealing with the aspect of the emerging ERA attempted to shed light on recent developments. First indications seem to indeed point to a respective development.

2.2.3 Relationships between collaboration and impact of research

As already mentioned at the beginning the relationship between collaboration and productivity is one interesting question that was dealt with by a number of studies basically starting with the pioneering work by de Beaver and Rosen (1978, 1979) and their conclusion that collaboration enhances productivity.

A couple of studies analysed the relationship between international collaboration and the impact of the respective research. In particular it was investigated whether higher citation rates may be found for internationally co-authored papers. Narin et al. (1991) as well as Gomez et al. (1995) reported that internationally co-authored papers on average tend to have higher citation rates. Similar results were found by Glänzel and Schubert (2001) and Glänzel and Schubert (2004). Also Katz and Martin (1997: 15) state that on average a paper written by multiple authors is likely to be more frequently cited and thus, has a higher impact.

Glänzel (2001) confirms the above finding at the national level. However, he also found differences between fields of science if pairs of countries were analysed. While in biomedical research the observed citation rates of almost all pairs of countries were above the domestic values this seems to be different in chemistry and mathematics where for some pairs of countries very low citation rates were found. In particular this was the case if developing or Eastern European countries were concerned. Thus he concludes that international co-authorship does not pay for all partners. However, the explanations for these findings remain unclear.

According to the findings by Narin et al. (1991) internationally co-authored papers were cited two times higher than single institutional, single country papers. At the same time it was found that there was no difference concerning the citation impact between intra-EU papers and internationally co-authored papers from Non-EU authors. With other words, for internationally co-authored European papers the impact was as high as for any others in the world.

More recently Moed (2005) analysed the relationship between international collaboration and citation impact. His particular focus was on bilateral international collaboration. According to his findings the picture is rather mixed. Whether or not international collaboration leads to higher citation rates depends on who is collaborating with whom. In the case that scientifically advanced countries collaborate with each other in a specific area there seems to be a positive effect, meaning that the citation impact of those papers is most often higher than it is the case for purely domestic papers. However, in the case that scientifically advanced countries engage in collaborative papers with scientifically less advanced countries the outcome may negatively affect the citation rates of the advanced country (p. 290).

2.3 Co-Patenting

2.3.1 General Overview

The literature on co-patenting is comparatively small.[10] To inform the literature review a brief bibliometric analysis was carried out. In the Web of Knowledge not more than 50 publications can be identified that are related to co-invention or co-patenting.[11] A substantial share of these papers are not immediately relevant to this study as they refer to particular instances of co-inventions and describe accounts of individual inventors rather than offer studies and analyses of co-patenting. The most relevant papers and reports are summarised in Appendix 1.

Apart from very few but notable exceptions (e.g. Guellec/van Pottelsberghe de la Potterie 2001; Guellec/Pluvia Zuniga 2007; Edler 2004; Edler et al. 2003), co-patenting data has been used in general overviews of patent statistics, such as the OECD (2007) compendium of patent statistics, or as supplementary information in reports on internationalisation of R&D (see e.g. the 2005 report by Arthur D Little on the UK). The focus of these studies and reports is here indeed on transnational knowledge flows or transfers at the country level. In addition, co-patenting data tends also to be offered as complementary information on international collaboration in domain studies of new technologies (e.g. OECD 2005; Glänzel et al. 2003a, 2003b).

Increasingly co-patenting is being explored in other contexts, for instance, academia-industry collaboration (e.g. Lissoni et al. 2008) or econometric studies to explore research and development collaboration within the context of regional innovation systems (e.g. Maggioni et al. 2007). While the focus of this review is on international flows and exchange processes, we will briefly point to examples of co-patenting studies covering also these aspects. Apart from co-patent data, other tools and techniques have been employed to explore international knowledge flows. Also here we will briefly refer to exemplary studies.

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10 A recent literature review (Fontana/Geuna 2008) confirms the impression that there are very few studies that focus exclusively on co-patenting.

11 The Web of Knowledge search covered the Social Sciences, Arts and Humanities, and Science Citation Indexes as well as the proceedings databases by Thomson-ISI. A search in the Scopus database identifies around fifty publications; after closer inspection only a handful of publications seemed pertinent to this study.

2.3.2 Different Types of International Co-patenting

Generally speaking, one can distinguish different types of international co-patenting (e.g. Grupp 1997; Grupp/Schmoch 1992; Hullmann 2001):

- Domestic inventor, foreign applicant (or assignee)
- Domestic applicant, foreign inventor
- Domestic and foreign inventors
- Domestic and foreign applicants

Figure 2-2 illustrates the various possible combinations. These categories can be used to track co-patenting. However, it is much more difficult to make judgements about knowledge flow or exchange processes on the basis of patenting data. The direction of the knowledge flow is often challenging to trace. For instance, it is difficult to say much about the extent and direction of knowledge flows if inventor teams are from different countries. One would assume that knowledge has been transferred in both directions but it is impossible to make judgments as to which partner benefited the most. Also, having both domestic applicants and inventors does not necessarily mean the invention is utilised in that country. Licensing arrangements (which cannot be tracked through patent analysis) might well assign the exclusive right of use of the invention to a foreign company.[12]

When interpreting co-patenting data it is also important to recognise that there is a difference between the concept of *domestic inventors* and a perspective that is based on the *nationality of inventors*. Patent data can offer only information on the former, not on the latter aspect. This means that co-invention data is based on residential addresses of inventors as they are listed in patent documents. A foreign national would be counted as domestic as long as he or she lives within the country analysed.[13]

At the organisational level, co-patenting activity is at times seen as an "imperfect proxy for collaboration among firms since it only picks up collaboration which result[s] in patenting, and since it also may involve inventors from the same company located across its various subsidiaries, the data reflects both inter – and intra-firm international collaboration" (ADL 2005: 93).

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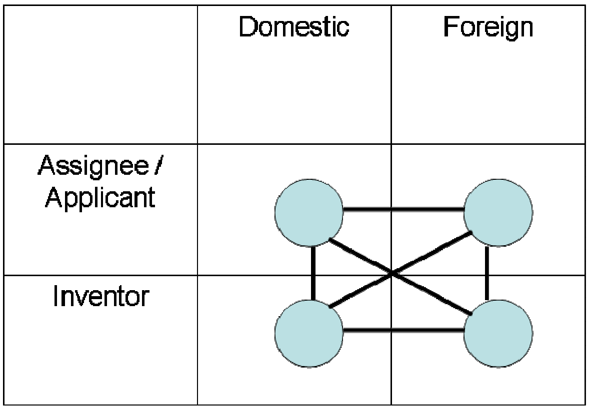
12 Also note that the term 'co-patenting' can be defined in different ways. While most analyst will define co-inventions and co-assignations as co-patenting, the situation might be less clear when one looks at combinations of foreign ownership of domestic inventions, domestic ownership of foreign inventions. Some analysts (e.g. Hullmann 2001) follow this very broad perspective while other may view 'foreign owned national inventions' and 'nationally owned foreign inventions' as a group of indicators which is essentially different from co-patenting.

13 These sorts of aspects will be emphasised even more if one focuses on regions.

Figure 2-2: Various Co-Patenting Combinations



Having stressed the overall utility of patent indicators to measure globalisation, Guellec and Pluvia Zuniga note that patent measures are not without shortcomings:

> "A large part of the caveats have to do with the practical limitations in patents to properly identify companies' countries of origin and their strategies for dispersion/location of ownership" (Guellec/Pluvia Zuniga 2007: 113).

They go on to distinguish three issues in particular (ibid.: 113-114):

1. "The owner country as identified in the patent document may be in some cases, not the country where the headquarter of the company is located (where the resources come from), but the country of the subsidiary in charge of management of international intellectual property (i.e. an intellectual property holding company). Certain companies have set up an IP-holding company which files patents on its behalf world-wide and which is located in a low tax country.
2. A second issue concerns the actual economic meaning of the cross-border ownership. A patent invented abroad may not necessarily mean a setting up of a R&D laboratory but rather from an acquisition or merger. Hence, such an invention would have become cross border only some time after it was made, and the cross border character could not have affected the invention process. Patent databases do not register such changes in the ownership of patents. Changes in ownership, in our database, are registered until the grant of the patent (on average 3 to 5 years after application), not later. So, this problem should not be too large. [This may lead to overestimating cross-border inventions.]
3. A third issue is that a patent can be taken directly by the local affiliate of the foreign MNE, without the MNE being mentioned on the patent filing. The consequences are that ownership in fact does not belong to "domestic" firms and therefore foreign ownership for some countries is under-estimated (e.g. see the case of Belgium in Cincera et al. 2006); and symmetrically domestic ownership of foreign inventions is underestimated for the owner country." [This could result in underestimating cross-border inventions.]

Guellec and Pluvia Zuniga (2007) point to casual evidence which suggests that overall patent data tend to underestimate the degree of internationalisation of technology.

2.3.3 Specific Findings

2.3.3.1 Studies of Countries' Internationalisation of R&D

We could identify only a small number of reports and scientific articles dealing with transnational knowledge flows specifically.[14] One notable exception is the work by Guellec, van Pottelsberghe de la Potterie and collaborators (e.g. Guellec/van Pottelsberghe de la Potterie 2001; Guellec/Pluvia Zuniga 2007) that draws on patent data specifically to explore transnational knowledge flows at the country level.[15] There are also studies that look at these issues from the perspective of an individual country. For instance, Edler and colleagues (Edler 2004; Edler et al. 2003) explore revealed technology advantages for Germany across a wide range of science and technology fields.

'Cross-border ownership' of patents occurs when "at least one inventor and the applicant reside in different countries" (Guellec/van Pottelsberghe de la Potterie 2001: 1255). Figure 2-3 presents recent data on the worldwide level of cross-border ownership showing an increase in crossborder ownership from about 10% in 1990 to almost 18% in 2002.

At the country level, Guellec and colleagues used mainly two indicators that mirror each other:

- the **share for a given country of patents with a foreign inventor and a domestic applicant in the country's total domestic applications** ('SHAI'). It reflects the extent to which domestic firms control foreign inventions. Recent data published by the OECD (2007) is presented in Figure 2-4. It illustrates that domestic ownership of inventions made abroad is particularly high in small open economies[16] and that over-

14 Note that almost all studies we identified draw on an analysis of European or US patent data. Especially in recent OECD work, EPO data is utilised. Whenever no specific reference to a patent system is made in the following section, EPO data has been used in the analyses described.

15 Note that there is a broader literature on multinational enterprises that is related to the field in question. Guellec and van Pottelsberghe de la Potterie, for instance, refer to e.g. Patel and Pavitt (1991, 2000), Dunning (1994) and Dunning and Wymbs (1999). Guellec and van Pottelsberghe de la Potterie argue that these studies – unlike their own, more comprehensive work – were focused on patenting activity of multinationals which account for most but not all of cross-border patenting activity.

16 The OECD (2007) compendium reports for patents filed with the EPO that in the case of Luxembourg more than 80% of inventions owned were made by inventors abroad, more

all most economies have become more strongly involved in cross-border inventive activity over the course of this decade. The share of foreign inventions owned by domestic companies has more than doubled in Brazil, Finland, India and Sweden as compared to the early 1990's.[17] Comparing EU and US, it is interesting to note that more than 50% of inventions with cross-border ownership in 2001-03 were made with inventors located in European countries, which represented twice the number of inventions made by US inventors (Figure 2-5). The breakdown at the country-level points to the importance of geographical and cultural proximity in the choice of location. European countries own inventions from other EU countries more frequently than from other locations. When intra-EU locations are netted out, the United States is the leading location.[18]

- the **share for a given country of patents with a domestic inventor and a foreign applicant in the country's total domestic inventions** ('SHIA'). It reflects the extent to which foreign firms control (own) domestic inventions (Figure 2-5). Recent OECD data suggests that, on average, nearly 17% of all inventions filed at the EPO were owned or co-owned by a foreign resident in 2001-03, which is a substantial increase from less than 12% in 1991-93. Having said this, one must note that there is considerable variation from country to country.[19]

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than 30% in the cases of Belgium, Ireland, the Netherlands, Singapore, Sweden and Switzerland. In some of the aforementioned countries, foreign countries have established research labs to a larger extent than elsewhere (e.g., in Belgium in the pharmaceuticals and biotechnology areas and Switzerland in the electronics sector; Singapore pursues a policy of attracting companies and researchers to build up science-based industry, with Biopolis being the most prominent amongst a number of initiatives). In other countries, such as Sweden, some of the national players (esp. in the research-intensive pharmaceuticals sector have merged with or been acquired by other MNE's.

Italy, Japan, Korea and Spain report the weakest share of inventions made abroad (less than 10%). A number of factors could explain this situation. It is argued that especially Asian firms tend to do most of the R&D in their respective home countries (e.g. Patel/Frietsch 2007). In other cases, countries specialisation in sectors that are less technology-intensive might be a reason to explain the comparatively low share.

17 A significant rise is also reported for France, where the share increased from 11% to 21% in 2001-3.

18 For other countries the OECD (2007) compendium reports: "Canada, India, Israel, Korea, Japan and Singapore own more patents with US inventors than with EU inventors. China shows a more even distribution of domestic ownership across regions while the Russian Federation collaborates mostly with other countries."

19 In countries, such as the Russian Federation, Luxembourg and Hungary, over 50% of domestic inventions are foreign-owned, having increased over the past decade. In contrast to this markedly decreased foreign ownership of patents is reported for Finland, India, Korea, Poland and Singapore, foreign ownership. The US and Germany have declining shares of foreign ownership (between 14 and 15%). Korea and Japan report the lowest shares in 2001-03 (with less than 5%).

SHIA and SHAI are not entirely unproblematic indicators in terms of the extent to which they truly trace knowledge flows and cross-country ownership relations. While patent documents always need to include a complete set of inventors and their addresses, they do not always contain as complete information on applicants, or assignees. When analysing indicators on foreign-owned inventions or nationally owned inventions, one must also take into account that especially multinational corporations, which account for most cross-border inventions, have differing patenting practices. There are considerable differences in where they file patent applications for their inventions (e.g. Patel/Frietsch 2007) and whether they are owned centrally at the MNE's headquarters or in affiliates in other countries where most of the research and development activity leading to invention was carried out (e.g. Guellec/Pluvia Zuniga 2007). One needs to bear in mind these limitations when interpreting these types of patent indicators.

A third indicator Guellec and van Pottelsberghe de la Potterie (2001) used is the **share for a given country of patents with a foreign resident as co-inventor in the population of patents with a domestic inventor ('SHII').** One could argue that this indicator is captures more the essence of co-patenting than the two aforementioned measures. This measure is also methodologically on safer ground as all patent documents must contain complete information on inventors and their addresses. As mentioned earlier, this is not necessarily the case for applicants and assignee.

The authors report a steady increase in cross-border co-inventive activity from around 2% in 1985 over almost 5% in 1995 to 7% in 2001-03 (see Figure 2-11 and Figure 2-12 for a country comparison based on recent data). Having said this, one needs to note that international co-inventive activity varies widely between large and small countries with small and less developed economies more strongly engaged in international collaboration.[20] Co-inventions are discussed further in the section on field specific studies below.

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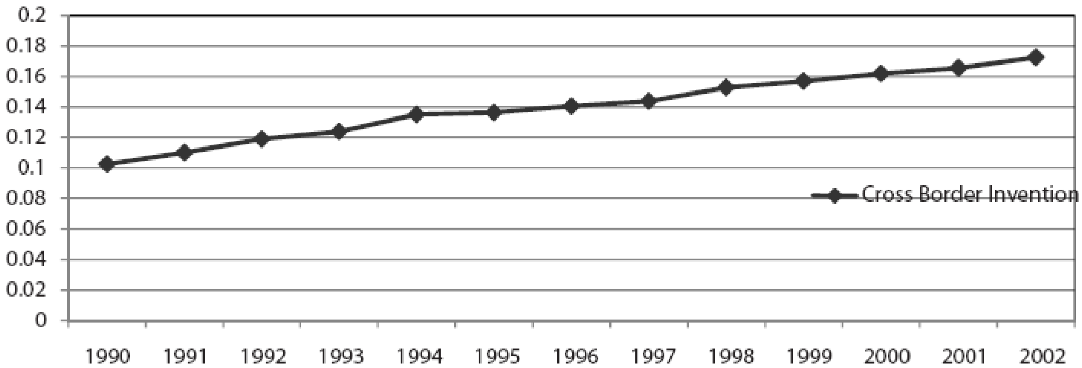
20 The OECD report states that "co-invention is particularly high in Luxembourg (52%), followed by the Russian Federation, Singapore, the Czech Republic and Poland. This reflects these countries' need to overcome limitations due to the size of internal markets and/or the lack of the necessary infrastructure to develop technology. Large countries, such as France, Germany, the United Kingdom and the United States report international co-operation of between 12 and 23% in 2001-03, the greatest expansion in the extent of international collaboration from the early 1990s. In France, for instance, it increased from 8 to 16% in 2001-03. The breakdown of collaboration by main partner country (Figure 2-8) reveals patterns similar to those reported for cross-border ownership. European countries collaborate essentially with other EU countries; whereas Canada, China, India, Israel, Korea and Japan collaborates the most with the United States. More than 20% of inventions made in India and Canada are co-invented with a US inventor, Brazil and South Africa collaborating mainly with EU inventors" (OECD 2007: 37f).

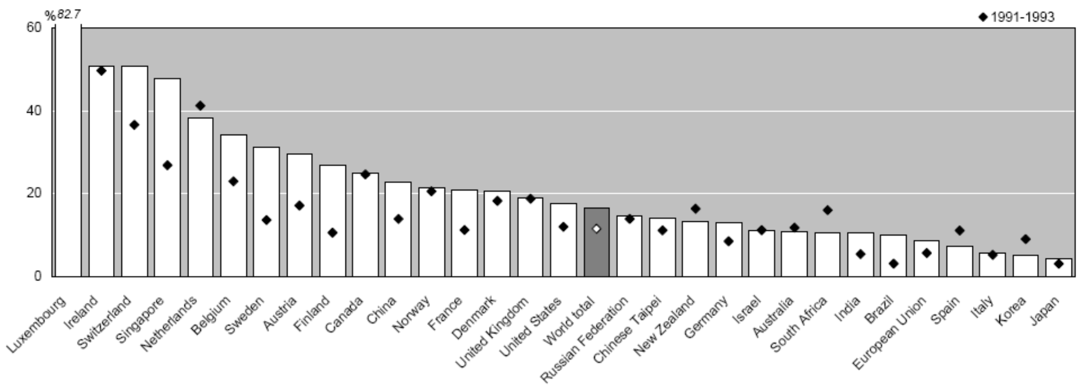
Most of the above cited work has been carried out at the OECD.[21] Other reports utilise this data. A recent consultancy report by Arthur D Little (ADL 2005) on the internationalisation of R&D may serve as an example. The United Kingdom is discussed in terms of co-patenting as an exception among large countries, with around 40% of domestic inventions owned by foreign residents, compared to 30% in the early 1990s. One of the reasons is the relatively large number of foreign research labs, for instance, those of US and Japanese corporations. The report draws on basic co-patenting statistics as one of many indicators. Other indicators included are human resource statistics, R&D investment by foreign and domestic firms, foreign direct investment, and co-publications.

Figure 2-3: Crossborder ownership of inventions – Global



Source: Guellec and Pluvia Zuniga (2007), Fig. 1

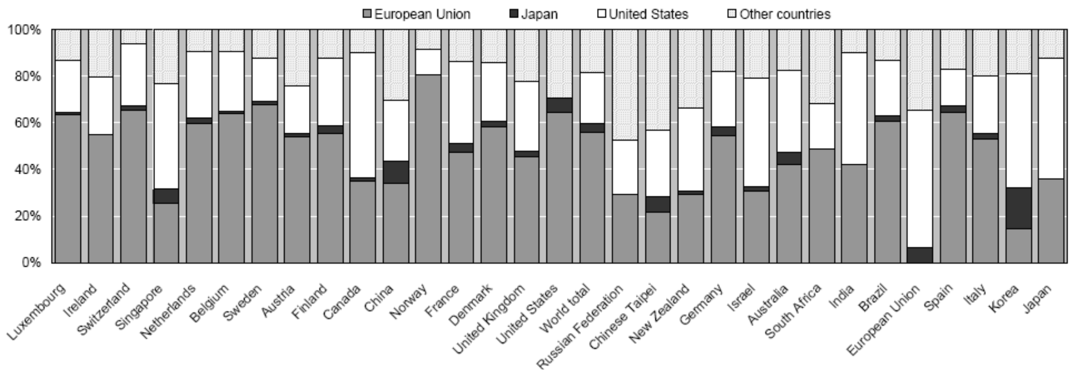
Figure 2-4: Domestic Ownership of inventions made abroad, 2001-2003



Source: OECD (2007), Tab. 6.1.3

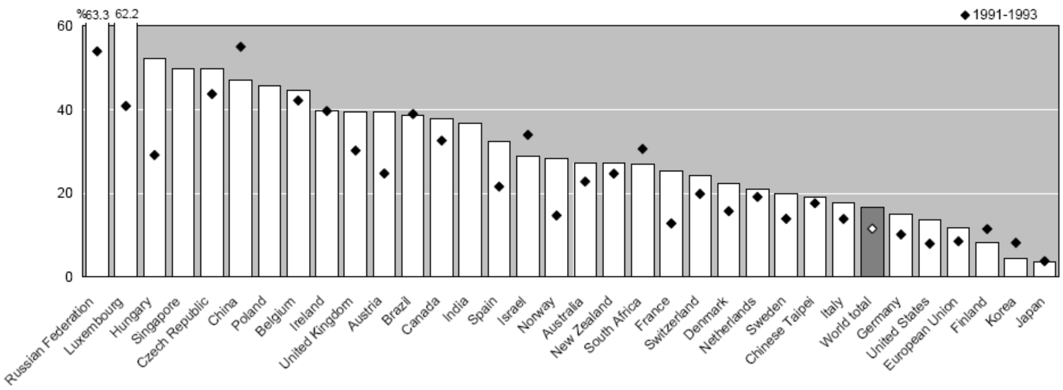
21 The Third European Report on Science and Technology Indicators (2003) did not include overall data on co-patenting. The report called "A more research-intensive and integrated European Research Area" (European Commission 2008a) also focus on other measures.

Figure 2-5: Domestic ownership of inventions made abroad: Partner in the three major regions (2001-2003)



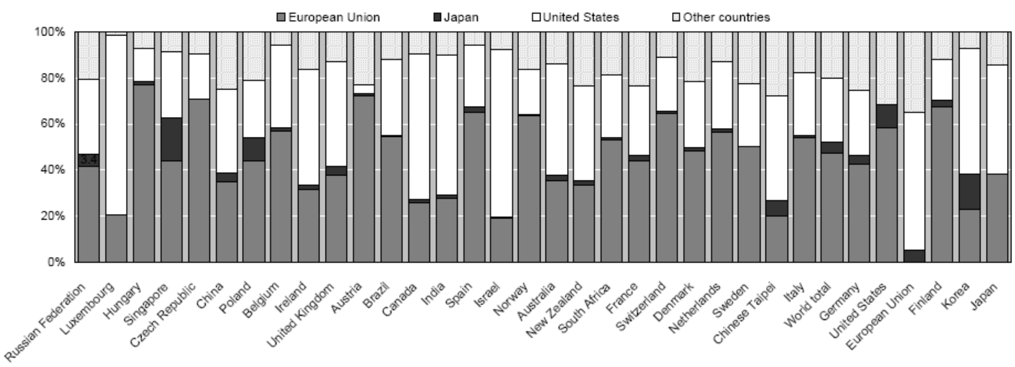
Source: OECD (2007), Tab. 6.1.4

Figure 2-6: Foreign Ownership of domestic inventions (2001-2003).



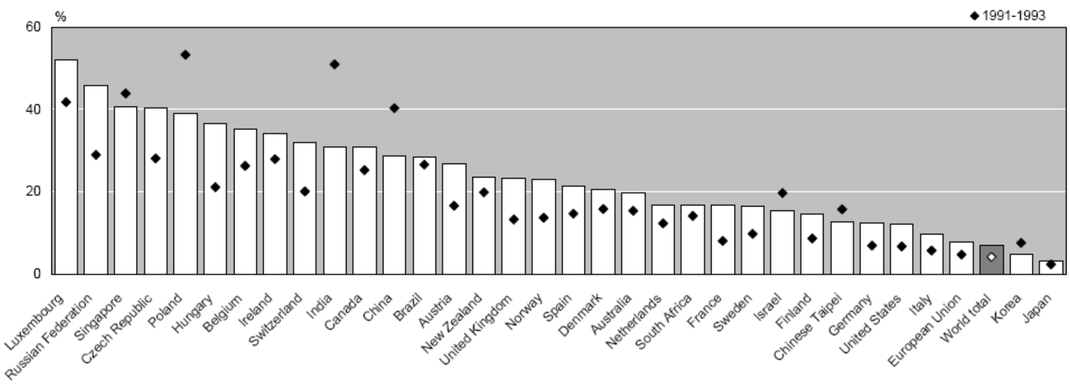
Source: OECD (2007), Tab. 6.1.1

Figure 2-7: Foreign Ownership of domestic inventions, partner in three major regions (2001-2003)



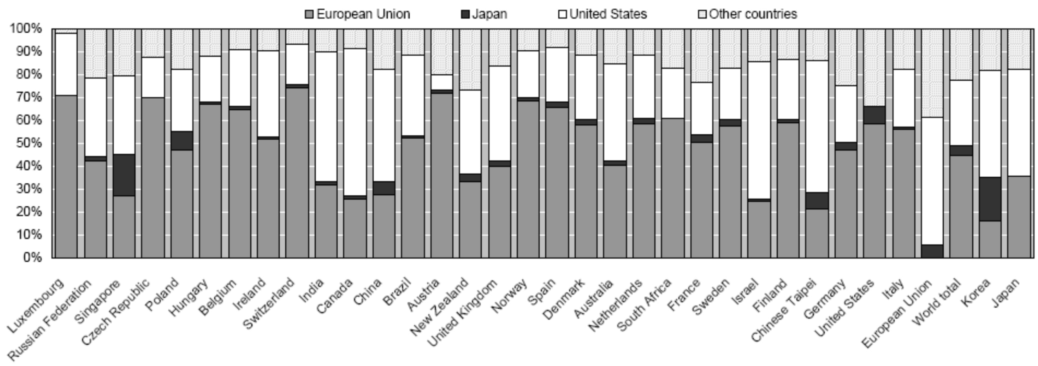
Source: OECD (2007), Tab. 6.1.2

Figure 2-8: Patents with foreign co-inventors (2001-2003)



Source: OECD (2007), Tab. 6.2.1

Figure 2-9: Patents with foreign co-inventors, partner in the three major regions (2001-2003)



Source: OECD (2007), Tab. 6.2.2

2.3.3.2 Co-patenting and the Importance of Technological Specialisation

Innovation research has often pointed to the importance of technological context on innovation processes. Studies distinguishing between different types and fields of technology illustrate the importance of technological specialisation (e.g. Frietsch/Schmoch 2006). When analysing patent activity at the technology level one must bear in mind that patenting intensity varies between industrial sectors and technological areas. Patenting is seen to be associated with certain sectors rather than others. The propensity to patent is generally greater in science-based or high tech areas.

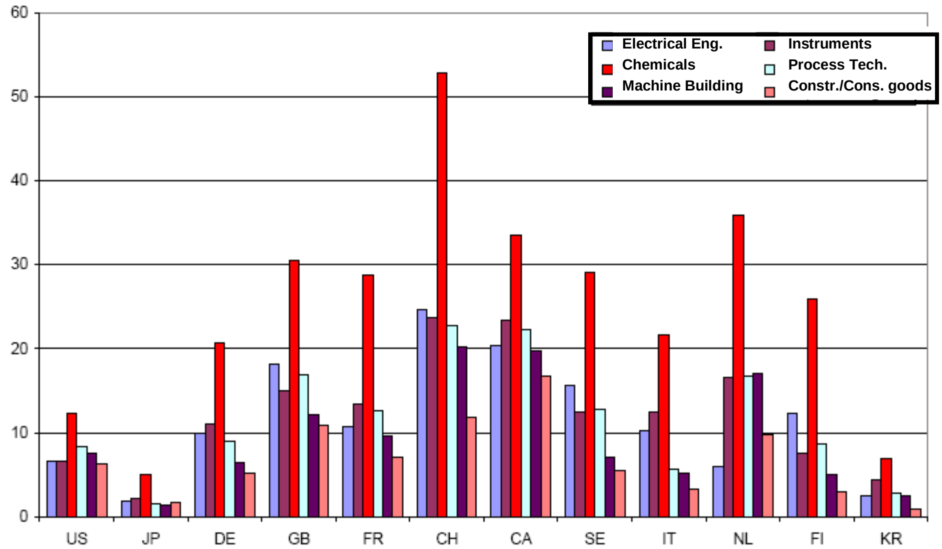
Analysing Triad patents, Frietsch and Schmoch (2006) report that

- there is considerably less international collaboration at the country level in less research-intensive technologies,

- countries tend to cooperate relatively more in the technology fields in which they are less specialised,
- Chemicals are the technology area with the highest propensity of international collaboration whereas construction and consumer goods related collaborative patent activity is commonly the least international.

Figure 2-10 offers a comparison of selected countries' co-patenting (on the basis of inventor addresses).

Figure 2-10: International co-patenting of selected countries by technology fields (2004)



Source: Frietsch/Schmoch (2006)

2.3.3.3 Studies of Technological Domains

Our review of the literature could also identify a number of studies with a focus on emergent technologies or already established science-based technologies. These studies cover technology areas, such as nano or biotechnology (e.g. Hullmann 2001; Glänzel et al. 2003a, 2003b). Some studies limit themselves to presenting co-patenting data in co-invention and co-assignee format whereas others try to associate co-patenting indicators with international knowledge transfers. Both approaches are described below.

2.3.3.3.1 Co-invention and co-assignee analyses

The studies by Glänzel, Meyer and colleagues (2003a,b) can be used as an example as to how studies of technological domains draw on co-patenting data. Again, co-patenting is one indicator of many. The focus is on collaborative activity at the country level. The studies distinguish two approaches:

1. Co-inventions: This measure tracks the composition of inventor teams either at the individual, organisational or country level. A co-invention link points to individuals who generated technology in a common endeavour. It is similar to co-authorships in publications. Some studies even refer to co-inventions as 'patent co-authorships' (e.g. Tsuda et al. 2006). This might suggest that co-authorship and co-patenting are very similar processes. While there are similarities there are also considerable differences. Whereas both patents and papers are generated by teams rather than individuals, patents result to a larger extent from efforts of individuals and small teams rather than larger groups. Co-inventions appear to occur less frequently as cross-institutional collaborations than scientific publications. While one can trace co-authorship networks, co-invention networks occur at best in a rudimentary form (e.g. Meyer/Bhattacharya 2004).[22]
2. Co-assignation: This link connects actors that share the ownership of a patent. Co-assignations of patents point to a shared interest in utilising a patented invention rather than co-operation in the creation of a technology. Co-assignations occur usually at the organisational level and not the individual level.[23]

Studies often use Salton's measure to analyse collaborative activity. In the context of co-patent analyses, Salton's measure is defined as the number of inventions (assignations) shared by two countries which is divided by the geometric mean of the total number of inventions (assignations) attributed to the two respective countries, or:

$$r = \frac{p_{ij}}{\sqrt{p_i \cdot p_j}},$$

with p_{ij} = the number of links between the countries *i* and *j* and $p_i(p_j)$ the total of inventions (assignations) for the country *i* (*j*).

Co-inventions across countries are quite frequent. For instance, Glänzel et al. (2003b) found that around 27.9% of all biotechnology patent applications with the EPO were

22 See also Appendix 2 for a comparison of co-inventions with co-authorships.

23 Co-assignations indicate joint ownership of invention and may point to joint exploitation intent of the partner organizations. They occur between business firms but links between public sector research institutes and firms may play also an important role. These collaborations may happen more frequently within a national than international context. Licensing (on which no data is available) is still the more common form of joint exploitation of patents. This may also be one reason as to why the share of co-assigned patents is relatively low. Also note that information on assignee and applicant organizations is less complete in patent documents than for inventors. All caveats discussed earlier in this context apply also here.

international co-inventions in the EPO system (12,412 out of a total of around 44,483 for the period 1992-2001).

However, the share of co-assigned patents is relatively small in comparison to co-inventions, even though observers find there is an increasing trend to joint ownership and exploitation of inventions in areas, such as biotechnology (Pyka/Saviotti 2002). Glänzel et al. (2003b) identified 3,926 European patent applications (in relation to around 45,000 patent applications in this area during 1992-2001).[24]

The co-patenting matrices in Figure 2-11 and Figure 2-12 provide examples of cross-border collaboration in terms of co-inventions and co-assignations in biotechnology. The Appendix includes data for nanotechnology.

24 They traced 1,764 international co-assignations out of around 45,000 biotech patents granted in the US (1992-2001), respectively.

Figure 2-11: International co-inventions based on EP data (for application years 1992-2001), values given in Saltons' measure

	US	DE	GB	BE	FR	NL	CH	JP	CA	DK	AU	SE	IT	IL
US		4.13%	6.62%	2.07%	3.67%	1.84%	2.87%	2.96%	4.56%	2.01%	2.13%	2.07%	2.05%	3.18%
DE	4.13%		2.31%	2.85%	4.00%	3.05%	7.56%		1.05%	2.58%	1.21%	1.50%	1.62%	1.98%
GB	6.62%	2.31%		2.48%	3.58%	2.80%	1.69%		1.80%	1.83%	2.82%	1.78%	1.66%	
BE	2.07%	2.85%	2.48%		3.60%	5.96%	1.20%						1.58%	
FR	3.67%	4.00%	3.58%	3.60%		1.34%	5.77%		2.11%		1.15%		2.24%	1.28%
NL	1.84%	3.05%	2.80%	5.96%	1.34%		1.22%			2.25%				
CH	2.87%	7.56%	1.69%	1.20%	5.77%	1.22%				1.01%	1.13%		1.45%	
JP	2.96%													
CA	4.56%	1.05%	1.80%		2.11%						1.21%			
DK	2.01%	2.58%	1.83%			2.25%	1.01%				1.29%	3.13%		
AU	2.13%	1.21%	2.82%		1.15%		1.13%		1.21%	1.29%				
SE	2.07%	1.50%	1.78%							3.13%			1.26%	
IT	2.05%	1.62%	1.66%	1.58%	2.24%		1.45%					1.26%		
IL	3.18%	1.98%			1.28%									
Total Count	2866	1325	1178	366	893	507	618	452	440	298	256	276	253	191

Source: Glänzel et al. (2003b), Tab 7

Figure 2-12: International co-assignations based on EP data (for application years 1992-2001), values given in Saltons' measure

	US	GB	BE	DE	CH	NL	FR	AT	JP	CA	DK	AU	IL	SE
US		3.90%	0.57%	0.95%	0.97%		0.92%		0.94%	1.29%	0.79%	0.64%	1.44%	
GB	3.90%					5.36%	0.53%					0.85%		0.49%
BE	0.57%			0.62%		0.90%								
DE	0.95%		0.62%		2.22%		0.74%	2.34%					0.55%	
CH	0.97%			2.22%				14.95%						
NL		5.36%	0.90%											
FR	0.92%			0.74%										
AT				2.34%	14.95%									
JP	0.94%													
CA	1.29%													
DK	0.79%													
AU	0.64%	0.85%												
IL	1.44%			0.55%										
SE		0.49%												
Total Count	914	521	74	287	253	191	160	177	107	99	62	62	62	48

Source: Adapted from Glänzel et al. (2003), Tab 9

2.3.3.3.2 Co-patenting as a tool to track international knowledge transfers

There are also studies that try to relate various forms of co-patenting to certain types of transnational knowledge transfer. Hullmann's (2001) study is a good example. The author relates different patenting rates to another. The patent rate is here defined as the number of nanotechnology patents per 1,000 FTE researchers of a country. This is then related to different co-patenting rates. Hullmann distinguishes between four types:

- Domestic inventor/foreign applicant;
- Domestic applicant/foreign inventor;
- International inventor teams;
- International applicant teams that have joint ownership of the patent.

Most of these analyses are presented in graphical format. Hullmann found considerable differences between the various co-patent rates. For instance, small countries, such as Switzerland and Belgium, have a high level of co-patenting when this is defined as a combination of domestic inventors and foreign applicant. One in two domestic patents includes a foreign applicant. Russia follows a similar pattern. When international co-patenting is defined as a combination of domestic applicant and foreign inventor and set in relation to the country's respective normalized patent rate, Hullmann observes a statistically significant correlation between the two measures and suggests that "more so than in the reverse case [of domestic inventor and foreign applicant] the application of an overseas invented patent has a positive effect on the application figures, thus the assumed knowledge transfer to the country has positive effects on the technological performance of the given country" (Hullmann 2001: 202). Again one must bear in mind the considerable limitations associated with cross-border ownership of patents that were discussed earlier.

In addition Hullmann relates countries' overall patent rates to their co-publication rate. The latter is defined as the number of international co-publications divided by number of all publications of a given country. In her study, Hullmann found only weak, not significant correlation between the two measures.

2.3.3.4 Other Co-Patenting Studies

There is a range of other studies that use co-patenting but not primarily to trace transnational knowledge flows. Co-patenting is either used to understand aspects of collaboration and clustering at regional level or to explore exchange and collaborative processes between academic science and industry. Even though these are not the core subject of this review, exemplary studies for both fields will be briefly mentioned.

2.3.3.4.1 Econometric studies of innovative activities in the context of regional innovation systems

Econometric analyses increasingly draw on co-patent data to analyse research and development collaboration in a regional context. Two studies are used here as an illustration for this type of work.

Cantner and Graf (2004) draw on co-patenting data to explore cooperation and specialization in German technology regions. The authors use co-patenting as one of the proxies for research collaborations and find that technologically moderately specialized regions show the highest number of research co-operations, and the higher a regions specialization, the more co-operations take place with partners inside that region.

Maggioni et al. (2007) use co-patent data as one aspect in their exploration of the importance of traditional 'geographical' spill-overs vis-à-vis 'relational' spillovers. Combining participation in the same research networks (within the EU Fifth Framework Programme) and EPO co-patent applications, the authors examine the factors that underlie patenting activity. They make a distinction between structural features, geographical and relational spill-overs to test whether hierarchical relationships based on a-spatial networks between geographically distant excellence centres prevail over diffusive patterns based on spatial contiguity.

2.3.3.4.2 Studies exploring university patenting with industrial partners

Increasingly links between industry and public sector research are explored. For instance, Van Looy et al. (2003) studied the co-patenting activity of knowledge generating institutes. Co-patenting between universities and public research institutes on the one hand and industrial companies on the other is becoming a more common topic as public sector research organisations are increasingly aware of the need to manage their IP actively. In some countries this is more pronounced than in others and also institutional practices vary greatly (see e.g. Lissoni et al. 2008; Meyer et al. 2008). Legal frameworks for university patenting can also have an impact on co-patenting.

If co-patenting is understood as a combination of different organisations owning and through its members having contributed to the inventions, then one must include studies of university/invented but not owned patents. Considerable work on this has been carried out on this topic (e.g. Lissoni et al. 2008; Meyer 2003) suggesting that cross-sectoral (university-industry) knowledge flows are far more frequent than assumed previously.

2.3.3.5 Other Studies Tracking Transnational Knowledge Flows

Comparing a range of approaches to trace knowledge exchange networks, Klitkou et al. (2007) raise concerns about using a single approach, such as co-patenting, as the only tool to understand knowledge flows at the science-technology interface. They argue that only applying a range of indicators allows the analyst to form a proper view of exchange processes. Transnational knowledge flows have been explored through other ways than co-patenting. Already in the 1970s and 1980s studies were carried out on the foreign dependence of countries' technology bases (e.g. Carpenter/Narin 1983) which explored the extent to which patents of a given country cite patents originating in other countries. While one might remain sceptical about the nature of the 'knowledge flow' that is captured by a patent citation, a larger number of links can be traced. This literature and the related works on knowledge spill-overs (see e.g. Branstetter 2001; Hanel 1994; Hu/Jaffe 2001; Singh 2004) is considerably more established than work on co-patenting.

Another possibility to explore transnational knowledge flows is now beginning to be explored on the basis of cross-national science-technology links. Glänzel et al. (2008) presented a bibliometric and patent study on the emergence of China that also looked at patent references and citations of scientific papers at the country level. Table 2-4 presents an overview and points to the substantially increased role of China as an apparent absorber of scientific knowledge. As with co-patent data, also here one needs to be aware that size effects and time lags.[25]

Table 2-4: The fifteen leading countries according to science-technology links based on patent citations based on the SCIE and DII databases (q_{MOCR} denotes the ratio of the mean citation of papers cited by patents to that of all papers)

Rank	Patent references				Patent citations					
	1991		2001		1991			2001		
	Ctry	Share	Ctry	Share	Ctry	Share	q_{MOCR}	Ctry	Share	q_{MOCR}
1	USA	30.6%	USA	26.3%	USA	53.3%	3.17	USA	46.0%	3.63
2	DEU	9.3%	DEU	9.2%	JPN	10.2%	2.72	JPN	12.0%	4.30
3	JPN	7.6%	CHN	7.9%	GBR	8.3%	3.66	DEU	10.0%	4.05
4	FRA	7.1%	FRA	6.8%	DEU	6.8%	3.35	GBR	9.1%	4.08
5	GBR	6.5%	JPN	6.8%	FRA	5.2%	3.50	FRA	5.8%	4.92

25 Time lags can be even more considerable as the measures are patent citation-based (time lag due to patent process causes publication delay plus subsequent uptake).

Rank	Patent references				Patent citations					
	1991		2001		1991			2001		
	Ctry	Share	Ctry	Share	Ctry	Share	q_{MOCR}	Ctry	Share	q_{MOCR}
6	CAN	3.6%	GBR	6.3%	CAN	4.6%	3.25	CAN	4.3%	3.98
7	ITA	3.2%	RUS	6.1%	ITA	2.4%	3.26	ITA	3.4%	3.17
8	IND	2.2%	IND	3.8%	NLD	2.3%	2.92	CHE	2.8%	3.18
9	CHE	1.8%	ITA	3.8%	CHE	2.1%	2.95	NLD	2.7%	3.18
10	NLD	1.7%	KOR	3.4%	SWE	2.0%	2.84	SWE	2.7%	3.33
11	POL	1.6%	CAN	3.4%	AUS	1.8%	3.23	AUS	2.4%	5.09
12	ESP	1.4%	ESP	3.2%	BEL	1.2%	3.09	ESP	2.0%	7.21
13	RUS	1.4%	NLD	2.4%	ISR	1.1%	3.62	KOR	2.0%	2.58
14	BLG	1.1%	CHE	2.1%	ESP	0.9%	3.09	CHN	2.0%	8.02
15	CHN	1.0%	POL	1.9%	DNK	0.9%	2.85	BEL	1.6%	4.10

Source: Glänzel et al. (2008)

2.3.4 Concluding Remarks

The analysis of co-patent data can help improve our understanding of transnational knowledge flows, especially when used in combination with other data that can support the interpretation of co-patent statistics.

Co-patent data allows us to distinguish relatively 'open' economies with foreign R&D labs in the country and larger shares of 'foreign-owned' inventions from others with more 'closed' approach. However, one must bear in mind the overall specialization of countries on certain sectors and technology areas when interpreting co-patent data. Patenting intensity varies from sector to sector and technology to technology. International co-patenting is driven by multinational corporations that vary considerably in their own internal practices. It is important to recognize that co-patenting can encompass collaboration between a domestic and a foreign company but also does include technological developments within internationally active corporations that are, for instance, driven by an R&D team with members located across a number of countries.

It is also difficult to make judgments about the directions of knowledge flows on the basis of co-patents. Research labs of foreign companies are a case in point. It would be overly simplistic to say they merely absorb knowledge from their host countries. It might be more realistic to assume they engage in a process that involves some exchange between domestic and international researchers and engineers. As patent documents allow the analysts only to make judgments about the residence, not about the nationality of inventors it would be misleading to draw on co-patent data to make strong claims about 'brain-drain' from one country or region to another. To explore these issues, one would really need to examine human resource statistics drawn from R&D personnel registries which are either not available or difficult for the analyst to access in most member states.

The relatively small body of work focusing on co-patenting data at the country level suggests that

1. co-patenting is still dominated by multinational companies,
2. 'cross-border ownership' of inventions is still increasing even though rather varied from country to country,
3. 'domestic ownership of foreign inventions' is particularly high in small open economies,
4. cultural and geographical proximity are important for international collaboration in patenting,
5. small and less developed countries appear more engaged in developing co-inventive activity than large industrialised countries,
6. countries appear to cooperate relatively more in technology areas in which they are less specialized
7. there is considerably less international co-patenting at the country-level in less research-intensive technologies (e.g. construction and consumer goods in relation to chemistry).

Co-patenting analysis should be an element in an analyst's tool box to better understand transnational knowledge flows but it is only an imperfect measure. This is why co-patenting plays a supplemental, complementary role in analysing transnational collaborative R&D activities alongside a range of other indicators.

Utilizing co-patent data in conjunction with other data should help getting the most benefit from the analysis. Here, the literature review has also pointed to other patent-based indicators that might be useful in exploring countries' collaborative or knowledge exchange patterns further. Alternative approaches, such as patent citation analysis might be an option to further explore transnational knowledge flows.

Also these measures are not unproblematic but analysing several measures concurrently would allow for a more reflective interpretation of data. For instance, co-patent data suggests a very rapidly growing role for China. Data on patent citations and references appear to underline the growing role of the country as a knowledge absorber but are not indicative of China as a highly cited source of references in patents. While time lags will play a role here, this observation raises a number of issues, such as the perceived quality of patents, that are worthwhile exploring further and also help qualify the observations from the co-patenting data.

3 Feasibility Study

3.1 Introduction

A feasibility study usually addresses questions like "What is possible?", "What is not possible?", or even "What should be possible?". However, the following discussion also addresses questions of cost-benefit-ratios and what is worthwhile to be pursued and what is less worth to be done. Furthermore we will touch on questions of interpretability, reliability, or validity. All this is done in a more general manner trying to provide general statements that hold for both, patents and publications. The focus of this project is, however, on the applicability of co-patents and co-publications as indicators for knowledge flows and collaborations especially in the context of the European Research Area (ERA). Therefore, this chapter also provides a list of indicators that should be constructed for monitoring trans-national S&T collaboration based on co-publishing and co-patenting. The aim is to develop a set of indicators that can be regularly updated. Thus, data gathering and indicator construction procedures should be relatively easy and require limited efforts.

This report concentrates on S&T collaboration with the main aim being to develop a set of indicators and a methodology for measuring various aspects of S&T collaboration and their impact on S&T performance which can be used to regularly monitor developments concerning the evolving degree of integration of ERA. S&T collaboration in this project is specifically reflected by co-authorships (co-publishing) and co-patenting – knowing that these indicators cannot cover all aspects and all types of S&T collaboration (Schmoch/Schubert 2008). The literature survey provided a list of pros and cons as well as caveats and limits of this approach. For example, Katz and Martin (1997) or Laudel (2002) discuss the limits and opportunities of those indicators. Nevertheless, the methodology has been successfully applied for measuring structures of international collaboration in a number of studies (BMBF 2006; Edler et al. 2007; Glänzel/Schubert 2004).

This discussion of the feasibility has to be seen against the background of the literature review and the lessons learnt from it in the previous chapters where the state-of-the-art of the indicators used and the methodologies applied to measure and reflect trans-national collaborations using co-publication and co-patent data has been laid out. In this respect, the feasibility discussion tries to suggest an appropriate methodology and a limited set of bibliometric and patent indicators, which can be used to monitor the evolving degree of integration of the European S&T system into ERA.

This feasibility study focuses on co-publications and co-patents. It tries to offer a feasible framework for a regular monitoring based on these indicators and it discusses limits and caveats of different perspective.

3.2 Patent offices and the availability, topicality and comparability of patent data

A patent application has to satisfy at least three criteria: novelty, inventive step and industrial applicability. The criterion of novelty implies not only novelty for a national system or for the applicant, but novelty on a world-wide scale. Furthermore, any publication – for example in a scientific paper or contribution to a conference – or any implementation of the invention in any product or process is considered prior art and inhibits patent protection. The second criterion – the inventive step[26] – means that an inventive act had to take place, which is defined by the fact that the new idea is not obvious to a person skilled in the art.[27] The third requirement of industrial applicability is generally fulfilled because of the considerable costs of patent applications which are only spent with a realistic market perspective.

Starting from a simple legal perspective, patents give, for a limited period, an exclusive right of usage to the applicant for securing a quasi monopolistic revenue. From the perspective of analysing innovation systems, patents can be interpreted as an indicator of the codified knowledge of enterprises, and in a wider perspective of countries. The focus of the statistical patent analysis is directed towards technological innovations, especially visible in the manufacturing sector.[28] In consequence, patents only give an indication of these patentable and patented research results. They are not capable of the totality of possible innovation outputs, for example as they are defined by the OECD (2005). However, it can be plausibly assumed that any patent application is preceded by mostly large investment in the research and development process (Grupp 1998: 145-147; Kash/Kingston 2001). From this point of view, patents can be seen as a success or output indicator of research and development (R&D) processes (Freeman 1982: 8). On the other hand, most – but not all – technological inventions will flow into a product or process that will then be offered on national or international markets. Thus,

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26 In US patent law, the corresponding requirement is called "non-obviousness".

27 See Art. 56 of the European Patent Convention (EPC):http://www.european-patent-office.org/legal/epc/e/ar56.html#A56.

28 As to the appropriateness of patents as a technology indicator, see Schmoch and Hinze (2004) and the references cited there.

patents can also be interpreted as an input indicator (or throughput indicators) with regard to future market activities of enterprises, sectors or countries and therefore act as an early sign for future competitiveness.

Patents belong to the most important innovation indicators and are a reliable source to measure R&D performance especially in the industry sector. Though patents are only capable of technological innovations – and even here they cover only a fraction of all innovative activities – they can be interpreted, on the one hand, as an output indicator of R&D processes. On the other hand, patents also point to the future by the promise of implementing the technologies and opening new markets or gaining new market shares with new products. Especially in high-technology areas, patents can help to measure present and future competitiveness of companies, sectors, or economies (Frietsch/ Schmoch 2006; Schmoch 2004b).

However, the frequent use and the availability of patent data may give the impression that it is a simple and straightforward to use indicator. The opposite is the truth. As an innovation indicator, patents are rather complex as they do not only demand deep knowledge of the data sources, their reliability and validity, or their interpretability. But a mandatory prerequisite is also a deep knowledge of the central legal framework conditions, the application processes, different patent systems at different patent offices, incentives and disincentives as well as strategic aspects of patent filings and finally some idea about the decision processes in companies or research institutions, which apply for patents or decide not to do so. Furthermore, some knowledge on technologies and their representation in patent documents is a profitable asset for any differentiated patent analysis.

The most frequent and most misleading assumption by unfamiliar users is that there is one (and only one) patent application per invention, implicitly assuming that any invention is only filed once and any patent is the same as the other and any patent can be compared or summed up with any other patent. This is by far not the case. Patent offices administer patent applications, they examine the claims and they grant a temporary monopoly for the exclusive use of patents. But any patent office can only do this in the territory of its responsibility. If a patent protection is reached in Germany and France, for example, the technology can still be used freely in the UK, in Spain, in Italy etc. Therefore, more than one patent office is approached by an applicant if a broad coverage is intended. As a consequence, the first question in any patent analysis should be: which patents are to be analysed? And the answer to this question is highly dependent on the scope or the range of the intended analysis.

But for the interpretation of the result of the statistical analysis, the analyst should be aware of a caveat that is directly related to the selection of a certain patent office, namely the possible home advantage or home bias. The probability that a national applicant files a patent at his/her home office is usually higher than for any applicant from any other country. This means, for example, US applicants have a home advantage at the USPTO (United States Patent and Trademark Office), Japanese applicants have a strong home advantage at the JPO (Japanese Patent Office) and German applicants show a strong home bias towards the DPMA (German Patent and Trademark Office). Applicants from smaller countries with no large home market often directly file in a larger neighbour country or at international patent authorities. For example, traditionally, Swiss applicants show a strong focus on the German market – and thereby on the German Patent Office – Belgian applicants direct their activities towards France and also Germany, or Canadian applicants file more patents in the US than in Canada. However, in their individual home countries or home offices, respectively, they still have a strong home advantage. Using German patent filings to generally compare the German strengths and weaknesses of the German technological competitiveness with their counterparts from other countries is not advisable. If the interest is exclusively lying on the German market, this might be a good approach. A measurement of German and international applicants on the same scale or the same standard is not possible with this approach.

As a matter of fact, applicants file most of their patents at the national patent office of their resident country. Multinationals (MNEs) usually file more frequently in the country where their headquarter is located or where the research laboratory is resident, from which the invention is originated. With these first filings a priority is claimed, meaning that this is the first codified documentation of the invention. This is important for any subsequent patent application at any other office and – especially under the first to invent system – it is important to document by whom and when the invention was made. Any patent application has to fulfil the criteria of worldwide novelty, which means that the object of the patent must not be used, filed or published anywhere else in the world at any time before the first filing. Unfortunately, this also holds for patent filings by the same applicant with the same objective that are to be filed at any other office subsequently. Here the Paris Convention – signed in 1883 – puts remedy as it allows the application of a patent at any additional office within a one year period after the priority date – the date of worldwide first filing – and with reference to this first filing, which is called priority. This also means that after this first year an application of a certain invention at any patent office worldwide is not possible any more – never again!

Claiming priority at a national office first has several advantages for the applicant and is therefore still very frequently used. First of all, there is a language advantage as the filings are usually made in the mother tongue. Secondly, the distance – physically and of communication – to the patent office and also to and for the lawyers is shorter. And finally and foremost, a quick first processing of the patent application can be reached, which is important to get a priority date as early as possible, especially if competitors are about to work on similar projects. And this national filing is less costly than a direct international activity and leaves some more time to the applicant to decide on the next steps.

However, within the priority year – and given the expectation of international relevance of the object – further international patent applications might be pursued by the applicant. These applications together with the priority filing form a patent family, which is defined as the community of all patent filings claiming the same priority.[29] For example, a German priority patent might be subsequently also filed at the EPO, at the USPTO, and at the JPO. The EPO application may result in three additional national patents in European countries, e.g. the UK, France and Italy. All filings together form the patent family, which will consist of – sooner or later – four applications and – given that it is granted at all offices – six grants, namely Germany, the US, Japan, UK, France and Italy. How these patents are processed and how these procedures are organised will be described now.

Given that the decision for international patent applications is made by the applicant, several ways may lead to the same goal. The most straightforward way for an international application is a direct filing at another patent office, with all restrictions and procedural idiosyncrasies of that office that have to be taken into account. For example, the official language might be different, another lawyer has to be hired, who is an expert in that national patent law, and the fees have to be paid for this application process. If more than one international market is targeted, this application strategy might be very expensive and costly. Fortunately, more simple ways of applying for international patents are at hand. One of them is a patent application to the EPO. The EPO is a transnational filing and granting authority. It came into being in 1978 after the European Patent Convention was signed. At the moment (early 2009) 32 countries are member states of the European Patent Organisation that is based on the European Patent Convention and another 5 countries are associated.[30] The EPO is not an institution of the European Union and some of the member countries do not even belong to the EU, for

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29 Effectively, this is only the simple and short version of a patent family. Different international procedures make the reality a little bit more complicated as filings might claim more than one priority. For a description of patent families see Dernis and Kahn (2004); Hingley and Park (2003); Nanu (2003).

30 For a list of member countries see http://www.epo.org/about-us/epo/member-states.html.

example Switzerland. An application to EPO has many advantages compared to a large number of individual national applications. First of all, the EPO has three official languages and the application can be made in any of them: English, French or German. If you seek protection in more than one country, there will still be only one examination and one granting decision. However, at the end of the process there are still national patent documents, so that in case of entering the national phase, translations are necessary and the annual fees have to be paid in each individual country. Therefore, usually not all 32 countries are selected at the same time for the final realisation of patent protection. A decision is made based on the market interests. To sum up, the EPO accepts patent applications on behalf of 32 countries, it examines the patents and it grants them, but at the end of the process there are still a number of national patent documents.

Another simple way for an international patent is an application to the WIPO[31] via the PCT procedure. Different to the EPO, the WIPO is only an application or receiving office. The WIPO does not examine and it does not grant. Effectively, the patent filings don't even have to be filed in Geneva – where the headquarter of WIPO is located – but it can be filed in of the receiving offices, which have a prescind role among the 139 Contracting States of the PCT.32 The advantage here is that a patent procedure can be started in many countries, without the direct need of translation. At the beginning, the filing process can be pursued in the mother tongue, if the national office is the receiving or administering office. Furthermore, by a preliminary search report, which is of no legal use, a first indication of success can be reached. And in addition to that, a preliminary search report may postpone the entering into the regional – for example at the EPO – or national – for example at the USPTO – phase up to 30 month after priority date. Many companies use this procedure to postpone the decision if they should enter the regional/national phase or not to a point in time where they have more information about the success of the application and especially about the market potential of the object. By this, of course, they also postpone the decision if the investment in further pursuing the application process is worthwhile or not, as national or regional patent

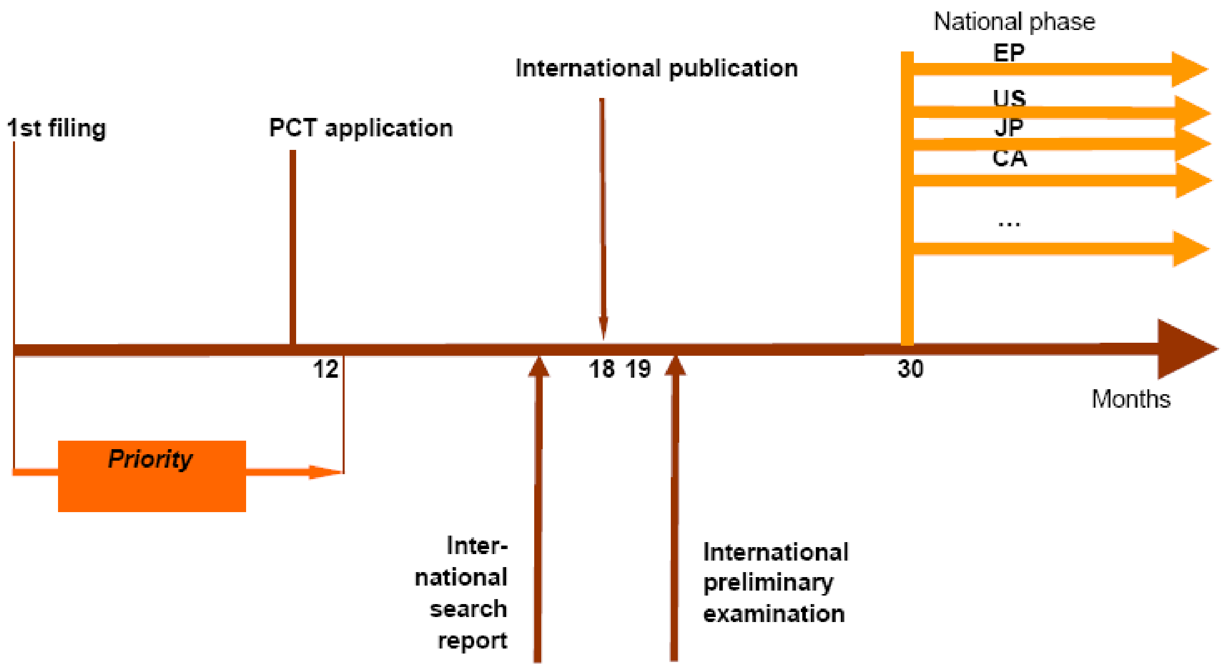
31 The WIPO also started working 1978, but it was not until the first half of the 1990s when the applicants discovered this procedure broadly and started to use it much for frequently. This adaptation and shift towards this procedure lasted the whole decade so that the absolute growth rates of the PCT filings in the 1990s do not only reflect technological developments, but also a change in the behaviour of the applicants. For time trend analyses and assessments of the competitiveness of individual countries and economies, the data is not recommended.

32 For a list of countries see http://www.wipo.int/treaties/en/ShowResults.jsp?lang=en&treaty_id=6.

procedures all recommend massive investments in fees, translation costs and costs of lawyers.

Figure 3-1 depicts the usual and standardised time line of applying for a PCT patent. The timeliness of an "ideal" procedure is as follows. At the beginning there is a national first filing – a national priority. Within one year – the priority year – a subsequent filing of this patent is made via the PCT procedure. At this stage it is – in principle – possible to name all member countries of the PCT as designated countries. The number of countries named does not have any impact on the pricing or the application fees. It is important to note that the PCT application will be published 18 months after priority date – which means the same time like the national priority itself – and is then also accessible and usable for patent statistics. By asking for a preliminary search report, which gives a first indication of success or failure of the application process, entering the national or regional phase can be postponed up to 30 month after priority date. At this point the applicant has to decide at which offices the application shall really enter the national/regional phase and thereby decides on the number of subsequent examination and granting procedures, which are – from then on – individual applications and may individually fail or succeed and each has to be paid individually. And at the very end of each process there will be a number of national granted patents. In the context of this study it is important to note that a PCT filing might enter the national/regional phase both at the EPO and the USPTO (United States Patent and Trademark Office), but with an additional delay of 12 months after publication date. The cohorts of total patent applications per priority year are considerably affected by this fact.

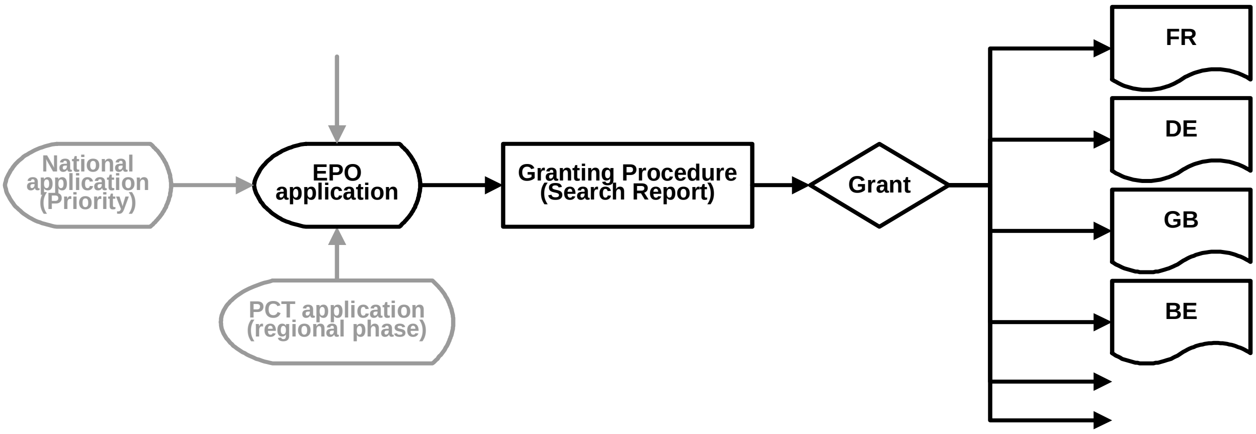
Figure 3-1: Timeliness of PCT filings



Source: Felix (2007: 2).

As can be seen in Figure 3-2, there are three paths to apply for EPO patents: 1) a national priority subsequently filed at the EPO under the Paris Convention, 2) a direct first filing to the EPO, which is possible since 1994, and 3) a PCT filing – of course originating in a national priority – that enters the regional phase at the EPO. And this is a rather frequently used path as about 60% of all EPO applications are filed this way. And the reason why PCTs with designation to more than one European country are filed in this way is the common examination and granting procedure at the EPO compared to using the PCT route to enter the designated European countries directly (Felix 2006). The procedures at the USPTO are rather similar to the procedures at the EPO in this respect. Three possible paths for an application exist: 1) a priority at another office that is subsequently filed at the USPTO under the Paris Convention, 2) a first filing to the USPTO (a priority itself), and 3) a PCT filing that subsequently enters the national phase at the USPTO.

Figure 3-2: Process of an EPO filing

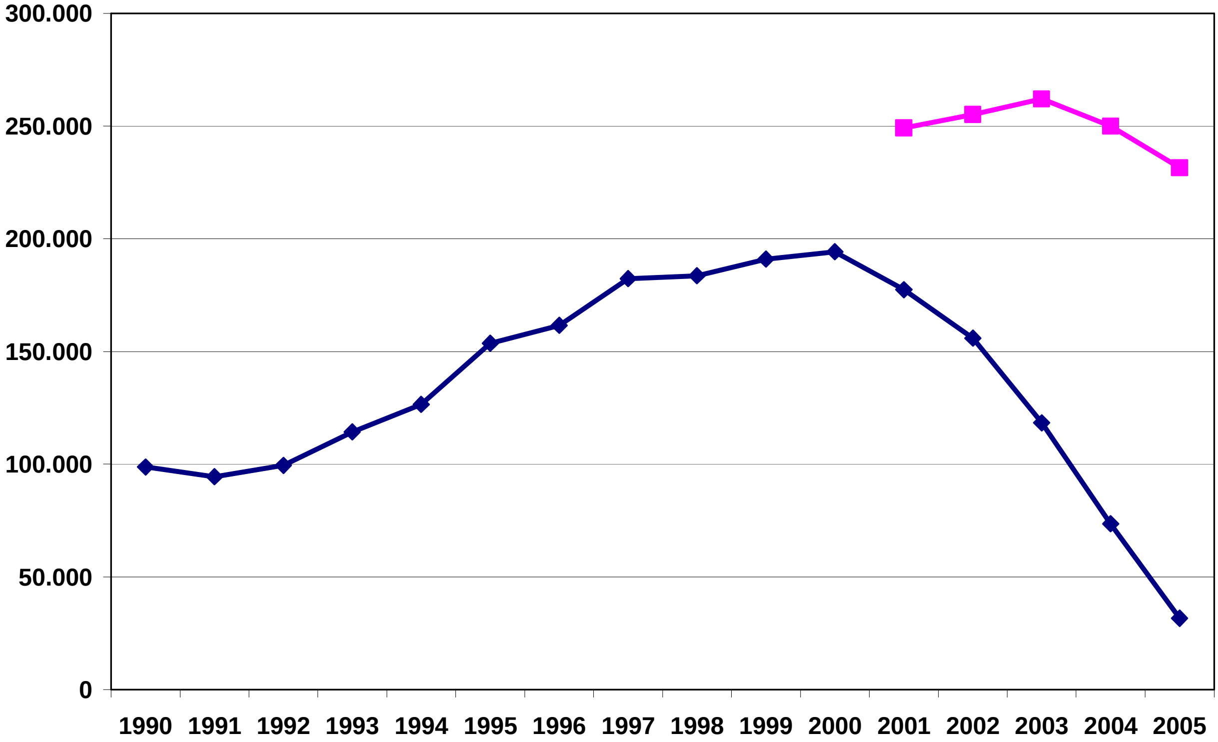


Source: Frietsch and Schmoch (forthcoming)

The United States Patent and Trademark Office (USPTO) still covers the most important national market for technologies in the world, namely the US market. However, it is still a national market. Some countries, especially the upcoming and emerging countries like South Korea or India, have a special focus on the US market and hardly file every patent on a worldwide scale. In consequence, the home bias of US applicants/inventors is considerable and the imbalance of European, North-American and emerging countries cannot be neglected.

Different to the EPO – for example – the USPTO only published granted patents instead of applications until the publication year 2001. Since then, they publish both, applications after 18 months and grants immediately after the granting procedure is finished (which might take up to 7 years and more after priority). Though, pure national filings are still exempted from the pre-grant publication demand so that some applications are still unpublished until the granting of the invention. In this transition phase from grant- to pre-grant-publication it might not be meaningful to analyse longer time series at the USPTO, though it seems that the transition to the new system as such has been successfully finished already in the mid of the first decade of the new century (Schmoch 2008; Schmoch forthcoming). As a matter of fact the analysis of longer time series has to be restricted to granted patents only. Figure 3-3 shows the absolute number of total granted patents and total number of applications at the USPTO by priority year. It can be seen that the cohorts of the years after 2000 are still incomplete. Furthermore, the application cohorts are incomplete for the years 2004 and 2005 – for similar reasons as in the case of the EPO.

Figure 3-3: Grants and applications to the USPTO



Source: PATSTAT; Fraunhofer ISI calculations

Applications versus granted patent documents

This study uses patent applications rather than granted patents, as applications are published earlier than grants and reflect technological competitiveness in a more appropriate way. As a matter of fact, only records of published patent filings are covered. This means that not all applications – for example to the EPO – are accessible, but only those which were published. In other words, only applications that are maintained until the publication of 18 months after priority filing are stored. Applications that are withdrawn or rejected – for whatever reason – are not covered by publicly available databases. The share of withdrawn or rejected patent filings may amount to nearly 50% of the published filings at the EPO, for example.

The data source for patents – PATSTAT

The EPO Worldwide Patent Statistical Database – called PATSTAT – is the most important data source for scientific research on patent activities and patent data. The database covers patent information from more than 70 offices all around the world, among them the most important offices like the EPO, USPTO, Japanese Patent Office (JPO), the Korean Intellectual Property Office (KIPO), or the State Intellectual Property

Office (SIPO) of the People's Republic of China. Also WIPO applications under the PCT procedure are covered. The patent data – also of the PATSTAT database as well as of any other publicly available patent database – is not collected for the sake of statistical analyses, but as a direct demand by the processing of the patent applications and the documentation of the filings and grants. As a direct consequence, only such information are collected and stored, which are relevant to these processes. For example, information on the sector of the applicant or the gender of the inventors are irrelevant for the patenting process. Fortunately, the data quality is very high and the coverage of the data is very broad as it does not only contain a sample, but the information on all patent applications (and grants) at most offices are available.

However, it was already mentioned that the same invention might be filed at different offices, as each individual office is only capable of granting a patent right in their territory. Comparing applications of the same invention at different offices reveals that there are still some considerable differences in reliability and validity of the data. Not all information have the same relevance to all offices so that different emphasis is laid on the correctness of these information. For example, the USPTO is an inventor-oriented system, while the EPO is an applicant-oriented system. In the case of the EPO, both information are collected carefully and are a reliable source of information. The USPTO data is less complete and also less reliable. For the newly introduced pre-grant publications of patents – this is what we call the publication of the application – the information on the applicant, so the owner of the patent, is not mandatory. Many applicants leave this field empty in their application form as they try to avoid providing too much information to their competitors. In consequence, part of the data is missing and also not available for data analyses. In the case of SIPO or JPO, the information has to be translated from Chinese or Japanese, respectively, into English. Not all information is translated, not all information is translated correctly, and especially not all information is available in due time. Though the offices have made some considerable efforts and reached progress in automatic translation, it is still not the same as if the original application was made in English.

However, in general the data quality is still excellent. The database is – as already mentioned – not compiled for statistical but for processing reasons. Next to the provision of information to competitors and others, it is also used for the patent examiners as a source to do their prior art searches. It was mentioned above that each patent has to fulfil the novelty criterion. Novelty means worldwide novelty and also spreads across uses and applications of the technology and not only patent applications at other offices. Though, the examiners are experts in their fields and have a broad overview over their field as well as a deep knowledge of the prior art, they still have to rely on patent databases to conduct prior art searches. In the case of the EPO, this internal database which covers patent information from many sources and offices, an extraction of the examiners database is made twice a year and is made available for the scientific public. This extraction is the PATSTAT database.

Next to information on applicants and inventors – their names and addresses – additional information is available on the technical features (claims), the title, the classification and several dates like priority, application or publication dates are accessible.

What does all this mean for the analysis of co-patents in the context of ERA?

Patents do not reflect all inventions and also not all innovations that occur in research or innovation systems. Patents are restricted to technological innovations only. Patent documents are only valid in the scope of the authority/office where it is filed. In consequence, the same invention/innovation might be filed at several offices. Therefore, summing up patent documents across offices might result in multiple counts of the same invention/innovation. Furthermore, companies located in the country of the office will have a home advantage compared to non-national applicants/inventors. We use EPO patent filings for this study as the EPO is a transnational authority so that the home advantage is somehow balanced. Furthermore, we are interested in the European market that is – to some considerable extent – covered by the European Patent Office. However, European applicants/inventors still have a higher probability to file here than outside Europe. On the other side, when USPTO patent filings are taken into account, the home bias for US-residents and even for Canadian applicants/inventors is much larger than for Europeans. Next to the totals, this bias also affects co-patents of European and North-American applicants/inventors, so that the structures might be different when USPTO and EPO co-patents are compared.

The timeliness of the application processes and the timeliness of the publication of the patents have a direct impact on the topicality of the data to be analysed. Mid 2008 (date of data extraction for this report), EPO filings are completely published only for the priority years up to 2006 (publication phase of 18 months). However, due to the fact that more than 60% enter the EPO via the PCT route and the fact that entering the regional phase at the EPO might be postponed up to 30 months, the last two priority years (2005 and 2006) are still incomplete. This is why the analysis is restricted to the priority years before 2005. USPTO data is not analysed due to the missing topicality of the grants and the strong home bias, which has an unfavourable impact on the European applicants/inventors. The pre-grant publications of the application are not yet ready for long-term analyses and the system is still shifting.

For future analyses it should be considered to analyse alternative data sets. The triadic patent approach could be one, but the fact that more and more international patent applications are filed via the PCT-route also reduces the topicality of the available information. Frietsch and Schmoch (2007; forthcoming) recently suggested an approach of Transnational Patents that integrates EPO and PCT applications and that provides an analytical framework for structural analyses of the most important innovation oriented nations with a high topicality of 18 month after priority date. This latter approach already proved its feasibility and reliability in several studies (Frietsch et al. 2008; Frietsch, Schmoch 2007; Patel, Frietsch 2007) and could also be an approach for measuring co-patents in the context of the ERA.

Patents are one – among others – output of (mainly private) R&D. They are reliable and valid as they have to fulfill high standards, which are examined by patent offices. However, as an innovation indicator, patents are rather complex. One of the dimensions of this complexity is the fact that there might be applications of the same technology/invention at different offices, leading to different patents (documents). Therefore, for the analysis is has to be decided which office's documents are to be analysed. Due to international filings procedures and as a matter of fact, the restriction to EPO applications – as it was requested in this project by DG-RTD – is not appropriate for a permanent and topical monitoring system of collaborations. Instead, the use of patent families are recommended, where the so called Transnational Patents (EPO or PCT applications) have been suggested as the most appropriate one. USPTO data is not recommended for several reasons: 1) it covers a pure national office, where US-inventors and –applicants have a home advantage; 2) time series are not long enough as until 2001 only grants and not applications have been published.

3.3 Publication data – SCI versus SCOPUS

For the analysis of scientific publications in this report the Science Citation Index (SCI), an internationally, multidisciplinary database, was used. The SCI is widely acknowledged and accepted for evaluating research institutions and analyzing research performance of regions or countries. The SCI covers about 6,000 of the most significant and relevant scientific journals from a wide range of scientific and technological fields. However, the SCI has certain limits and restrictions, which are worth to be kept in mind for the analysis. First of all, even coverage of about 6,000 journals does not reflect the totality of papers published worldwide. In addition, the main focus is on reviewed journals and (selected) conference proceedings – with some additional, but minor document types like letters, notes and reviews also included. Furthermore, neither so called "grey literature", nor monographs or edited books are contained. Secondly, the SCI covers sciences and engineering, whereas social sciences or arts and humanities are covered by the Social Science Citation Index (SSCI), which is not taken into account here. The reason is that these latter fields are very nationally oriented so that international comparisons are almost meaningless. Concerning the SCI it still has to be acknowledged that sciences (especially life sciences) reach a higher representation rate than engineering journals (Schmoch 2004a) – and engineering is the scientific and technological strength of many European research and innovation systems. Thirdly, the SCI is biased in favour of English-speaking countries, especially with respect to the USA. Though, other countries are catching-up, especially China, so that the US-American share in all SCI-publications is decreasing steadily over time.

Scientific publications for the period 1990-2006 were retrieved. A special focus is on the period 2000-2006. Only the so called citable items namely articles, general reviews, notes and letters were included in the analysis. The data used for this study was retrieved online via the host STN. Similar to other online-retrieval accesses – for example like the "Web of Knowledge" – this kind of data access has certain advantages and disadvantages. The advantages are flexibility, topicality and – in the case of STN – professional and uncomplicated handling. However, the limits are to be seen in the analytical possibilities as well as in the high costs of certain analyses. For example, fractional counting of authors or classes is impossible and citation analyses – next to the fact of high costs for the analysis of large datasets – are not possible at all, for example like expected citation rates (see for example Moed et al. 2004; van Raan 1988). Though, these kinds of analyses were not in the scope of this study, future studies might want to analyse not only quantity but also quality – measured by citations – of scientific publications. In this case an in-house or offline database is mandatory.

For a very long time the SCI held a monopoly for this kind of analyses of a large number of scientific areas. Since a few years Elsevier publisher provides an alternative database called SCOPUS, which has not yet reached the same dissemination for bibliometric analyses like the SCI, but which is able to overcome some of the disadvantages of the SCI – though by the cost of some additional disadvantages. SCOPUS claims to cover about 16,000 reviewed journals. It has a broader coverage of engineering publications and it also has a broader coverage of non-US authors and journals, especially from Europe. However, disadvantages are shorter time series (about 50% of the publications only date back to 1996), a less differentiated classification scheme and less clear indication of the quality of the underlying journals and the reason for their inclusion (or exclusion). However, future studies might want to compare results from the two data sets or maybe exclusively use the SCOPUS database.

Publications are an important output of the (especially public) science system. SCI data has been used for analysing this data. This is a reliable and well-established data source, though it has some limits: 1) bias towards English speaking countries; 2) bias towards sciences and less engineering. In this study only quantity played a role, while it is recommended for future studies also to take the quality of publications (measured by citations) into account. It was also discussed that SCOPUS is an alternative data source that might be used for this kind of analyses instead of or in addition to the SCI.

3.4 Size effects and the resulting limitations

Europe is a rather heterogeneous entity, not only in terms of language, wealth per capita, infrastructure, political systems or many more dimensions, but also in terms of research orientation – for example reflected in R&D expenditure, qualified employment etc. This of course also has an impact on the number of published papers and filed patents. In addition, we are focusing on SCI journals as well as European patent filings so that the orientation towards these markets/communities also affects the total number of publications or patents, respectively. In consequence, the number of patents or publications is rather low for some countries – first of all the smaller ones – and especially in some of the selected fields. As a result of these matters, the interpretability and stability of the data in some countries like Malta, Cyprus, Luxembourg and others is restricted. For example, Malta reaches a total number of 64 SCI-papers in the year 2006. 16 out of these 64 are single country publications, which means that 48 are internationally co-authored publications. Analysing this co-author structure by the other 26 European member countries individually is not really meaningful. The same holds for dividing these 48 publications by the 26 scientific fields of our analysis. A matrix of 26 co-author countries by 26 scientific fields is even more meaningless and would result in a large number of empty cells and another large number with only few observations. This latter approach is even problematic for countries with a larger number of co-publications per year. The problem with co-patents is even more pronounced as the number of EPO patent filings is much smaller than the number of scientific papers per year and country.

Summing up the years and analysing long periods over time to get a larger number in the sample to be analysed would be possible, but one would loose another important dimension – namely structural change over time. Especially the new member countries and the smaller countries have considerably caught up in the recent past and this change comes along with a structural change of their orientations towards certain fields as well as with a change in their collaboration pattern. Against the background of recent changes and the fact that the emergence and impact of the European Research Area is in the focus of this indicator study, such an approach is not recommended.

In the course of the project it was agreed that it is not appropriate to analyse each possible collaboration structure between individual member countries, but to analyse the collaborations of each individual member state with the remaining 26 members as a group. Two reasons influenced this decision. On the one hand, the low absolute numbers of co-patents and co-publications of most of the member states would have resulted in many empty cells in this 27x27 matrix. On the other hand, for the question of ERA activities and the networking, it is – in this very first step – not necessary to analyse with which other member countries the collaboration took place, but just to quantify the number of internal linkages.

Small and/or less research oriented Member Countries have low absolute numbers of patents/publications. Therefore it is not appropriate to differentiate the analysis in terms of partner-countries and/or scientific/technological fields too deeply. The use of aggregations – for example summing up data for several years – is not recommended as this would result in a loss of tracking structural change over time.

3.5 Classifying scientific fields and technological areas

The classification of patents and the aggregation to technological areas

To structure the data and to separate technological and scientific fields, it is mandatory to rely on a robust and reliable classification scheme. The large number of patents and publications to be analysed demands a sophisticated and well-grounded grouping of data. In general, the possibilities with the data source and especially the research questions to be addressed steer the classification schemes to be used. In the case of patents, the data already comes along with a very sophisticated, detailed and well-organised classification scheme. The International Patent Classification (IPC) distinguishes about 70,000 different classification symbols in it deepest disaggregation level. This holds for the so called "advanced version", while the so called "core version" differentiates about 20,000 symbols. The core version is intended to provide a scheme for small and medium-sized national patent offices to classify their patents, while the advanced level is intended to be used by large offices. The reason for the use of these two levels is a practical one: smaller offices have lower numbers of applications to administer and differentiating them too deeply is neither economical nor necessary.

The IPC has – in contrast to the vast majority of other classification schemes – a huge advantage, namely the fact that the assignment of the patents to the classes is done by patent examiners, who are experts in their fields. In consequence, the quality of the assignment in conjunction with the very deep differentiation scheme of the IPC provides a sound and reliable foundation for any analysis. Though, each individual patent is usually assigned more than one patent class as it might have links to and features of different technologies. Until the 7th version of the IPC, which was in use before 2006, one main class and several secondary classes have been assigned. Since the 8th version of the IPC this is not done any more. So until the 7th edition it was possible to come to unique assignments to one group of technologies by using the main class only. This is not possible any more so that the whole set of IPC-classes has to be taken into account.[33] In consequence, in the analyses conducted here double/multiple counts of patents are possible according to the number of different symbols.

It has to be kept in mind that a patent is a vested right of a technology – and not of a product. The number of 70,000 symbols – or even 20,000 symbols – are by far too much to be examined in structural analyses like the one undertaken here. And the biggest challenge indeed is to aggregate the IPC classes to technology fields that can be used for this kind of structural analyses. Next to the fact that it is mandatory to have a deep knowledge and understanding of the patent system and the motivations and way of thinking of the applicants, it is a mandatory prerequisite to have a sound knowledge on technologies to aggregate these classes. Instead of setting up a new aggregation scheme, we decided to make use of an existing and established one (Schmoch/Gauch 2004). In our case, this differentiates between 19 technological fields, which we aggregate to 6 technological areas that are analysed. The classification scheme can be found in Annex 5.

The category codes of the SCI and their aggregation to scientific fields

The Science Citation Index classifies all journals in the database in almost 200 so called Category Codes. Two things are important to be known and kept in mind for the analysis. On the one hand, the journals are classified and not the individual articles. This means that – for example – a paper on pharmaceuticals which is published in a chemistry journal might be classified as chemistry and not as pharmaceuticals. On the other hand – and this balances the first effect to some extent – the journals are assigned more than one Category Code. In consequence, also here double counts of

33 It would be possible to use the first instead on behalf of the main class, but in the PATSTAT database – which is a relational database – the information on the position of each individual IPC-class is not available for all documents/offices.

journals/articles may occur. Next to the fact that no unique assignment is possible, this also means that the sum of the individual classes is higher than the total number of publications. For structural analyses this is usually no problem, but for the calculation of indicators like shares or specialisation indices, the reference to the sum instead of the total needs to be made.

An alternative to the use of the existing Category Codes would be the use of keywords to define scientific fields. By the way, an approach that cannot exclude double/multiple counts, too. However, certain caveats exist and clear disadvantages of this strategy can be identified. The first question to be addressed is, if the keywords are searched in the titles – title of the article and/or title of the journal –, in the abstracts[34], in the journal keywords, or in any combination of them. A restriction to one of them might drop out a lot of relevant articles as the decisive keywords might not appear in the title, for example. A search in all available items might result in the inclusion of irrelevant articles/journals. Here a first problem of false positives and false negatives emerges. However, the biggest challenge of a keyword strategy is the clear, distinct and correct definition of the scientific fields. Next to a deep knowledge of each individual field, the keywords for each class must be checked and verified for false positives and false negatives. Using too general terms does not allow a strict distinction between fields and too special terms might drop out a lot of relevant documents. To sum up, a keyword strategy is very complex and hard work. It only makes sense for individual – maybe new and upcoming – scientific fields, but not for a structural analysis like it is undertaken in this study.

The classification scheme used for the analyses in this report can be found in Annex 5. As discussed, it makes use of the Category Codes provided by the database provider and it differentiates between 26 disciplines, while a further aggregation is possible, but not used here. Double/multiple assignments are possible.

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34 Abstracts are not available in the SCI databases before the publication year 1991.

Patents are classified according to a very detailed and sophisticated classification scheme (IPC). The reliability of and validity of this classification is very high as the assignment is usually done by patent examiners, who are experts in their fields. However, this classification is not very handy for statistical analyses. Therefore, for practical reasons and the reason of comparability, it is recommended to rely any regular monitoring on existing and established aggregations of the IPC.

The SCI uses Category Codes to classify journals and not individual articles within the journals. Each journal is assigned multiple Category Codes so that no unique assignment and classification is the consequence. A keyword definition of scientific fields is not recommended and would be a study in its own to properly define these classes.

3.6 Full counts versus fractional counts and intensive versus extensive definition of intra-EU publications

3.6.1 Full counts versus fractional counts

In the previous sections it was already mentioned that double or multiple counts can occur. This – first of all – happens in the context of the classification schemes as unique assignments to classes are not possible, both for patents as well as for scientific papers. At the same time, double counts might also occur in the light of multiple authors/inventors from different countries. This is of special interest against the background of the research question addressed in this project, namely the measurement of international collaborations by co-patents and co-publications.

In the case of single authored articles or single invented patents no problem occurs. The same holds if only one nationality of the authors/inventors is given. The patent or article is counted for one country only. For example, three researchers from France, Belgium and the USA collaborated in a research project and have published a joint paper. How to count this document? The first option would be to count it for the first author only. Next to technicalities of the databases, which might not allow a realisation of this approach, it first of all ignores the contribution of the other countries. In addition, international collaborations are in the scope of this project, so ignoring international co-patents or co-publications would pervert this question. The second option is to apply a fractional counting of authors, so that ⅓ of this publication is assigned to France, Belgium and the USA each. This approach assumes equal contributions of each author. The third option is to assign the article to each of the countries that occur and fully count it for each of the countries. In the example above it would mean that the article counts for France, Belgium and the USA, so it would be counted three times. If two French, one Belgian and one US-American author collaborate, this publication would still be counted once for each country. This is different to the second approach where this example would lead to counts of ½ for France and ¼ for Belgium and the USA each. While in the first and the second approach the sum of the articles equals the total number of documents, this is not the case with the third approach. This surely has advantages for the calculation of shares and other indicators. Thus the other approaches are – from a technical perspective – much more complicated while they do not lead to completely different conclusions, when structures – and not absolute numbers – are analysed. In the case of the Science Citation Index via the host STN – the data access that was used for this study – a fractional counting of countries is not possible at all.

This problem of double/multiple counting of the origin of the authors/inventors is even more pronounced when regional collaboration structures are to be examined. The European Research Area does not necessarily end at the borders of member countries. The differing size and heterogeneity of the member countries would even make it necessary to go below the level of nations for the analysis and discussion of research and technology collaborations. However, in this case one more dimension to the question of full versus fractional counting is added. It is not in the scope of this report and this project to deeply discuss this question. The probability of double/multiple counts is higher when regional – defined as sub-national – levels are concerned, anyway.

3.6.2 Defining Intra- and Extra-EU Collaborations

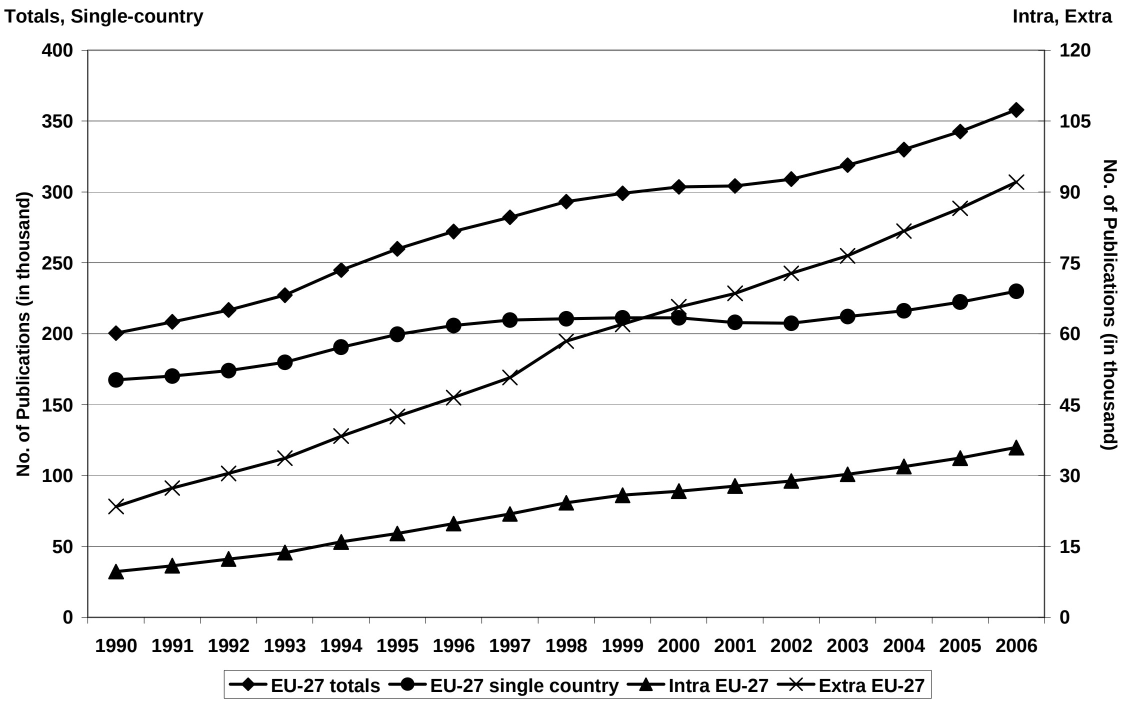
In the context of this project the biggest challenge was to define intra- and extra-EU collaborations. At the beginning, it was agreed that intra-EU collaborations are to be seen exclusively. This means that only collaborations between – at least – two EU member countries were counted while extra-EU collaborations were defined as any collaboration of at least one member country and one non-member country. In consequence, the number of intra-EU collaborations was rather low as all co-patents and co-publications were excluded by this definition, where two EU-members and one non-EU-member worked together – this was counted as extra-EU collaboration.

This second version of defining intra-EU collaborations was set to a broader level and all collaborations were counted as intra-EU, where at least two different member countries collaborated. In consequence, extra-EU collaborations were defined exclusively as publications where one – and only one – EU-member country collaborated with a non-EU-member country. This latter approach is listed in Appendix 4 as indicators 1b and 3b.

An alternative would have been to allow double/multiple counts also in this respect so that trilateral or multilateral collaborations were counted each time they occur. The example of France, Belgium and the USA would have been calculated as one intra-EU collaboration of France, one intra-EU collaboration of Belgium as well as one extra-EU collaboration of France and one extra-EU collaboration of Belgium. However, as this would have increased the number of publications/patents to be analyses and especially as a simplified data extraction strategy was applied, we restrained from this approach.

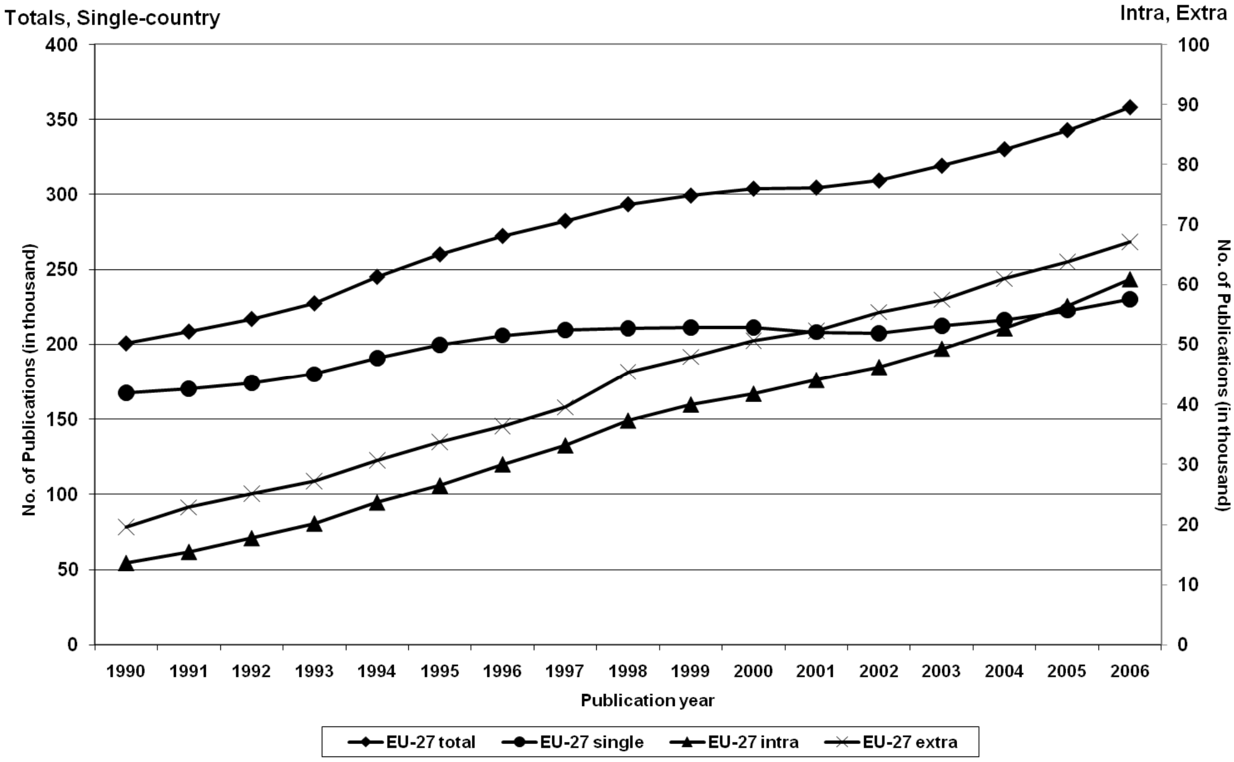
The differences of these two approaches become obvious, when Figure 3-4 and Figure 3-5 are compared. The data covers totals as well as intra-EU and extra-EU collaborations based on the two different definitions. While the extra-EU co-publications in the case of the exclusive definition increase much steeper than the intra-EU co-publications, this is not the case with the less strict, alternative definition. In Figure 3-5 the two lines of intra- and extra-EU co-publications are almost parallel, with a slight increase between 1997 and 1998 widening the gap between intra and extra. However, after 2002 the absolute numbers of intra-EU collaborations caught up, narrowing the gap again.

Figure 3-4: Number of publications and co-publications in EU-27 countries



Source: STN – SCISEARCH; Fraunhofer ISI computations

Figure 3-5: Number of publications and co-publications in EU-27 countries (alternative definition)



Source: STN – SCISEARCH; Fraunhofer ISI computations

The original definition of intra-EU, which focuses on exclusive intra-EU co-patents and co-publications, has been requested by DG-RTD and is therefore kept for the analyses. We have presented the differences of the two perspectives in this section. In addition, we will present more detailed analyses in the data analysis chapter, which compares the two perspectives at least for publications. A similar comparison also on the basis of patent data would have gone even more beyond the resources and the scope of this project.

3.6.3 The Simplified Data Extraction Routine

The simplified data extraction strategy works as follows: first, the total number of publications/patents per country was identified. Second, the total number of pure national publications/patents was calculated and third, the total number of intra-EU collaborations was counted. The remaining number of extra-EU collaborations was simply the differences between the sums of the pure national and the extra-EU publications/patents and the total.

As no unique assignments of classes or unique identifications of the country of origin, both of patents and publications, might occur, the way of counting patents and publications (and co-patents and co-publications) has to be decided before the analysis. There is no right or wrong answer to these questions, but it is a matter of analytical scope and research interest. In addition, practical reasons were considered.
In the case of classes/categories as well as of authors/inventors, we decided to use multiple assignments for this study. This approach results in a difference of the absolute numbers between the total and the sum of the individual publications/patents.

DG-RTD requested a definition of intra-EU collaborations that was very strict, defining intra-EU very exclusive as any co-patent or co-publications where only authors/inventors from EU Member Countries participated. Trilateral collaborations of two member country authors/inventors and one non-member country author/ inventor were counted as extra-EU collaborations. For this feasibility study we have also checked the alternative definition where also this latter example would have been counted as intra-EU collaboration. For future studies and a regular monitoring system this alternative definition is recommended.

3.7 Summarising conclusions: Do co-patents and co-publications reflect collaboration?

The literature review revealed that especially to measure science collaborations, international co-publications are rather frequently used, though restrictions of interpretability were discussed (Katz/Martin 1997; Laudel 2002). Co-patents are less often used so far, especially as they also cover intra-company (in MNEs) collaborations in international teams.

If the ERA is seen as a vision about coordinating national research activities and policies and creating an internal market for research with the free circulation of researchers, ideas and technology, then indicators to measure this circulation can be used. The ERA was initiated to overcome three weaknesses: insufficient research funding; inadequate framework conditions to stimulate research and its exploitation; and finally the fragmentation of activities and resources. Improving the co-operation and co-ordination among key players within the European Union is a key factor to overcome these shortcomings. In consequence, international – or better trans-national – co-patents and co-publications are an adequate mean to measure this at first sight. However, the literature review revealed some limits of these indicators, which need to be kept in mind when the data is interpreted. One of these limits is of course that co-patents focus on technological inventions – and even here only on a fraction of the totality of inventions

– and co-publications reflect one among possible other outcomes of the research system. Especially informal knowledge flows and exchanges are hardly to be covered by these indicators. In addition, the ERA is also made of additional instruments, means and infrastructures, which foster the exchange of knowledge and ideas, but which cannot be covered by patents and publications. Furthermore, the elements listed in the Green Paper on the ERA cover more than just the knowledge flows between companies and/or public research institutions. The motives to collaborate in general, but especially across country borders were identified as: geographical or cultural (language, history) proximities, economic or political factors as well as access to knowledge or resources (equipment etc.).

In general, applying indicators on co-authorship and co-patenting data provides a quantitative approach to the question of international collaborations. However, it has to be stressed that neither patent nor publication indicators as such allow an interpretation of the motivation behind, the direction of knowledge flows or the initiation of the joint work. Furthermore, intensities of networks and exchange as well as the quality of the collaboration or its output cannot be measured by the approaches presented in the literature review and also not by the indicators used in this report.

The data presented in this study first of all gives a general overview of the structure and the quantity of international collaboration in patenting and publishing in Europe. The emergence of the European Research Area cannot directly be measured by this approach and first of all has to be benchmarked against the networking activities of extra-EU partners. Furthermore, the change of these patterns and structures over time give an indication of positive or negative trends of trans-national co-operation in Europe. In this respect co-patents and co-publications are – first and foremost – instruments to monitor the past and present knowledge flows and network activities. However, the motivations and driving factors have to be examined and analysed with other instruments, for example like the survey of collaborating researchers and inventors, where the indicators approach is complementary to (and vice versa). The quantitative indicators can provide framing information as well as insertions for further research.

The results have to be interpreted with caution and the limits and idiosyncrasies of the data, the data sources and the indicators as such have to be taken into account. A very detailed analysis of individual member countries as well as of technology areas and scientific fields cannot be recommended. A stubborn and stolid exercise on all possible or desired links does not provide new and far-reaching insights. It is recommended to focus on EU-27 as the partner countries as well as groups like Asia, North-America, and EFTA. On the side of the individual countries to be analysed, it is recommended to gather the data on the level of the individual EU-27 countries. Though, for the analysis and the calculation of indicators a grouping of small countries is advisable so that – for example – Scandinavia, Baltic countries, Eastern Europe, Southern Europe, Central Europe are analysed as groups, whereas countries like, the United Kingdom, France, Germany, Italy and Spain are kept separately. This allows both, an analytical depth to look into structures, but also absolute numbers which are less influenced by random events in small countries.

Thus, in this report the standpoint of broad and general perspectives was taken. The instruments suggested and used here allow a permanent and comparable monitoring of science and technology linkages. In future studies additional attention might be paid to new data sources (e.g. SCOPUS), quality aspects of collaborations (e.g. measured by citations), or a regionalisation of the analysis.

A regular monitoring system based on co-patents and co-publications should be established with a clear strategy and strictly defined aims. The limits of these indicators for measuring the development of the ERA have already been addressed. However, the chances and benefits for policy makers to track the evolving collaboration in science and technology in Europe need to be stressed as well. A sophisticated data system is able to assist other measures on the ERA and to flank policy decisions. For this purpose it is mandatory to select a reliable, easy-to-implement, and very topical system. Based on this feasibility study it can be recommended to use the Science Citation Index to monitor the collaboration structures of scientific publications. The data is reliable and up-to-date. A new cohort of publications – a new publication year – is usually available and complete in March of the subsequent year. However, the shortcomings of this data source were addressed in the previous sections, mainly referring to the bias towards the USA and also towards science disciplines at the expense of engineering fields. In consequence, SCOPUS could be considered an adequate alternative, which is also available in the first quarter of any subsequent year.

Concerning patents, the first decision to be made is on the patent office to be analysed. Due to international conventions and international filing procedures, it is recommended to focus the analysis on Transnational Patents – that is patent families with at least an EPO or a PCT filing. The reason is the higher topicality, the reliability of the data, and the international comparability of the results. Based on this approach it is possible to add an additional year to the analysis in the mid of the next but one year, as both EPO and PCT filings are published with an 18 months delay. For example, in the second half of the year 2009, the data for the priority year 2007 will be available and ready to be analysed. If the data source is to be EPO's international patent database called

PATSTAT, then the data is available in each 4^{th} quarter of the next but one year. The use of USPTO or of EPO filings alone is not recommended.

However, the indicators that are presented in this report and that were used for the analyses of the structures of collaborations in Europe were requested by the DG-RTD of the Commission Services in exactly this form. We have not been free in our selection of data and indicators and we even have not been able to give advice to DG-RTD in this respect as the timeline was adapted to their short-term demand of data to be input to their Key Figures Report (European Commission 2008a).

4 Data Analysis

4.1 Scientific Publications – Trends and Structures of EU-27 countries

4.1.1 Introduction

The motivations and driving forces behind international collaborations – of which we focus on collaborations of EU-27 countries with a special attention to intra-EU collaborations – are manifold and range from seeking access to data or laboratory equipment to access to complementary knowledge (see literature review). Further impacts stem from geographical proximities as well as cultural similarities – among which language is the most important one.

Three different indicators were analysed: 1) Number of EU-single publications, covering all publications where authors from only one EU-country were on the list. In other words: pure national publications; 2) Extra-EU co-publications contain all collaborative publications, where at least one author from outside the EU-27 has jointly published a paper with at least one author from within the EU (also covering all publications where authors from two or more EU-countries have collaborated with researchers outside the EU); 3) The number of intra-EU co-publications reflect the activities that emerge out of the collaboration within EU-27 countries where no author from outside the EU was involved[35].

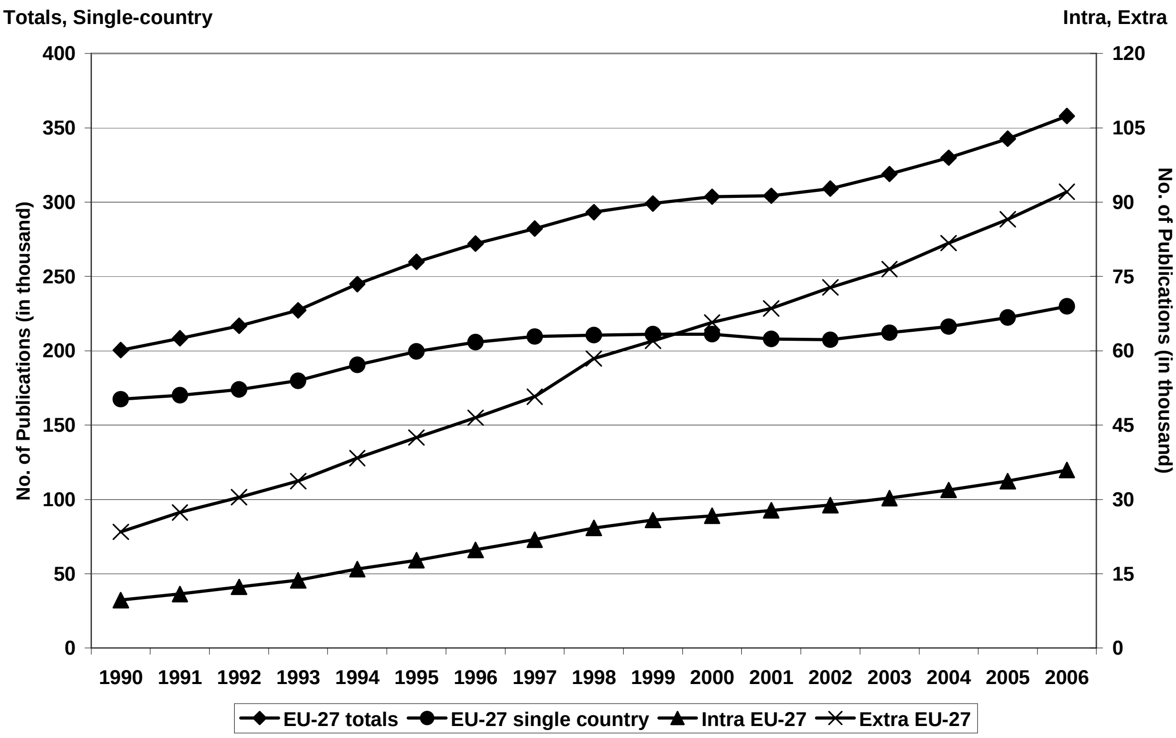
4.1.2 Trends and Structures

Figure 4-1 depicts the absolute number of publications and international co-publications of EU-27 countries in the years 1990-2006. The number of publications is steadily increasing. However, the number of single-country publications does not grow with the same pace, meaning that the international co-publications were growing much faster and have driven the overall development in the period under observation here. The second main lesson to be learnt from this graph is the fact that the pure intra-EU co-publications did not increase to the same extent like the extra-EU co-publications. The literature review has provided several reasons why researchers collaborate inter-

35 In the course of the analysis this decision proved to be too limited. Therefore, we have decided to additionally also collect the number of intra-EU-27 co-publications where also at least one author from a third country outside Europe could have been on the list. As a direct consequence, in relation to this we also calculated the number of extra-EU publications of EU-27 countries in collaboration with a third country as excluding other EU-27 countries – this matches with indicator No. 2.

nationally. Main motivations are the access to data and equipment, but especially the access to complementary knowledge. Increasing complexity and convergence of fields and even disciplines make the joining of knowledge even mandatory. However, as a matter of fact this additional knowledge cannot be found only within the EU in the same way or to the same extent as in collaboration with external partners. The reasons might be manifold – and it has to be objected at this point that we have made a distinction between extra-EU and pure intra-EU publications, whereas a large number of publications is also made in trilateral collaborations between EU-authors with external partners (see methodological discussion in chapter 3 of this report) – and can be summarised with two main arguments: 1) The other EU-27 Member countries are not always the providers of complementary knowledge to the collaboration-seeking country and 2) the structures and networks, also supported for example by the opening of the Framework Program to third countries, are not restricted to the intra-EU collaborations. A further reason is the location of international research centres – like CERN, for example – outside the EU. However, the main explanation is the fact that the USA are still the most important actor in science and technology and therefore also offer a wide spread of opportunities and possibilities for collaboration.

Figure 4-1: Number of publications and co-publications in EU-27 countries



Source: STN – SCISEARCH; Fraunhofer ISI computations

Next to the overall trend of increasing international collaboration in science and technology in general, another explanation can be found in the differing internationalisation and international orientation of countries within the EU. Furthermore, researchers within the member countries are engaged in different fields and disciplines, which results in different structures and different total shares. Figure 4-2 provides the shares of intra-, extra- and single-EU publications of the 27 individual member countries. As a rule of thumb it can be said that larger countries have lower shares of international co-publications. However, this is only a rough rule of thumb as countries like Greece, Poland, Slovenia, Lithuania and even Finland show high shares of single-country publications. In consequence, there must be other mechanisms active that explain the national orientation. In an internationally comparative study like this it is not possible to dig deep into the structures of each individual country and extract detailed information. Here it is more interesting to derive overall patterns that can be found in many countries. On the other hand, countries at the high end of the scale in terms of international collaborations like Bulgaria, Latvia, Malta, Cyprus, or Luxembourg have low absolute numbers so that their profile is simply the result of a size effect. However, if they publish at all, they collaborate internationally much more frequently.

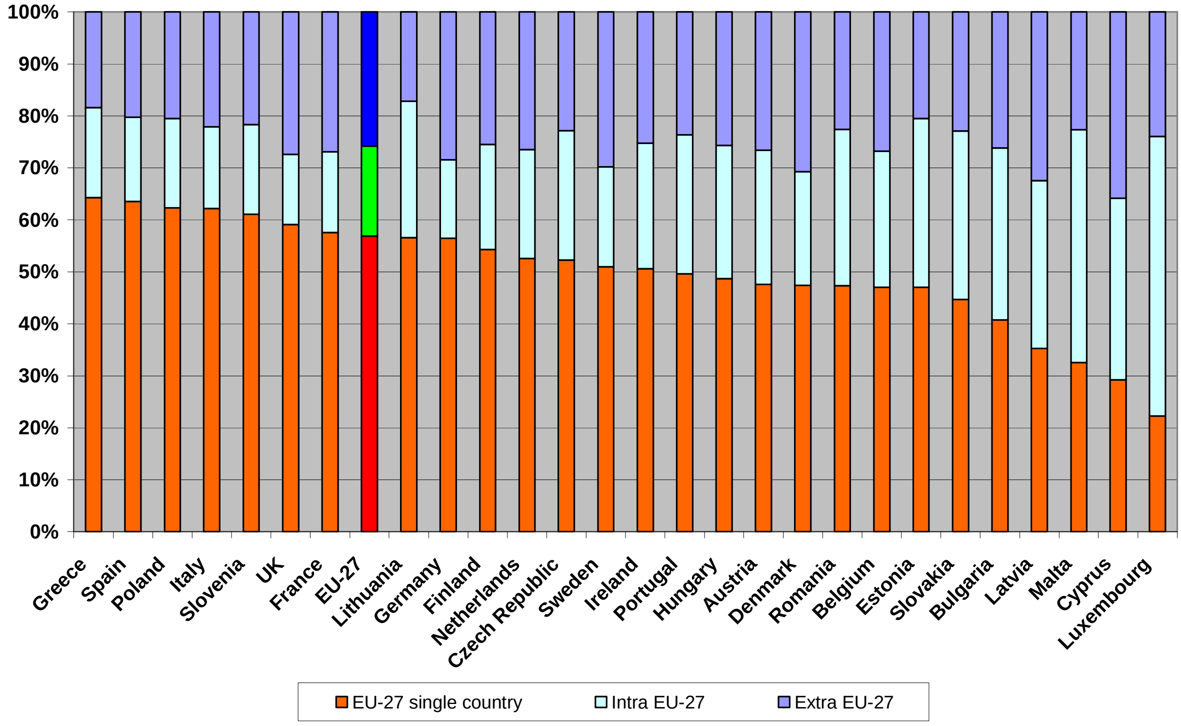
Another finding of Figure 4-2 is the fact that several countries – most of them are the large ones again – have high shares of extra-EU collaborations, which reflects their networking especially with Switzerland, North-America, but also other countries and areas like China, Japan or South-America. Eastern European countries seem to have higher shares of intra-EU co-publications than most of the other nations. Though still lower shares than Malta, Cyprus and Luxemburg.

On average the share of extra-EU co-publications is more than 26% and the share of single-country publications in all EU-27 countries is about 57%. In consequence, the share of pure intra-EU co-publications is 17% – but it has to be stressed again that this figure only covers international co-publications where no researcher from a non-EU country was involved at all.

Therefore, Figure 4-3 depicts the shares of intra- and extra-EU co-publications based on the alternative definition, where intra-publications do not only cover exclusive collaborations within the EU, but also publications between EU-members and third country partners. In consequence, extra-EU is defined as exclusive co-publications of one member country and at least one third country.

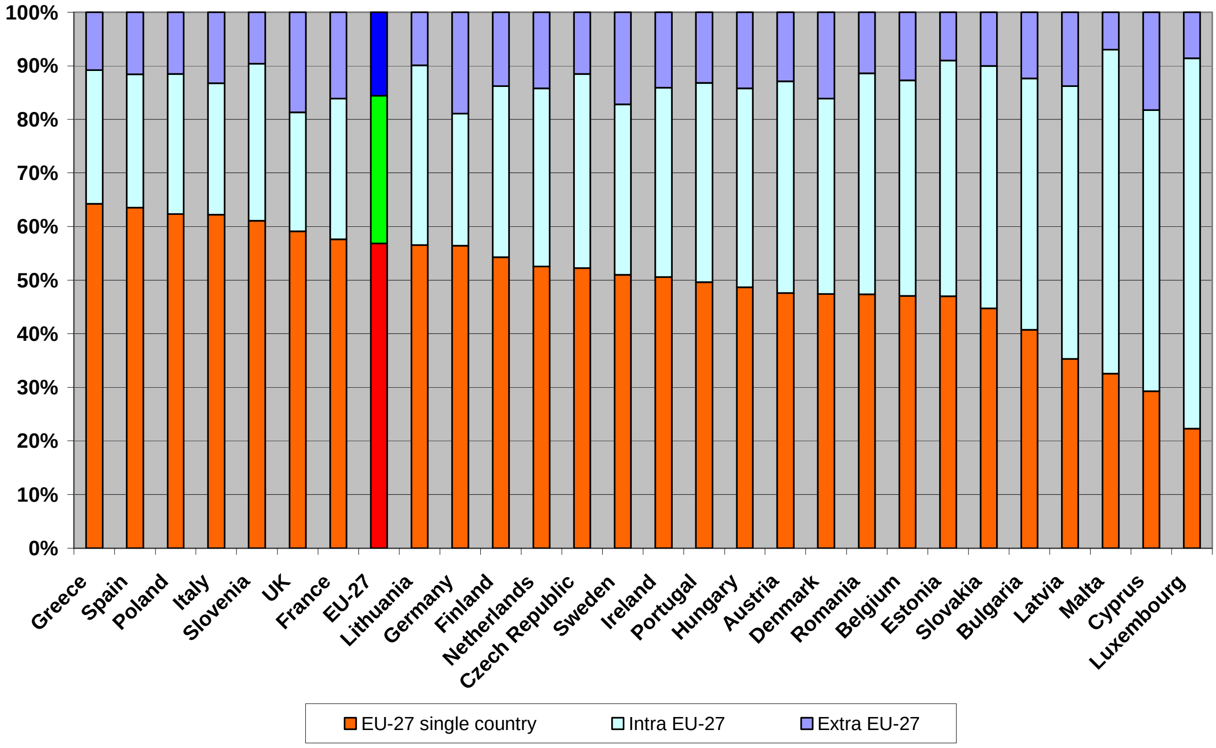
On average, the share of intra-EU co-publications raises to 27.5% whereas in the countermove the shares of extra-EU co-publications is only 15.6% under this definition. The relation between intra- and extra-EU collaborations in comparison of the member countries seems to be almost the same using the two different definitions. It is almost a parallel move of the bars in the two graphs. However, some countries prove to increase their shares of intra-EU publications more than the others, implying that they have a higher rate of (at least) trilateral collaboration also with external partners. Among them is France, which frequently collaborates with non-member-countries for example in Africa and Denmark, which works frequently together with Norwegian researchers. This is another proof of the impact of cultural (language) and geographical proximity.

Figure 4-2: Shares of single-country, Intra-EU and Extra-EU publications in EU-27 countries, 2004-2006



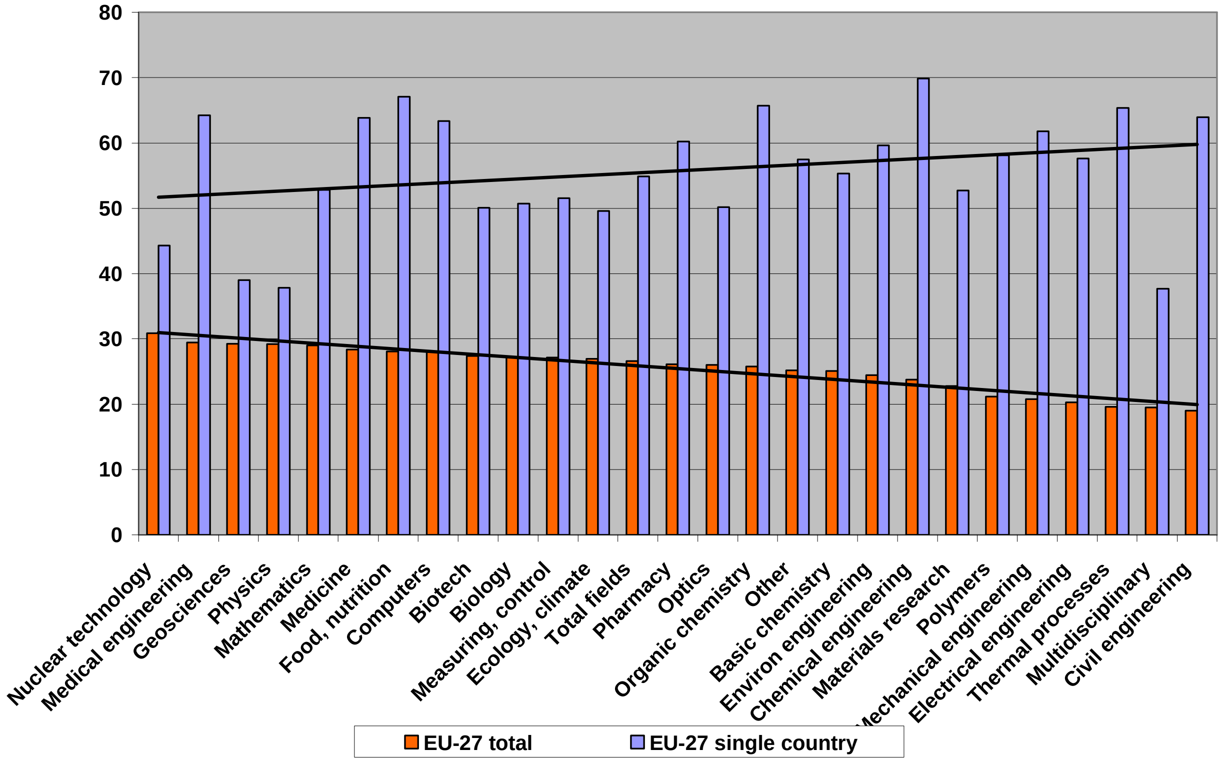
Source: STN – SCISEARCH; Fraunhofer ISI computations

Figure 4-3: Shares of single-country, Intra-EU and Extra-EU publications in EU-27 countries (alternative definition), 2004-2006



Source: STN – SCISEARCH; Fraunhofer ISI computations

Figure 4-4: Shares of Intra and Extra-EU publications in EU-27 countries by scientific fields, 2004-2006

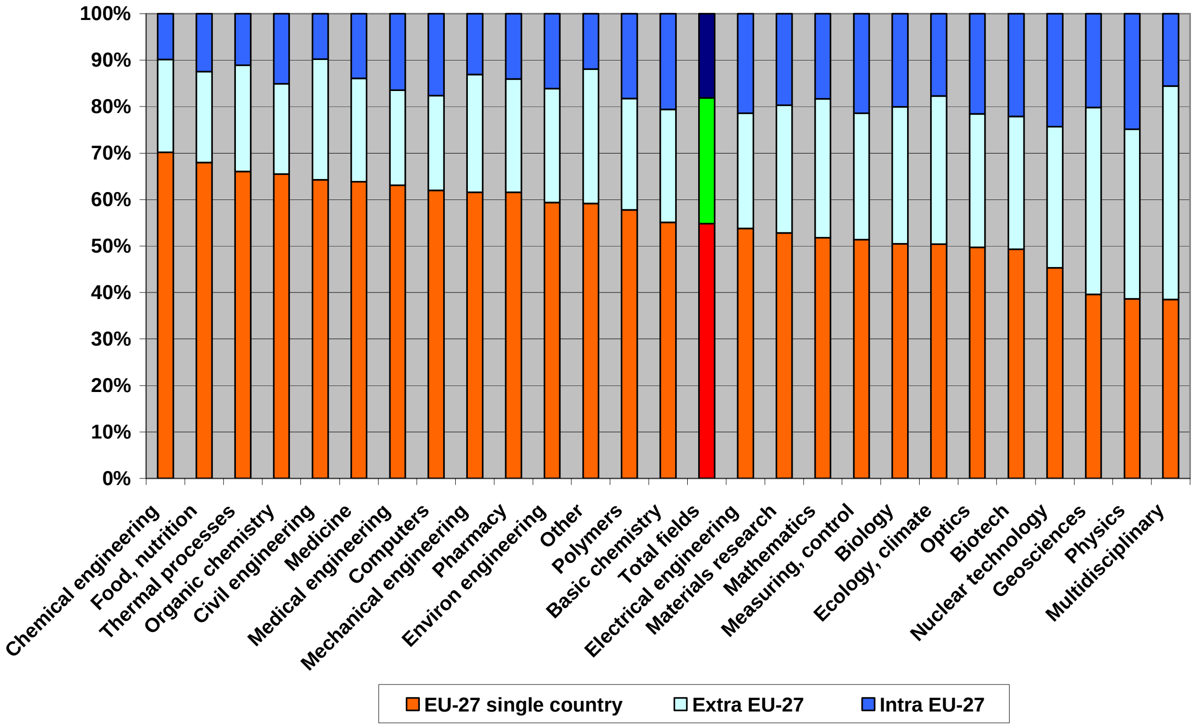


Source: STN – SCISEARCH; Fraunhofer ISI computations

One of the arguments introduced in the literature review and also mentioned above is the seeking for complementary knowledge. Differences in this cannot only be found between countries, but especially between scientific fields. Figure 4-4 depicts the shares of EU-27 countries of the worldwide publications as well as the shares of EU-single country publications by 26 scientific fields. The two trend lines in the graph reflect the fact that the shares of pure national publications increase while the EU-shares of the worldwide total slightly decrease when the fields are displayed in this order. To put it in other words, where the EU is strongly engaged, the shares of international collaboration are lower. However, one has to admit that this effect is not very strong and the variation between the fields is sometimes considerable. Tough, the correlation coefficient reaches a value of -0.29, indicating a medium co-variation of the two data series.

The shares of EU-single, intra- and extra-EU publications by scientific fields are displayed in Figure 4-5. Chemical Engineering as well as Food and Nutrition are at the top of the list in terms of EU-single country publications, while Nuclear Technology, Geology and Physics reach the lowest shares of pure national publications. It seems that more applied fields are less international while basic research areas seem to reach higher shares of internationalisation. The necessity to internationalise in the different fields has – of course – also an impact on the fields' performance in this respect. CERN plays an important role in Physics and Nuclear Technology, for example. Geoscientists analyse and compare sediments, samples, or tectonics, which are not necessarily in their home country. High shares of extra-EU collaborations can be found in Civil as well as Mechanical Engineering, where Switzerland plays a considerable role. On the other hand, pure intra-EU co-authorships are exceptionally frequent – compared to the other fields with similar international activity – in Organic Chemistry, Medical Engineering, Computers or Electrical Engineering. However, shares below the average of intra-EU collaborations are especially reached by Chemical, Civil, and Mechanical Engineering.

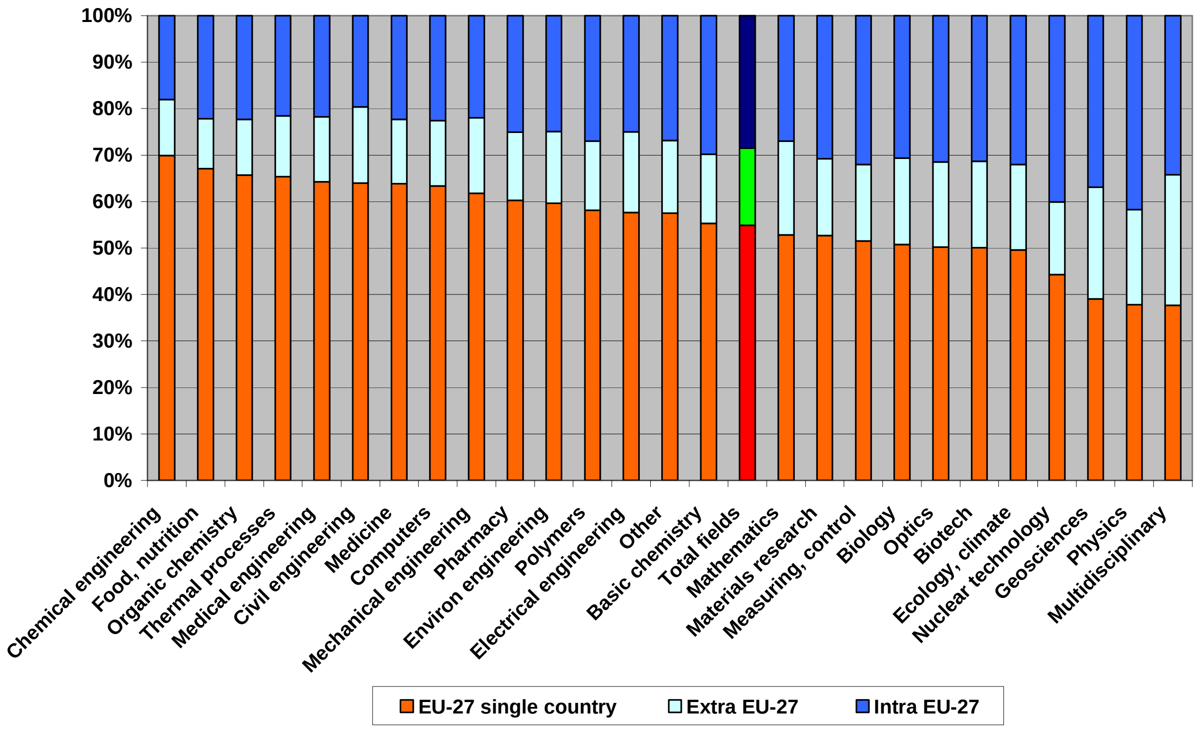
Figure 4-5: Shares of EU-single, Intra- and Extra-EU publications in EU-27 countries by scientific fields, 2004-2006



Source: STN – SCISEARCH; Fraunhofer ISI computations

While Figure 4-5 is based on the definition of exclusive intra-EU publications, Figure 4-6 uses the alternative perspective and allows intra-EU publications also to emerge out of collaborations with third country authors in addition. In general, the shares of intra-EU publications are much higher, of course, but it is still the engineering fields that reach collaboration rates below the average. Extra-EU co-authorship shares are lowest in Food and Nutrition – a finding that fits with patent analyses, which show that this kind of consumer market oriented applied technologies are mainly targeting national or regional markets. Nuclear Technology and Physics are reaching highest shares when the alternative definition is taken into account. Together with the above finding of exceptionally high shares of extra-EU collaborations in Figure 4-5, it can be stated that in these two fields trilateral co-authorships are very common.

Figure 4-6: Shares of EU-single, Intra- and Extra-EU publications in EU-27 countries by scientific fields (alternative definition), 2004-2006



Source: STN – SCISEARCH; Fraunhofer ISI computations

4.1.3 EU-15 co-publications

Until the year 2004 the European Union only consisted of 15 member countries. As we analyse the time series 2004-2006 and as the integration especially in research networks might take some time, we discuss the structures of co-publications of the former EU-15 countries in this section additionally.

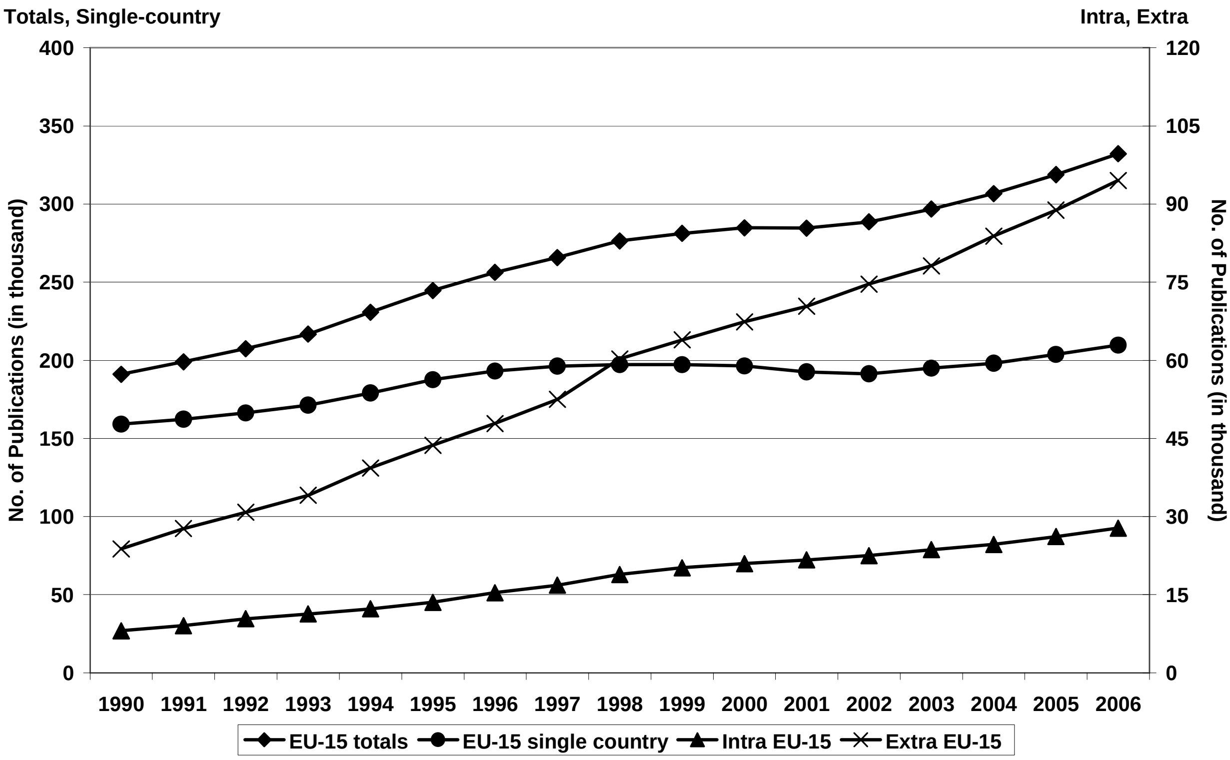
In Figure 4-7 the number of international co-publications in the EU-15 countries is displayed. Next to the totals also the single country, the intra- and the extra-EU collaborations are depicted. In this case the original definition of intra-EU-collaborations was applied, covering only those international co-publications where at least authors from two different EU-15 countries were involved and at the same time no author from a non-EU country made a contribution. The definition is also strict in terms of EU-15, which means that intra-EU only covers EU-15. A collaboration between an EU-15 member and a member from one of the new acceding countries (EU-12) has been counted as an extra-EU co-publication.

Similar to Figure 4-1, the trend in total as well as in co-publications follows a continual growth, while single-country publications are almost stagnating. This means again, the overall growth is mainly driven by internationally co-authored publications. However, also this trend is mainly shaped by extra-EU collaborations, whereas the pure intra-EU collaborations have grown much slower.

A comparison between Figure 4-1 and Figure 4-7 reveals that there is almost no difference in absolute numbers between the EU-15 and EU-27 publications trends. EU-15 total counts are about 5-7% lower than the corresponding EU-27 figures. Intra-EU are – of course – much lower, while extra-EU co-publications are higher in the case of the EU-15 example as the number of possible partners and thereby the number of opportunities to collaborate outside the EU-15 is higher.

On the other hand, the overall similarity of the two figures clearly indicates that the new member countries – this includes not only the two countries, which acceded in 2007, but also the other 10 member countries, which acceded in 2004 – have not yet found their role in the European Research Area. At least their research output in conjunction with EU-15 countries is very low and much lower than the activities of the EU-15 with some non-EU-countries like Switzerland or the USA.

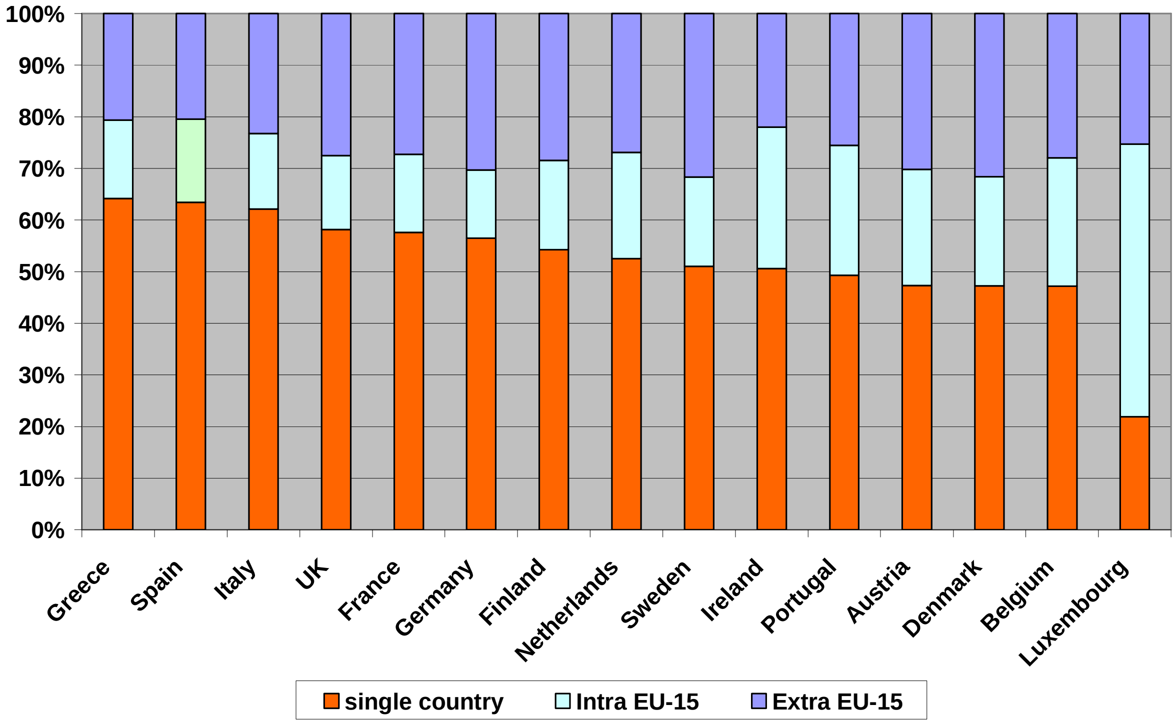
Figure 4-7: Number of publications and co-publications in EU-15 countries



Source: STN – SCISEARCH; Fraunhofer ISI computations

As can be seen in Figure 4-8, the share of single country publications is identical with the shares in Figure 4-2. However, the shares of intra- and extra-EU co-publications also differ in this comparison, due to the lower number of intra-EU collaborators and in consequence due to a higher number of collaborators outside the EU. For some of the EU-15 countries like Spain, France, the Netherlands or Denmark hardly any difference can be detected between the two figures. Countries like Finland, Austria, Sweden and even Germany have considerably lower shares of intra-EU co-publications, when only EU-15 is observed. This means that the latter countries collaborate more often with the new member countries than the first group. One explanation – as it was also found in the literature review – can be geographical proximity as most of the countries share borders with at least one of the new Eastern European member countries. Though, the rate of collaboration with the new members is lower also for the latter group of countries than it is within the former group of EU-15 members.

Figure 4-8: Shares of single-country, Intra-EU and Extra-EU publications in EU-15 countries, 2004-2006



Source: STN – SCISEARCH; Fraunhofer ISI computations

4.1.4 Conclusions

This chapter analyses international co-authorship patterns of EU-27 countries in total, by each country as well as by 26 scientific fields with a technological perspective. It is found that the shares of international collaborations have been increasing considerably over time, while the main driving force behind this trend was the collaboration with extra-EU partners. The absolute number of pure national publications has hardly been changing since the mid 1990s, but is slightly increasing nowadays.

The main results derived from the analysis of the international activity rates of the individual member countries are some indications that larger countries have lower shares of international collaborative publications. Some of these countries show considerable exchange with third countries outside the EU, among which Switzerland, North-America, but also other countries and areas like China, Japan or South-America play an important role.

The analysis by 26 scientific fields especially lead to the result that where the EU is strongly engaged, the shares of international collaboration are lower. Another finding is that more applied fields are less internationally oriented, while basic research areas seem to reach higher shares of international co-authorship. Chemical Engineering or Food and Nutrition are rather nationally oriented fields, while Nuclear Technology, Geology and Physics are very internationally oriented. Though, trilateral collaborations – between at least two EU member countries and one non-EU country – are rather frequent in Nuclear Technology research and in Physics.

An additional analysis of EU-15 collaborations revealed similar trends like in the case of all EU-27 countries, though on a slightly lower level, of course. Some indications were found that support the relevance of geographical proximity. The integration of the recent acceded countries might happen on this path. However, the statistical analysis provided here covers a period of the accession that is too short to prove the integrating effects of geography. Future studies might find more evidence for this.

4.2 Patent Analysis

4.2.1 Introduction

4.2.1.1 Aim

This section is focussed on identifying the main trends in international co-patenting involving the EU countries, to get an indication of the extent of international collaboration in technological activities. We analyse data according to: (a) EU as a whole (both EU-15 and (EU-27); (b) for each individual EU country and (c) according to 6 aggregate technical fields. In each case the aim is to show the extent of international co-patenting according to whether it involves other EU countries or those outside the EU.

4.2.1.2 Data Issues

The source for data on EPO and USPTO patenting is the PATSTAT database (more specifically the version released in October 2007) as supplied by the patent offices. PATSTAT is based on an internal database of the EPO which is used by patent examiners to search for prior art and especially to establish worldwide novelty. It is not primarily compiled to for statistical purposes, but to serve procedural needs stemming from the application procedure and the patent law. PATSTAT stores information on bibliographic details of the applicants, the inventors and of patents, including the date of first filing (priority) and legal status.

There are a number of issues regarding the data that need to be borne in mind when interpreting the results reported here.

- Patents have been aggregated according to ***priority years*** (beginning in 1990). This choice effectively means that the data are only complete for 2004 (as there is a considerable time lag of before publication). Additionally when PATSTAT contains no information on a specific priority application we have used the filing year as an indication of the priority year.
- The 'country' designation of a patent is the ***country address of the inventor***. Thus international co-patents are defined as any patents where at least two different inventors from two different countries have been involved. Where more than one inventor from the same country appears on a patent this is counted as a single patent for that country. This means, for example, that if two French and one British inventor have cooperated, this filing is counted both as one French co-patent and as one British co-patent application.
- The *'technical'* designation of a patent is based on the ***IPC class*** to which the patent belongs. Here we have used all the IPC classes that appear for a particular patent in the PATSTAT database and allocated them to one of the following aggregate classes:
  - Electrical engineering
  - ICT
  - Instruments
  - Chemistry
  - Mechanical engineering
  - Other.

An additional point to note is that the analysis for EPO patents is based on ***direct applications to the EPO plus the PCT applications*** that have entered the ***regional phase at the EPO***. At the same time the USPTO data refer to patents ***granted***, as this was one of the requirements mentioned in the ToR. As all patents used here are dated by the year of priority this means in effect that the data for the USPTO are not complete for the latest years (as these patents have not been examined as yet).

4.2.1.3 Indicators Constructed

The analysis below is based on the following data extracted from the PATSTAT database for the priority years 1990 to 2004:

- Total number of single country patents, where all inventors are within the same country.
- Total number of intra-EU co-patents, where all inventors are within the EU-15.
- Total number of co-patents with countries outside the EU, where at least one inventor is from outside the EU.

On the basis of this we constructed the following indicators:

- % of total patents that involve inventors from more than one country
- % of total patents that are intra-EU
- % of total patents that are extra-EU

We use these indicators as proxy measures for the relative importance of collaboration in total technological activities of countries.

In order to identify the main trends we aggregate the priority years according to the following time periods: 1990-1994, 1995-1999 and 2000-2004. In the case of the USPTO analysis below this mitigates (but does not eliminate) the effect of incomplete data for the latest priority years.

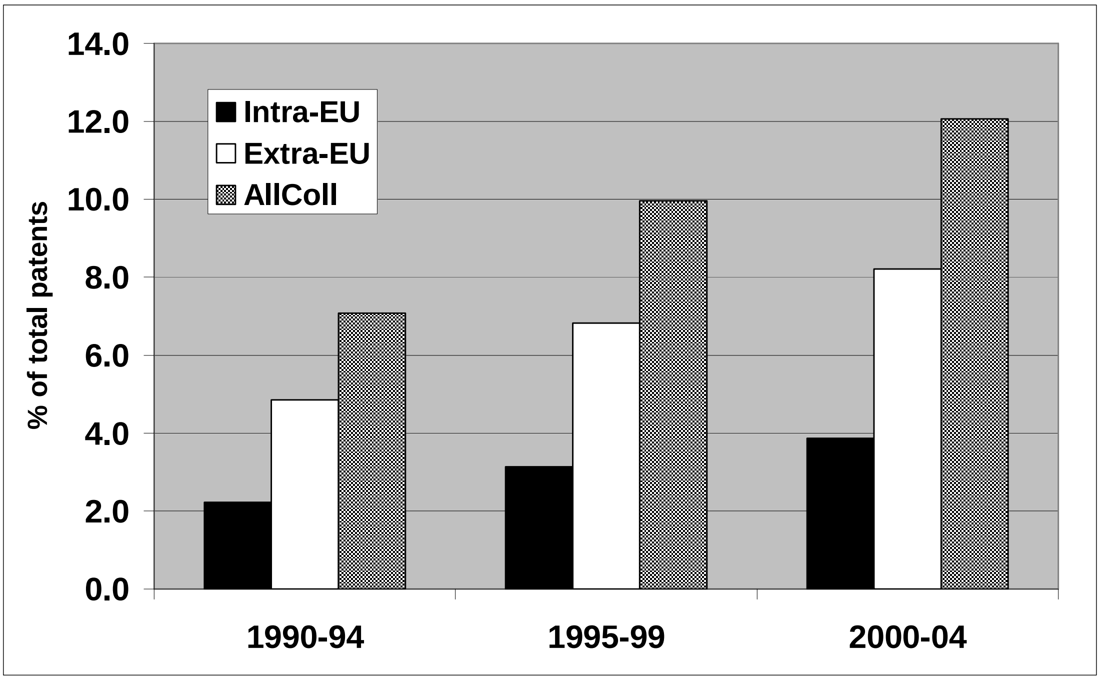
4.2.2 Main Results: EPO data

4.2.2.1 Aggregate level: EU-15

Taking the EU-15 as a whole, Figure 4-9 shows that there has been an increase in the extent of international collaboration in technology. Thus the overall proportion of EU invented patents involving inventors from more than 1 country rose from 7.1% in the early 1990s to 12.1% in 2000-04. Figure 4-9 also shows that extra-EU collaboration is relatively more important than intra-EU, as extra-EU-15 co-inventions accounted for 8.2% of total patents in 2000-04 and intra-EU-15 only 3.9%. However the trends in both indicators are very similar over time.

The more detailed data (see discussion surrounding Figure 4-18 and Figure 4-19 below) show that two countries dominate EU technological collaborations, accounting for nearly 80% of all extra-EU co-inventions in 2002-04: US (58%), Switzerland (20%). Two countries with the largest increases since the 1990s are China and India, albeit from a very low base.

Figure 4-9: The extent of international co-patenting EU-15 as a whole (EPO)



Source: PATSTAT; calculations by SPRU

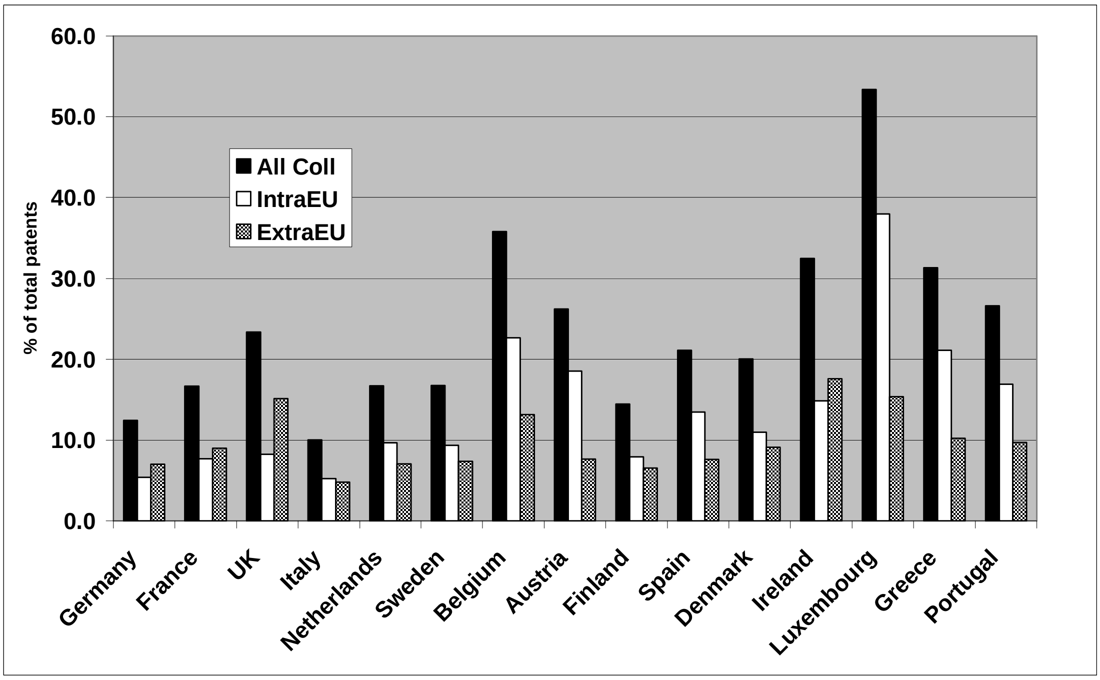
4.2.2.2 Differences amongst the EU-15 countries

In Figure 4-10 we plot the collaborative patterns for each individual EU-15 country. The first point to note from this analysis is that a number of the 'smaller' countries have relatively high rates of international technological collaborations, with the share

patents involving a foreign inventor ranging from between 25% and 53% of the total in Luxembourg, Belgium, Ireland, Greece, Portugal and Austria. At the same time some of the larger countries such as France, Germany and Italy have relatively lower levels of international collaborations. However the relationship between country size and collaboration is not straightforward as Finland and Sweden have relatively low shares of multi-country patents and the UK has a relatively high share.

The other point to note from the results in Figure 4-10 is that for most countries intra-EU technological collaboration is relatively more important than collaboration with countries outside the EU-15. This is especially the case for some of the countries identified above as having high rates of overall collaboration: Luxembourg, Belgium, Austria, Greece and Portugal. However for the UK, extra-EU collaboration is much higher than that with other EU countries. This pattern also holds for France, Germany and Ireland but in a much milder form.

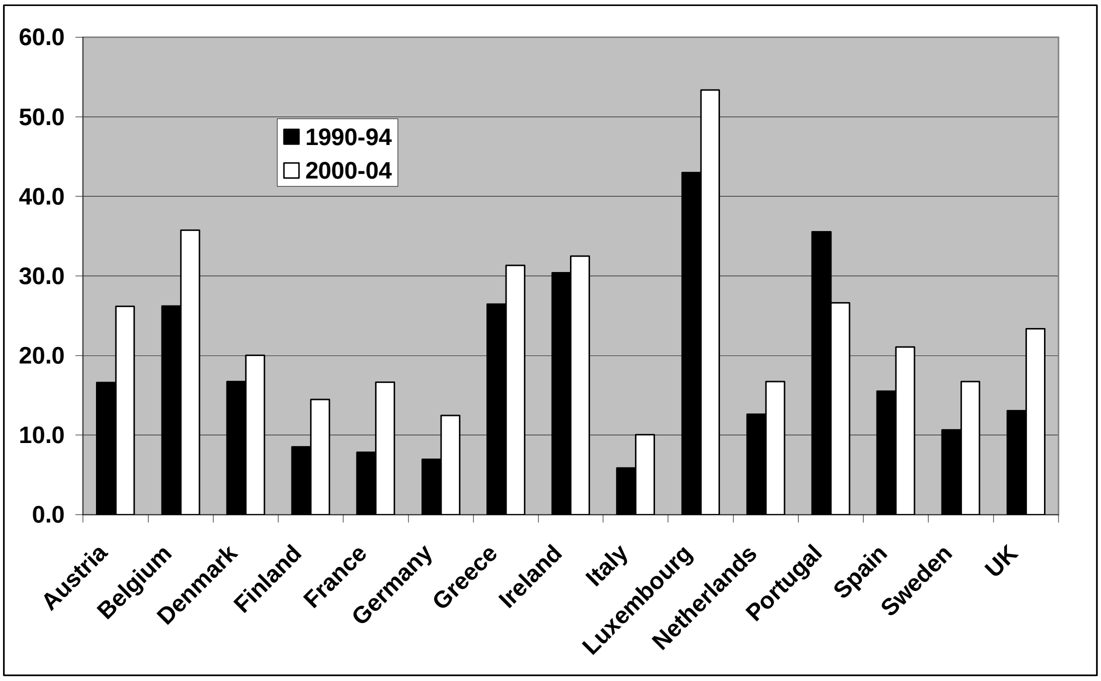
Figure 4-10: International Co-Patenting amongst EU-15 (EPO Data), 2000-2004



Source: PATSTAT; calculations by SPRU

Figure 4-11 shows the trends in the share of international co-patenting amongst the EU-15. According to this indicator all countries with the exception of Portugal have increased their level of collaboration with foreign partners. The largest proportionate increases have been for the larger countries: France, Germany, the UK and Italy. Indeed in France the proportion of all patents involving foreign inventors has more than doubled: from 7.8% to 16.7%.

Figure 4-11: Trends in International Co-Patenting amongst EU-15, 1990 to 2004 (EPO Data)



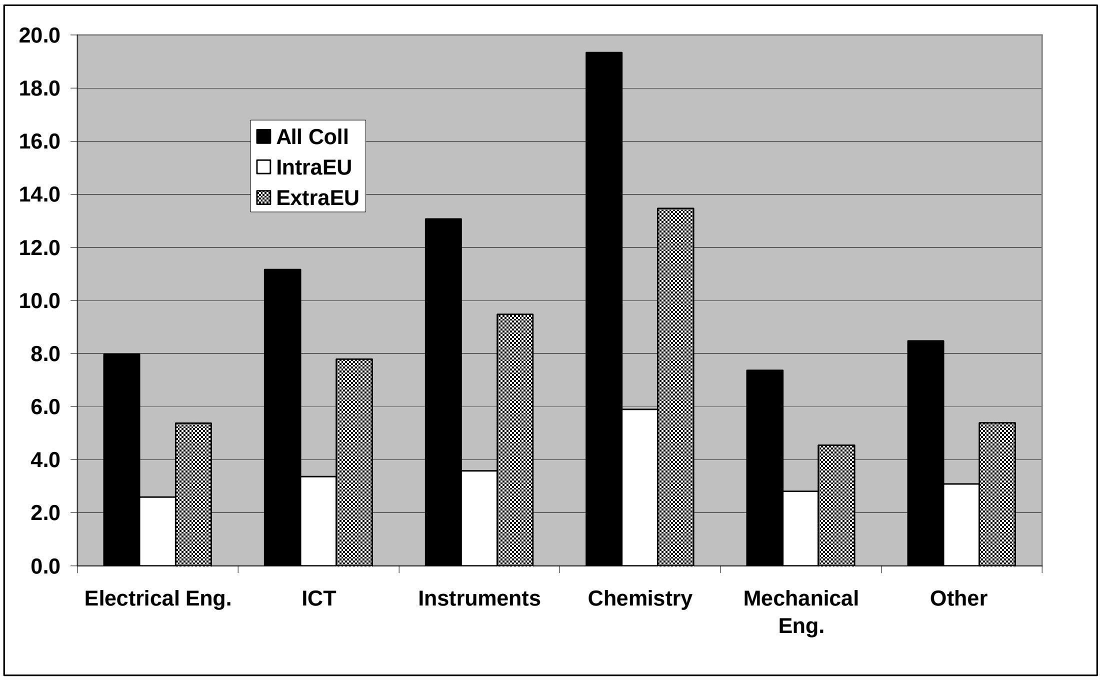
Source: PATSTAT; calculations by SPRU

4.2.2.3 Differences amongst Technical Fields

There are major differences across technical fields in terms of the level of international collaborations amongst the EU-15. Figure 4-12 shows that technologies related to Chemistry have a relatively high proportion of patents with foreign inventors and those related to Mechanical and Electrical engineering have very low proportions. Moreover across all 6 technical fields extra-EU collaborations are relatively much more important than those with other EU-15 countries.

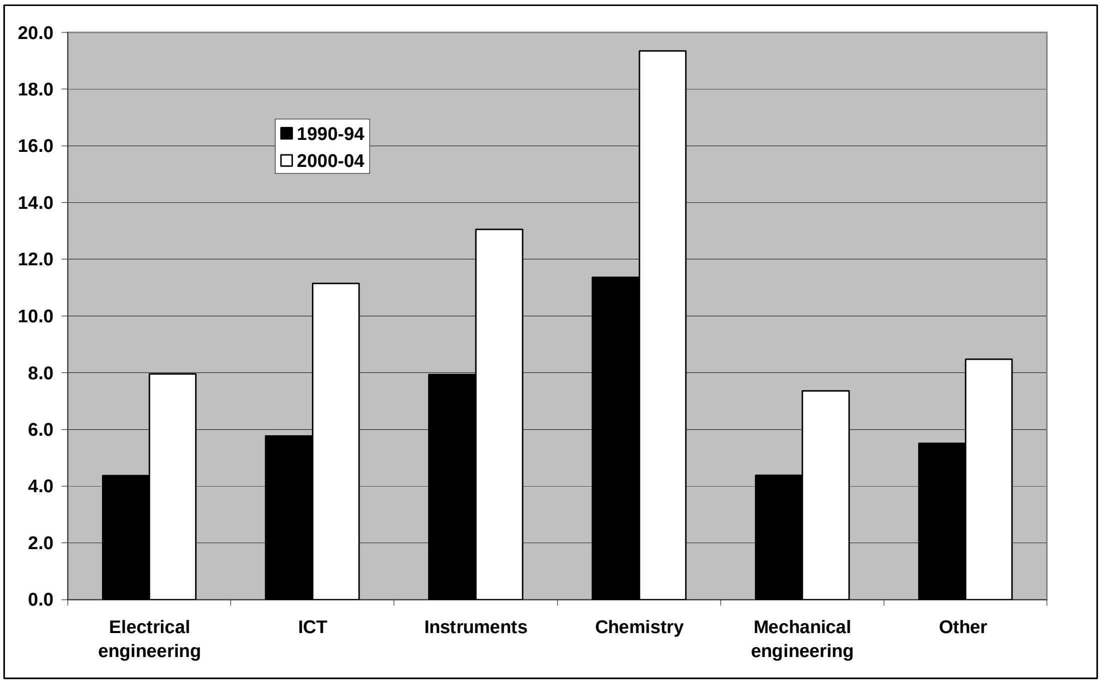
In Figure 4-13 we show the trends in the share of international co-patenting in different technical fields in the EU-15 as a whole since the 1990s. The main point to emerge is that technological collaborations have increased across all areas of technology. This trend is slightly more pronounced in Electrical engineering and ICT than in the other four technical fields.

Figure 4-12: International Co-Patenting of EU-15 countries in 6 Technical Fields, 2000-2004 (EPO Data)



Source: PATSTAT; calculations by SPRU

Figure 4-13: Trends International Co-Patenting of EU-15 countries in 6 Technical Fields, 1990 to 2004 (EPO Data)

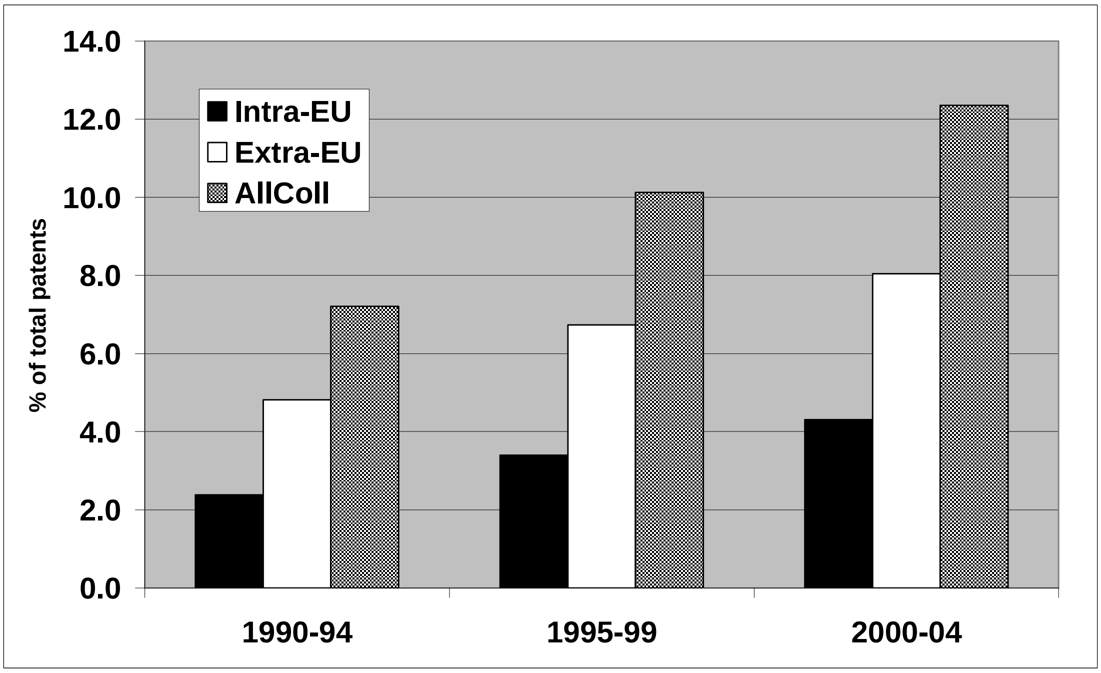


Source: PATSTAT; calculations by SPRU

4.2.2.4 Analysis according to EU-27 at the Aggregate level

The above analysis showed the patterns of technological collaboration amongst the EU-15. Here we extend the analysis to the EU-27. A comparison of Figure 4-9 and Figure 4-14 shows that at the aggregate level, the levels and trends of co-patenting of the EU-15 and the EU-27 are almost identical. This is not surprising as the former constitute a very large share of patenting of the latter.

Figure 4-14: Trends in international co-patenting: EU-27 as a whole (EPO Data)



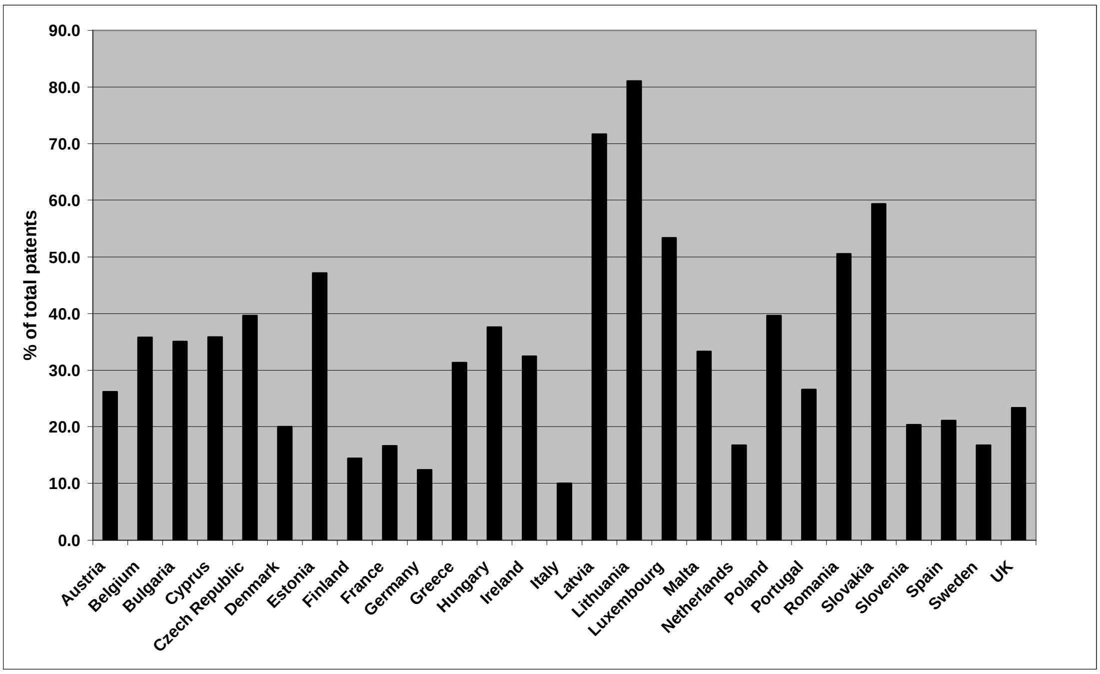
Source: PATSTAT; calculations by SPRU

4.2.2.5 Differences amongst EU-27 countries

In Figure 4-15-Figure 4-17 we analyse the differences amongst the EU-27 in terms of: (a) their overall level of collaboration; (b) intra-EU-27 collaboration; and (c) intra-EU-27 collaboration. The main message is that there are major differences amongst EU countries in their propensity to collaborate in the development of technology. In general the smaller EU countries have a much higher level of collaborations than the larger ones. Thus the countries with the highest level of international co-patenting are Latvia, Lithuania, Luxembourg and Slovakia (more than 50% of all their patents are collaborative) and those with the lowest are Italy and Germany.[36]

Figure 4-15-Figure 4-17 also show that there are major differences between the EU-15 and the New Member States. For example the average level of overall co-patenting (Figure 4-16) for the former countries is 24% but for the latter this average rises to 46%. The same applies to both intra and extra-EU co-patenting.

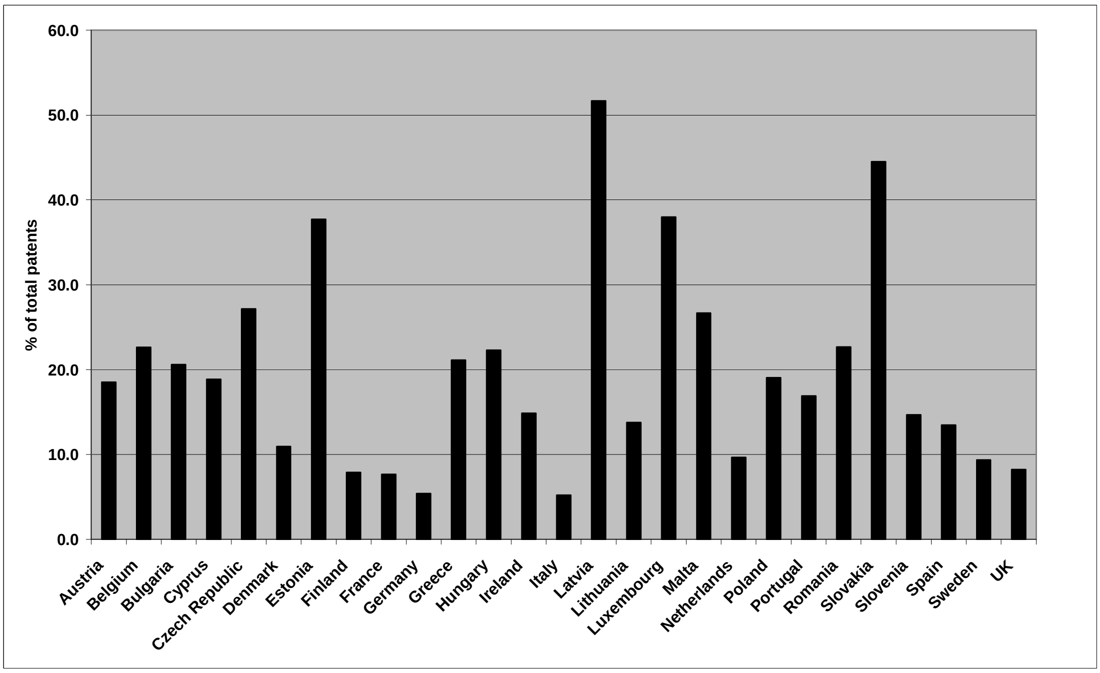
Figure 4-15: Differences amongst EU-27: All International Collaborations, 2000-2004 (EPO Data)



Source: PATSTAT; calculations by SPRU

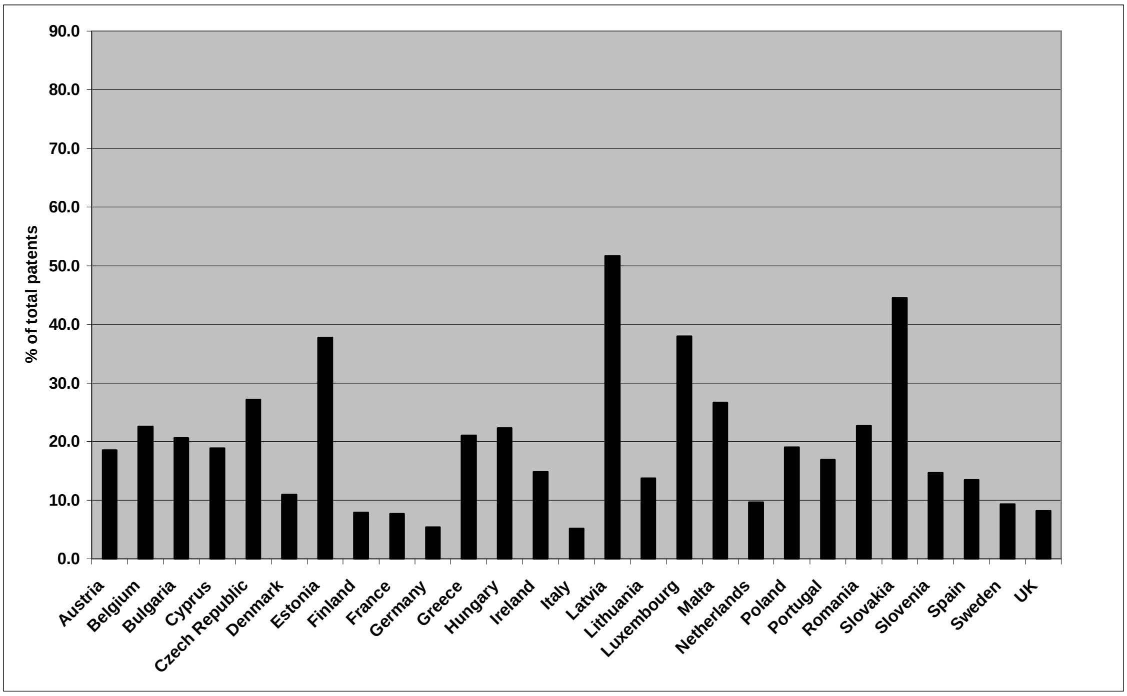
36 These results need to be interpreted with care as the level of patenting is very different between these countries (e.g. the average annual number of total patents for Latvia is 12 and for Germany this 23,106).

Figure 4-16: Differences amongst EU-27: Intra-EU Collaborations, 2000-2004 (EPO)



Source: PATSTAT; calculations by SPRU

Figure 4-17: Differences amongst EU-27: Extra-EU Collaborations, 2000-2004 (EPO)



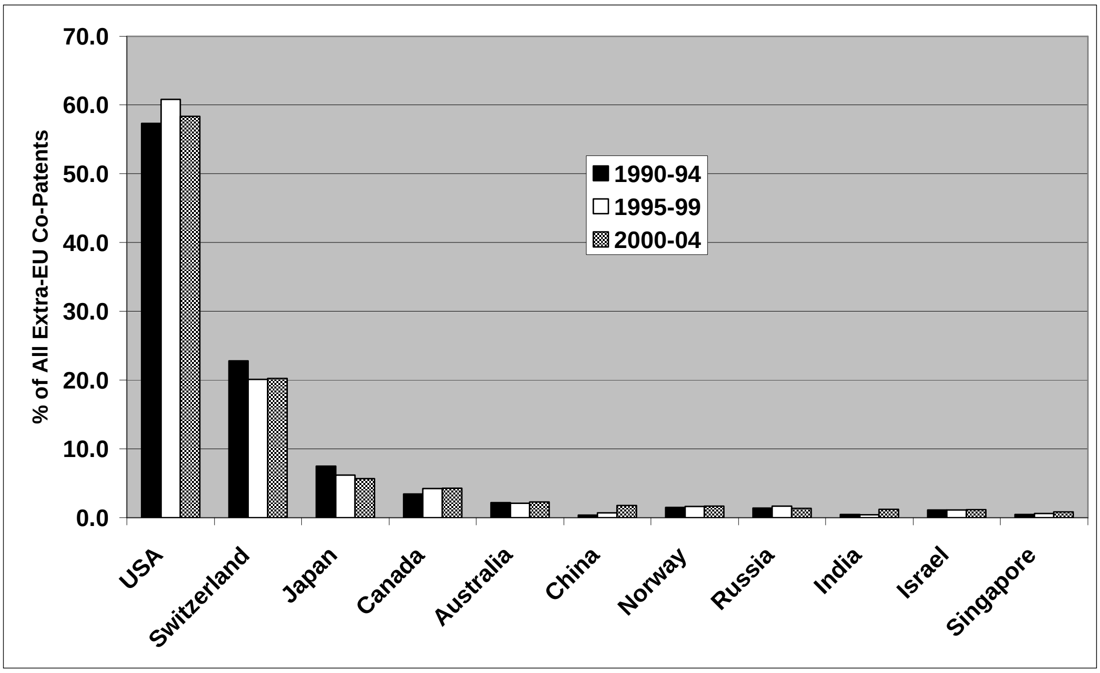
Source: PATSTAT; calculations by SPRU

There are some interesting patterns amongst countries. For example Lithuania and Latvia have very high proportion of patents that are internationally collaborative. However in the case of Lithuania the collaborations are with other EU countries and for Latvia these are with non-EU countries.

4.2.2.6 Collaborations with non-EU countries

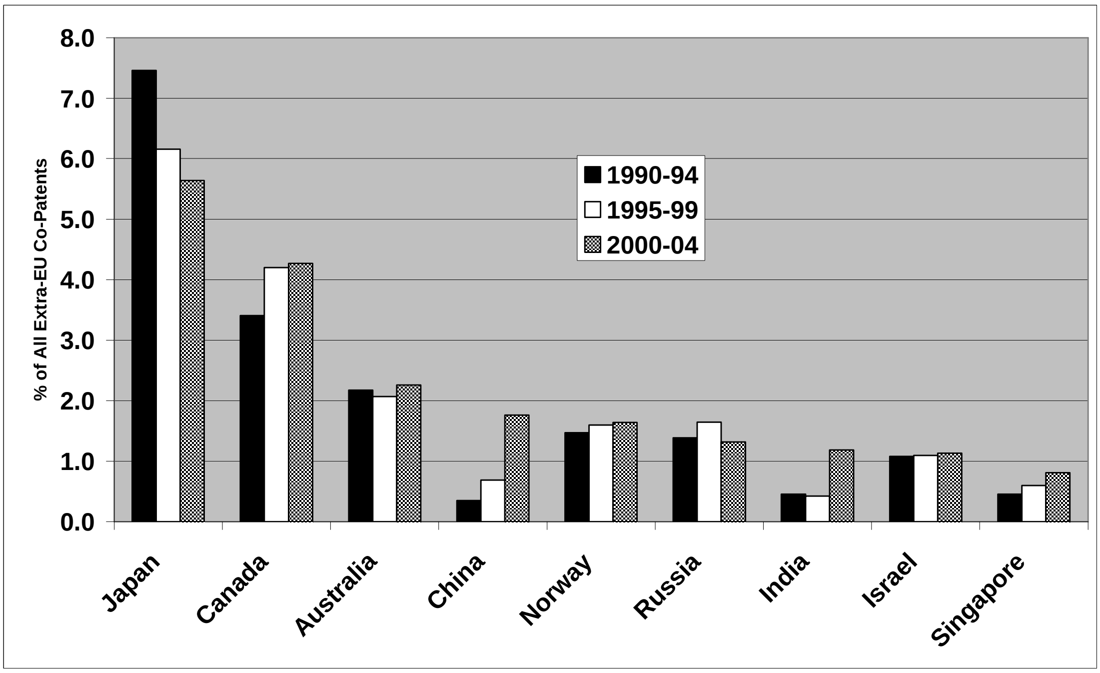
The final issue addressed on the basis of the EPO data is that of collaborations with non-EU countries. Figure 4-18 shows that two countries are dominant partners for the EU-27, namely US and Switzerland. They account for nearly 80% of all extra-EU co-patenting. Figure 4-19 highlights the fact that the biggest increases in technological collaborations since the early 1990s have been with China and India. They both accounted for less than 0.5% of all non-EU collaborations in 1990-94 but have since risen to 1.8% (China) and 1.2% (India) in 2002-04.

Figure 4-18: Extra-EU Collaborations (1), 1990-94 to 2000-2004 (EPO)



Source: PATSTAT; calculations by SPRU

Figure 4-19: Extra-EU Collaborations (2), 1990-94 to 2000-2004 (EPO)



Source: PATSTAT; calculations by SPRU

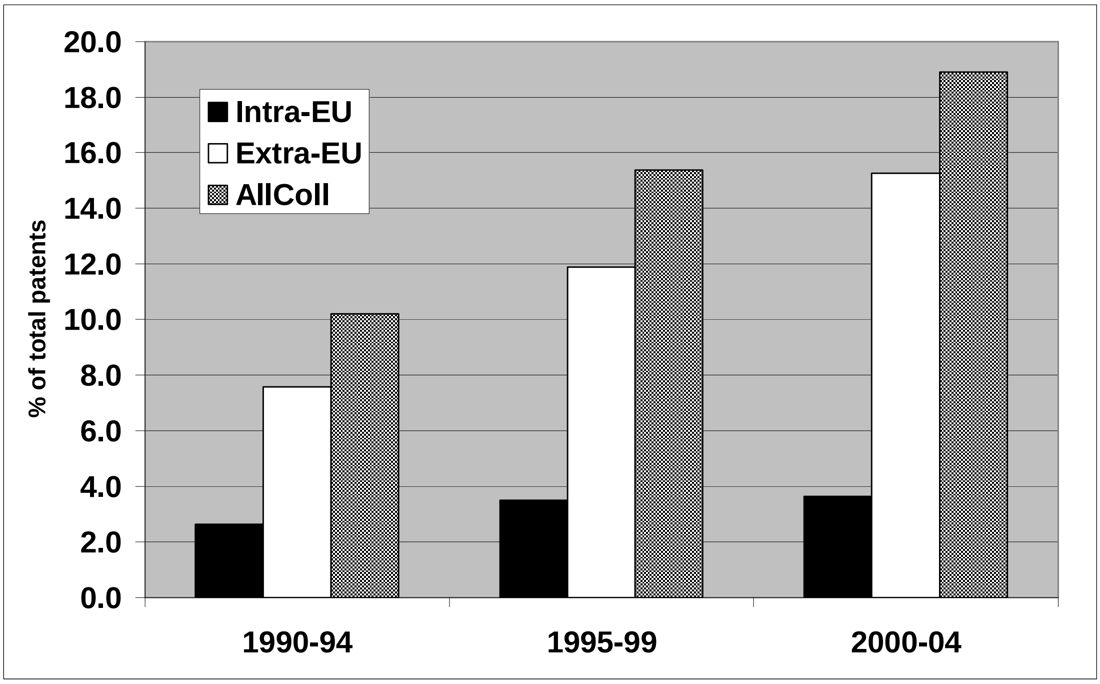
4.2.3 Main Results: USPTO data

We begin this analysis with a word of caution, which arises from the requirement of the ToR for the study that the analysis of the USPTO data should be based on the number of *granted* patents. This has two implications in terms of interpretation of the results. First it is difficult to compare the results here with those in section 2.2, which are based on patent *applications* at the EPO. It also means that the results for the latest priority years, reported below, have to be treated with some caution as many of the patents applied for in those years have not yet been examined. Our indicators, presented as shares, mitigate the last problem to some extent but do not eliminate it entirely.

4.2.3.1 Aggregate level: EU-27

The main message from analysing the EU-27 as a whole within the USPTO system, is that there has been an increase in the extent to which these countries are co-operating internationally (see Figure 4-20). Most of the increase can be explained by increasing level of collaboration with countries outside the EU. In 2000-04 more than 18% of all EU-27 patents were invented with inventors from more than one country. Within these international co-inventions nearly 80% involved inventors from outside the EU-27.

Figure 4-20: The extent of international co-patenting EU-27 as a whole (USPTO)

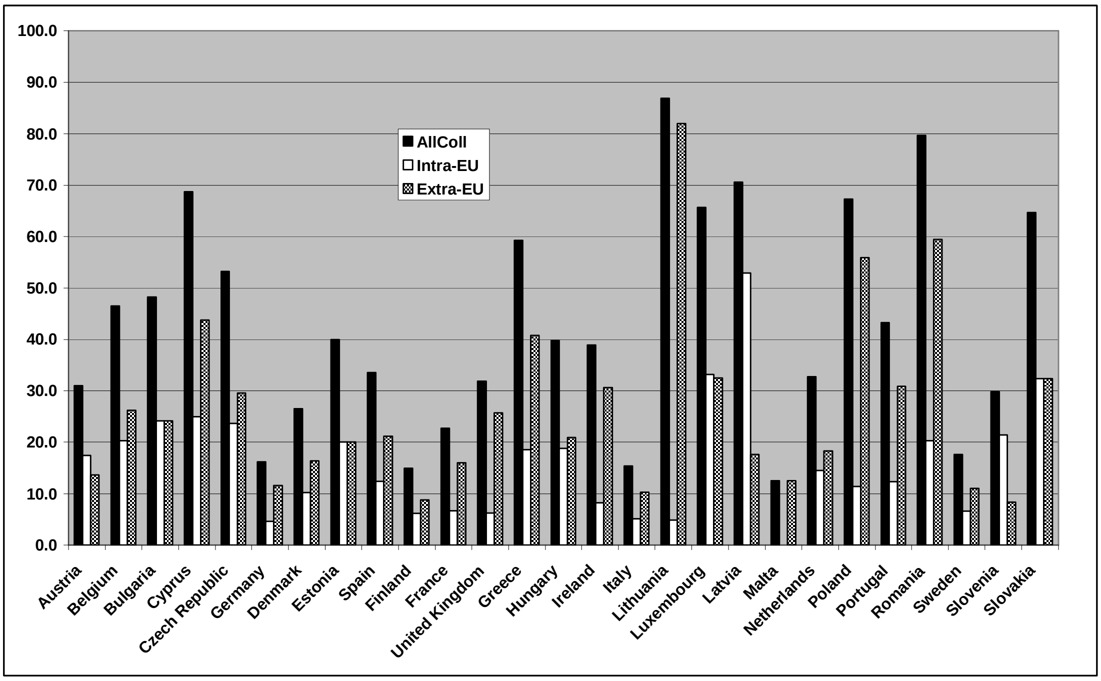


Source: PATSTAT; calculations by SPRU

4.2.3.2 Differences amongst the EU-27

Figure 4-21 presents the level of co-patenting amongst individual EU countries. It shows that these countries are in the main engaged in a high level of international collaboration. For 16 out of the 27 countries more than one-third of all patents are invented with inventors outside the home country, and for 9 of these the proportion is more than 50%.

Figure 4-21: International Co-Patenting amongst EU 27, 2000-2004 (USPTO Data)

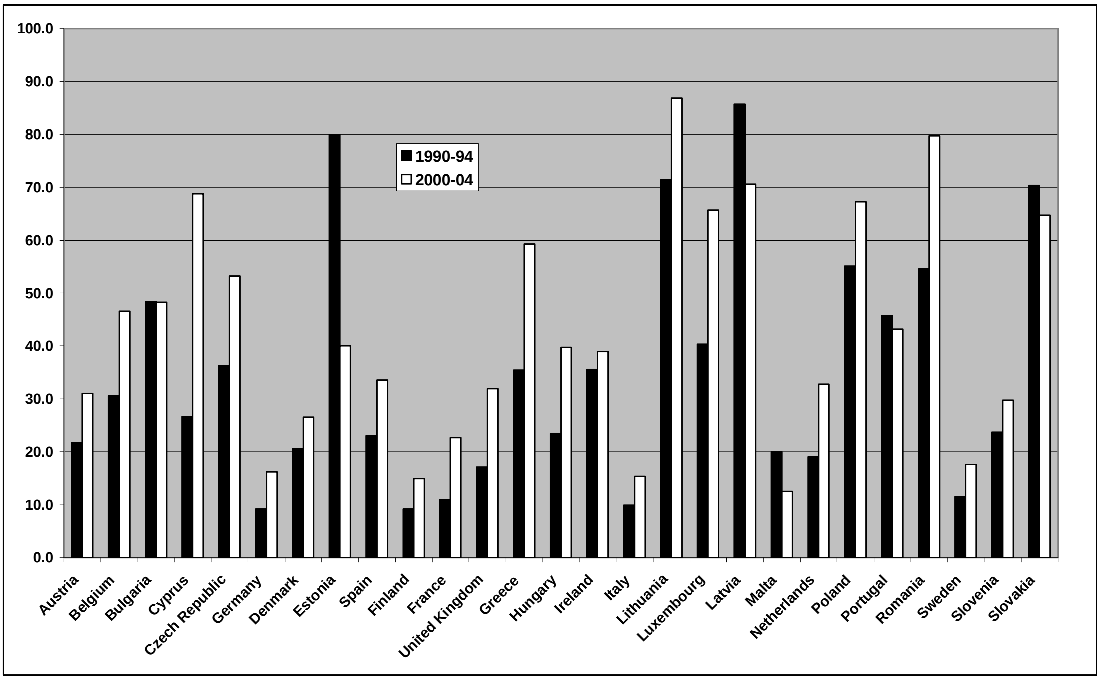


Source: PATSTAT; calculations by SPRU

There are some interesting differences amongst the countries in terms of the relative balance between intra-EU and extra-EU levels of technological collaborations. Thus for example for Austria, Latvia and Slovenia the proportion of intra-EU co-patenting is higher than that of extra-EU patenting. For most other countries the pattern is reversed.

In Figure 4-22 we report the trends in international co-patenting. The main message reported above in relation to the EU as a whole is equally valid here: there has been an increase in the extent to which EU countries are co-operating internationally to develop their technology. The only countries where this has not been the case are Estonia, Latvia, Malta and Slovakia.

Figure 4-22: Trends in International Co-Patenting amongst EU 27, 1990-1994 to 2000-2004 (USPTO Data)



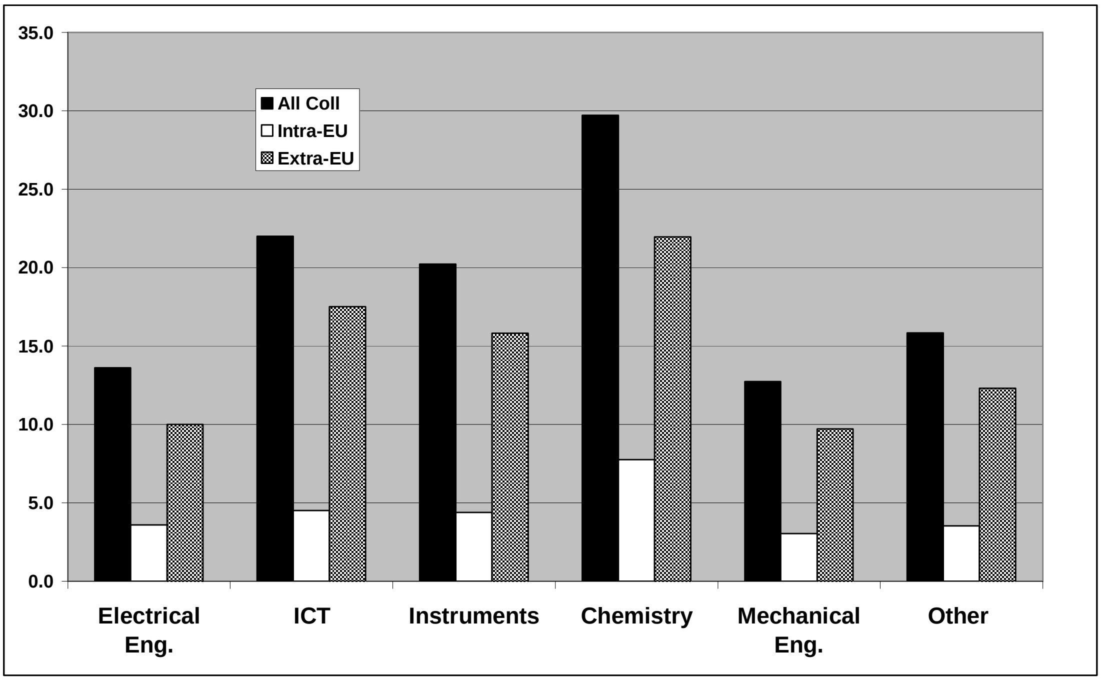
Source: PATSTAT; calculations by SPRU

4.2.3.3 Differences amongst Technical Fields

Figure 4-23 and Figure 4-24 report the analysis of co-patenting based on USPTO data according to 6 technical fields. The results show that there are major differences across these fields in terms of the level of international collaborations for EU countries as a whole. Figure 4-23 shows that technologies related to Chemistry have a relatively high proportion of patents with foreign inventors and those related to Mechanical and Electrical engineering have very low proportions. Moreover across all 6 technical fields extra-EU collaborations are relatively more important than those with other EU countries.

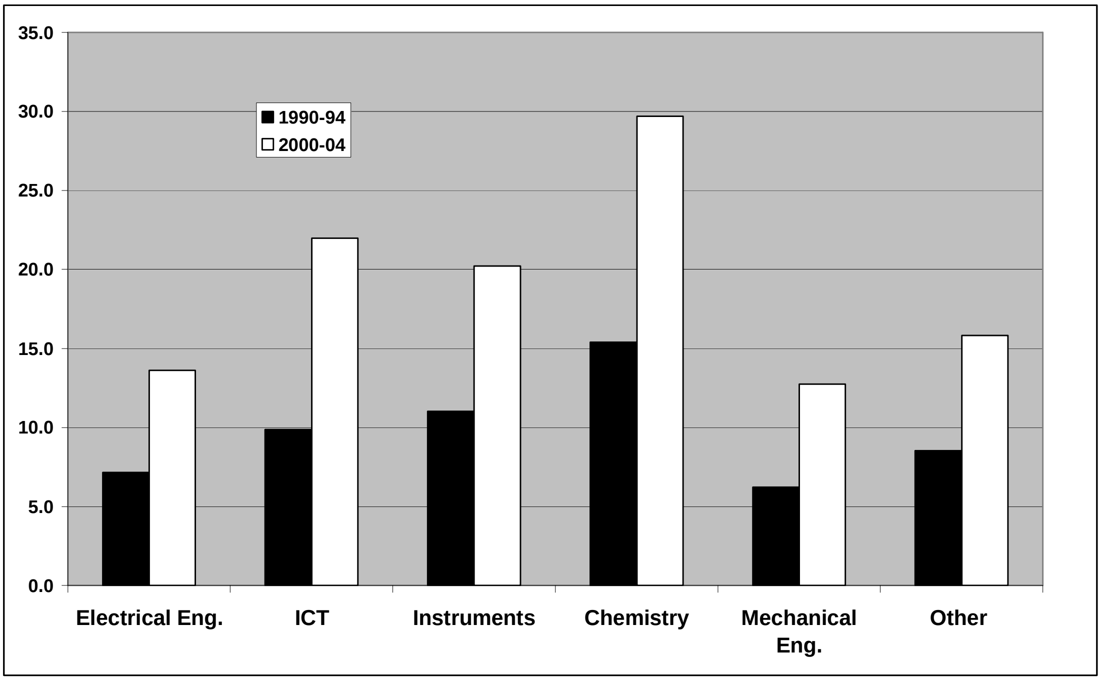
In Figure 4-24 we show the trends in the share of international co-patenting in different technical fields for the EU as a whole since the 1990s. The main point to emerge is that technological collaborations have increased across all areas of technology.

Figure 4-23: International Co-Patenting of EU-27 countries in 6 Technical Fields, 2000-2004 (USPTO Data)



Source: PATSTAT; calculations by SPRU

Figure 4-24: Trends International Co-Patenting of EU-27 countries in 6 Technical Fields, 1990 to 2004 (USPTO Data)



Source: PATSTAT; calculations by SPRU

4.2.4 Conclusions

The aim of this section was to report the results for analysing the levels and trends in international technological collaborations of EU countries, as measured by their co-patenting activities. The main results to emerge are as follows:

- Since the early 1990s, there has been an increase in the share of technology developed with international partners for the EU as a whole, and amongst most individual EU countries.
- This increase has been driven by increases in extra-EU collaborations. The share of intra-EU collaborations has increased but by much less than the extra-EU share.
- There is some indication that country size (whether technological or economic) may be a factor in explaining inter-country differences in the levels and trends of the share of international technological collaborations. However there are examples of large countries with relatively high proportions of collaborative activities and small countries with relatively low proportions.
- The three countries that appear amongst the innovation leaders in the EU (based on the European Innovation Scoreboard) namely Finland, Sweden and Germany have a relatively low share technology developed on the basis of international collaborations. On the other hand some of the countries with the largest share are below average in terms of the innovation scoreboard rankings: Latvia and Lithuania.
- The most important co-operation partners for the EU countries are the US and Switzerland. However the largest increases in technological collaborations, albeit for a small base, have been with China and India.
- The technical field with the largest share of international collaborations for the EU countries as a whole is Chemistry. This is traditionally an area of EU technological strength. The other field where the share of internationally developed technology is relatively high is Instruments.

4.3 Network Analysis of Publications and Patents

4.3.1 Introduction

In the following chapters we will attempt to identify the cohesion and changes in structures of cooperation among the 27 member states of the European Union as well as the United States of America and Switzerland. As the other chapters of the report have shown the relevance of cooperation, clearly visible through the rise of importance of both co-patenting and co-publications between countries, has increased gradually and steadily in the last decade. Still, measures that relate to abstract aggregates like the combined share of cooperation within the EU or outside the EU can only shed a dim light on the actual processes of structuring, i.e. the formation of patterns of cooperation and their changes over time. What is missing is a more refined view of the patterns that emerge between the actual countries. The reason for this is simple and can be exemplified easily. Even though the share of co-publications could rise for each single country within the EU-27 this does not necessarily mean that this increase is evenly distributed among the potential partners of cooperation. The easiest way to think about this is by thinking about different ways a cooperation network might look like. On the one hand such a network could be shaped like a star, i.e. a central actor that absorbs most if not all of the co-operations of all other countries with "satellite countries" arranging around this important country. An increase in cooperation would then all be aimed at an increase of this central country having the characteristic of a hub. On the other hand a network might be organized in a way where each country is connected to each other country, making the network appear like a huge, you might even say chaotic mess of linkages between all the countries with no clear structure. An increase in cooperation might then be evenly distributed among all partners, i.e. the number of cooperation pattern increases for all countries in the same way. Both patterns are rather unrealistic and research has shown that what is most often observed is a distribution of linkage that follows a log-normal distribution with many lowly connected countries and some few countries that feature a high level of linkage. Such patterns are potentially prone to change over time. Changes might occur on the level of a bilateral increase or decrease in importance of specific country pairs or clusters. Changes might also occur in the other sense, i.e. an increase in cohesion of the system seen as a holistic body. All those changes might have a thematic oriented focus, i.e. observing the changes in co-operation might greatly vary between fields of technology or research and even might vary systematically between "realms of activity", like the realm of science and research and the realm of innovation activities. Most of those aspects, which are of utmost importance to determine the state of the European Research Area, can not be covered using aggregates like the intra- and extra-EU share of cooperation. To answer the implicit questions that follow from these thoughts one is required to identify patterns. Such patterns can be discovered using specific methods, some of which have already been discussed briefly in the literature review. These methods, driven by the assumption of the relations between units of interaction, are based on graph theoretical approaches and can be found in the methods of Social Network Analysis and on exploratory methods like cluster analysis. In this report we use data based on publications and patents for a number of fields at two distinct timeframes, one of these timeframes in the early and mid 1990s and one that relates to the most recent years. Using the methods mentioned above, combined with appropriate visualization techniques, we will try to paint a picture of the European Research Area that highlights both the central players in the system as well as the development of the system over time.

4.3.2 Methods to identify changes in cooperation among countries

As we have already argued above an indicator-based analysis of the changes in the level of cooperation between countries can not be achieved using one single method. Rather, a set of methods has to be applied to achieve the following goals:

- Identification of the mutual interdependence on the levels of countries and observe the changes in these interdependencies over time.
- Identification of the breadth of countries portfolios of cooperation activities to differentiate between focussed convergence and diffused convergence on the level of countries.
- Measures that relate to the development of the realm of research and innovation as a whole (i.e. describe differences that relate to the whole network rather than the different countries).

To achieve the goal of reducing the complexity explorative methods like visualization of the networks are the most appropriate means. The advantage of this visual approach of analyses is that they can show the evolution of structures and changes on how countries are closely interrelated. The results of the visual analysis will help to identify broad stable interrelations between countries in the form of clusters of these countries. This explorative clustering is not sufficient for an analysis of cooperation as it neither provides adequate information on the breadth of the countries as well as the degree on how the interrelation of the countries developed over time.

To account for the latter issue we analyse the trends of structuration using a modified version of Cross-Impact Assessments (CIA), a methodology used in scenario techniques to make forecasts by using probabilities affixed to certain events and dependencies between those events. In our version of CIA we transformed the data by normalizing each column of the co-publication and co-patenting matrices according to the value on the diagonal of the matrix for this column. Our method here is similar to the method employed by Changwoo et al. (2007) who use it to determine the spill-over between technical fields in Information and Communication Technology.[37] The matrix resulting from this transformation then represents the portfolio of interrelations in terms of fractions of the number of cooperations with other countries leading to an asymmet-

37 In contrast to Changwoo et al. (2007) our approach is different as it accounts for all interrelations not just those of a subset of fields that neglects the importance of the fields missing from the analysis that leads to a gross overestimation of the mutual impacts of the fields in the subset. The other difference relates to the above mentioned substitution of the matrix diagonal with the number of co-classifications rather than taking the absolute number of all documents as a reference.

rical matrix that can be analyzed from two points of view. For each pair of country A and country B two different measures can be derived which relate to the relative importance of each country in the other country's portfolio. That way, the analysis accounts for the share of country A in the portfolio of country B and vice versa. Using this method we also account for asymmetrical importance relative to the differences in total number of patents or publications in a country. Using this method we search for trends in the country portfolios where both shares have increased. This is repeated for all possible iterations of country pairs. The information we get from this analysis is very detailed in nature allowing for country-based analysis and is to be seen as complementary to the agglomeration of countries resulting from the cluster analysis.

A further methods applied is a measure of breadth that helps us distinguish between focused countries and countries that are broad in a sense that the cooperation portfolio of the country is more evenly distributed. We used the measure of Entropy which in mathematical formulation is represented as

$$F_i = -\sum_k p_{ik} \ln p_{ik}$$

where F_i denotes the Entropy of country i and p_{ik} is the share of another country k in the portfolio of country i under the condition that

$$\sum p_{ik} = 1.$$

This measure can be determined for each country portfolio using the asymmetrical matrices produced for the cross-impact assessment. The Entropy measure has a range between 0 representing a country where the cooperation is limited to one country whereby the share of this iteration is 100% and the theoretical maximum of Entropy for the number of countries n as

$$F_{max} = -\ln [\ 1/(n-1)\ ].$$

An Entropy value of 0 therefore represents a highly focused country and high Entropy values represent more diversity in a country portfolio. This measure is then analyzed for each time period and is used to determine the relative level of functional differentiation of these countries relative to other countries.[38] A country that is characterised by an increase in Entropy can then be analyzed further as to which countries are relevant for this differentiation using the results from the CIA analysis. Generally speaking, an

38 As the number of countries n is held constant in the analysis the entropy measures can be compared over time.

increase in Entropy values for a large number of countries using data based on EU-27 cooperations might cautiously be referred to as an "ERA effect".[39]

Apart from these methods that are more rooted in foresight we use methods that have been developed in the discipline of Social Network Analysis. In the case of a cooperation network we might generally use methods that can be applied to integer valued undirected graphs.[40] In our case we used basically two methods from network analysis combined with several visualization methods. Those two measures are the density measure to describe the system as a whole and the betweenness measure that relates to the individual network positions (countries). The density measure tells us something about the extent of the strength of interrelations in a network. An increase in density of a network therefore gives information about the change of the network as a whole. Generally, if the density of a network increases this means that on the whole the system under analysis becomes more connected, i.e. there are more links between the individual nodes (in this case the countries). The more connections can be found the stronger the overall level of colaboration. Usually this is done by counting the links in a network and compare it to the maximum number of possible links within a network. In a valued graph, i.e. when the number of publications are taken into account, this might lead to confusion as we want to make a valid judgement about the actual extent of cooperations relative to the number of cooperations. We therefore use an alternative density measure for valued graphs.[41] The measure we used can be safely interpreted in the following way. If the average number of co-publications increases the system

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39 A word of caution is in order here. As we analyse only EU-27 (+US and CH) one might overshoot the interpretation of an ERA effect. Such an effect might well be rooted not in the effects of policy actions but rather in the inherent logic of the scientific sphere itself, e.g. a tendency of the research system to evolve into a denser network. An analysis that could aim to find a policy-based ERA effect would have to include substantially more data both in the number of countries used in the analysis as well as more points in time to account for cause-effect relationships.

40 Actually, the fact that we have a valued graph allows us to use the more straightforward cluster analysis which is easier to interpret rather than using blockmodels which have are based on more complex calculations and are more cumbersome to interpret correctly bearing the danger of misinterpretation.

41 The usual density measure works in a binary fashion, i.e. it differentiates only between "link present" and "link not present" and is the ratio of links present to all links that could be realized. In our case this is not a sensible measure. There is considerable discussion in the research community about how to determine a sensible density measure of a valued graph. Usually, the average values attached to edges of a network (number of cooperations between dyads of countries) across all edges (countries). The authors position on this issue is that what is generally suggested as a good measure in fact is not as in bibliometrics we are most of the time faced with log-normal distribution of values. We therefore also report the Quartiles including the median as well to give a better impression of the overall change in the density of the network and the distribution of co-publications.

becomes more "averagely more coherent" as to the level of cooperations. As we hold the number of countries constant we can compare these values over time. Another measure, the betweenness centrality, relates to the network positions (countries) and generally helps to pinpoint units that are "in the middle" of other units, in our case the countries that are "between" other countries and exert, according to theory, a stronger control over information flows.[42] In our case the interpretation is that those countries are important to link groups of other countries together. Assuming that large projects require information to flow across the ERA those countries that feature a high betweenness are those that can distribute that knowledge more effectively. Generally such a position becomes more probable with the increase in size (total amount of output) of a country and the increase in number of total cooperations. Still, it is valuable to analyze this notion as to determine a ranking of those countries that are most important to the operation of the system as a whole.

For visualization we refer to the usual methods of plotting graphs used in network analysis. We use different methods of layouting the network graphs. One method of placement is the commonly applied Fruchterman-Reingold force-directed algorithm. In other representations we use either the position of the capital of a country (with slight modifications in certain cases) to show how the cooperations relate to geographical positions. As we use valued paths we are posed with certain challenges of which links to plot in a network graph. For instance, it will not help to analyze these plots visually if all the links are plotted regardless of the strength of the link, e.g. if there is only one cooperation between two countries and both countries produce a large amount of output it is hard to justify drawing that link. We use the Jaccard Index which is defined as the ratio of the intersection of two sets (A and B) and the union of those two sets (A or B) or

$$n_{ij}/(n_i+n_j-n_{ij}).$$

with n_{ij} as the number of cooperations and n_i and n_j as the total amount produced by both countries. The Jaccard Index differs from the Salton Measure which is definded as[43]:

$$nij/\sqrt{ni*nj}\ .$$

---

42 In order to use the betweenness measure we transformed the integer weighted graph to an unweighted multigraph as suggested by Newman (2004). The interpretation of the values is similar to the betweenness measure that can be applied to binary graphs.

43 The Jaccard Index is 0 if the two sets are completely disjoint, i.e. there are no cooperations and 1 if they are identical, i.e. all publications of two countries are co-publication involving both). The Jaccard Index usually produces results at half the numerical values of the Salton Cosine. For a more detailed explanation of this refer to Hamers et al. (1989) or Leydesdorff (2008)

We prefer the Jaccard Index over the Salton Measure as it can be shown that the latter underestimates the links between small and large countries (Luukkonen et al. 1993).

4.3.3 Science and research cooperations within the European Research Area

In the following we will analyze the scientific cooperation patterns within a set of 29 countries (EU-27, US, CH) at two different points in time and for certain based on publications extracted from the Science Citation Index. To analyze the trends in the formation of a European Research Area we use data from the fields of Engineering, Life Science, Medicine, Natural Science as well as all publications produced by the 29 countries. We also cover two periods, the including publications from 1994 to 1996 the second covering the years from 2004 to 2006. Our aim here is to analyze the evolution of the fields as a whole as well as the emergence of new structures in the ERA based on the formation of agglomerations of countries. Moreover we will try to validate the claim that the recent development in the European Research Area does not only benefit the large players like Germany, France or the United Kingdom but also led to an integration of smaller countries.

4.3.3.1 Analysis of overall network density measures in publications

Most of these tendencies are also reflected if we analyze the evolution of the network structure in the different fields. Still, there are differences between fields as to their level of overall cohesion. In total we can see that both the median as well as the average number of co-publications (density) has nearly doubled if we take the whole system into account. The strongest increase in average number of co-publications over all country dyads is found in medicine where the average number of co-publication has increased by a factor of 2.7. number of co-publications.

Table 4-1: Overall network density measures of co-publications in the periods of 1994-1996 and 2004-2006

	Minimum	1st Qu.	Median	Network Density (Mean)	3rd Qu.	Maximum
Engineering (1994-1996)	0	1	10,0	70,5	53	1872
Engineering (2004-2006)	0	6	38,0	171,5	136	4063
Life Science (1994-1996)	0	1	9,0	101,6	51	3609
Life Science (2004-2006)	0	5	27,5	206,9	133	6728
Medicine (1994-1996)	0	2	11,0	143,6	70	4206
Medicine (2004-2006)	0	10	44,0	385,4	231	10250
Natural Science (1994-1996)	0	2	43,5	227,1	174	6595
Natural Science (2004-2006)	0	17	106,5	560,1	461	13720
All Publications (1994-1996)	0	9	87,5	522,9	363	14380
All Publications (2004-2006)	0	37	189,0	1150,0	843	29550

Source: SCI (STN), calculations Fraunhofer ISI

The same holds true for the median of the distributions where the increase in some cases even quadrupled like in the case of medicine or Engineering. Still, such aggregate measures only represent a fraction of the information in the data. It is therefore useful to also look at the evolution of the networks over time as we did in the previous figures. From a network perspective we can see that the strongest increase in strong network links can be found in the more basic fields like the natural sciences or medicine. Both in Life Science and Medicine we also can see the development of a Scandinavian-North European Network. In the field of Engineering the situation is different. Here we find that the increase in Density is mostly to be attributed to strong links between the larger countries of continental Europe. Overall we found an increase in cohesion over all fields.

4.3.3.2 Visualualisation of network structures for publications

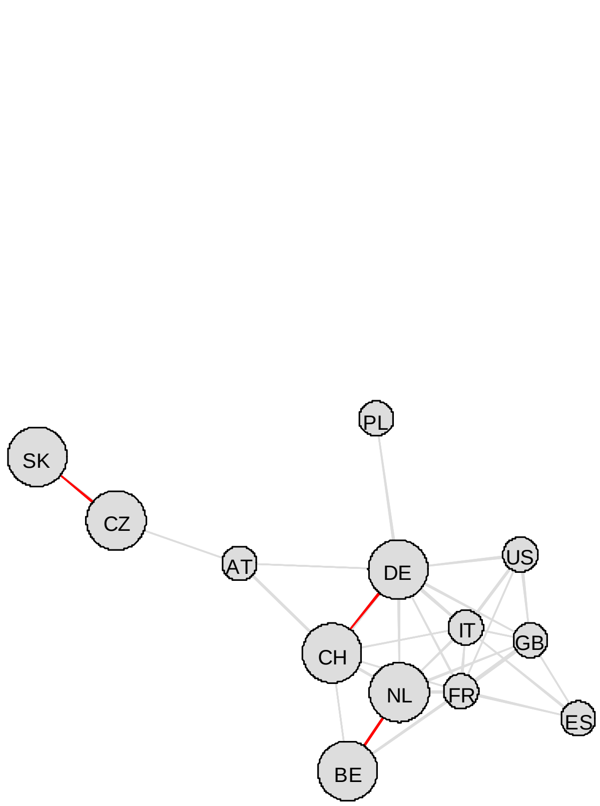
Our first attempt will aim at a description of the whole research system, i.e. all the publications covered in the two periods. The network data has been visualized using Jaccard Indices with red lines representing a Jaccard Index above .2 and light grey lines representing a Jaccard Index above .1. Links that are below that threshold as well as countries that do not feature at least one link above a Jaccard Index of .1 are excluded from visualization. Visualizations layouts are based on the Fruchterman-Rheingold algorithm which gives a better impression of the clustering of the network (see Figure

4-25 and Figure 4-26). Another advantage of this type of visualization is that as the linkage between countries increase the algorithm will position them closer together. Apart from this visualization we use the geographical location of the countries which will help to analyze how the distance between countries influences the strength of links and how the European Research Area integrated the smaller european countries in the north and east of Europe (see Figure 4-27 and Figure 4-28).

Comparing the periods of 1994-1996 and 2004-2006 we can see that overall the strength of links has increased especially among the large central European countries. While in 1994 to 1996 only Switzerland and Germany, Denmark and Sweden, Belgium and the Netherlands as well as the Czech Republic and Slovakia[44] are strongly linked, the number of strong links in the period of 2004-2006 covers most of the possible links between the large core countries of Europe. Moreover the US is stronger integrated now featuring a strong link to the Germany and the United Kingdom.

44 This link is very stable over all fields and bears and shows how history plays an important role in scientific cooperation structures.

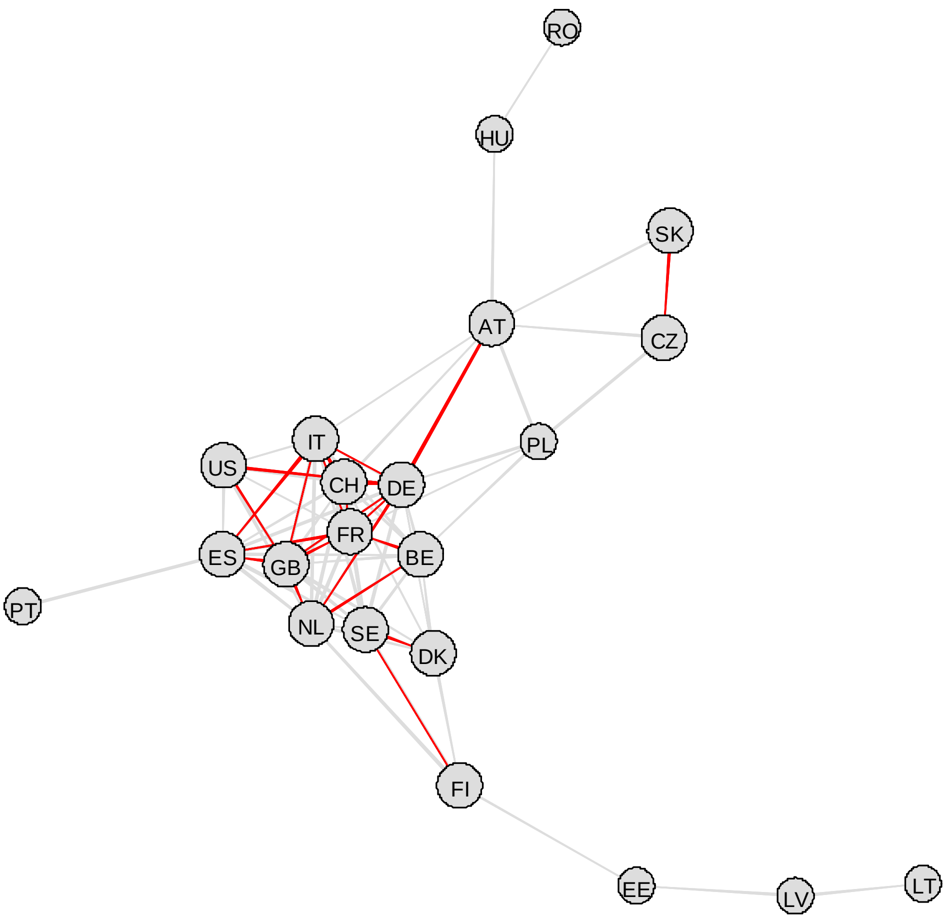
Figure 4-25: Network of EU-27 plus US & CH based on all publications in the period of 1994-1996



Source: SCI (STN), calculations Fraunhofer ISI, positions using Fruchterman-Rheingold algorithm

Apart from the increased strength of links we also find that the Scandinavian countries form a separate group in 1994 to 1996 that is not integrated into the continental European cooperation structure. This situation has changed and in the period of 2004-2006 we can find that the Scandinavian countries now are stronger integrated into the ERA via a large number of links of Sweden and Denmark to continental Europe. This evolution of cooperation between continental Europe and Sweden and Denmark can also be observed through the change in position in Figure 4-26 where both Sweden and Denmark moved closer to the continental European network which is itself closely connected.

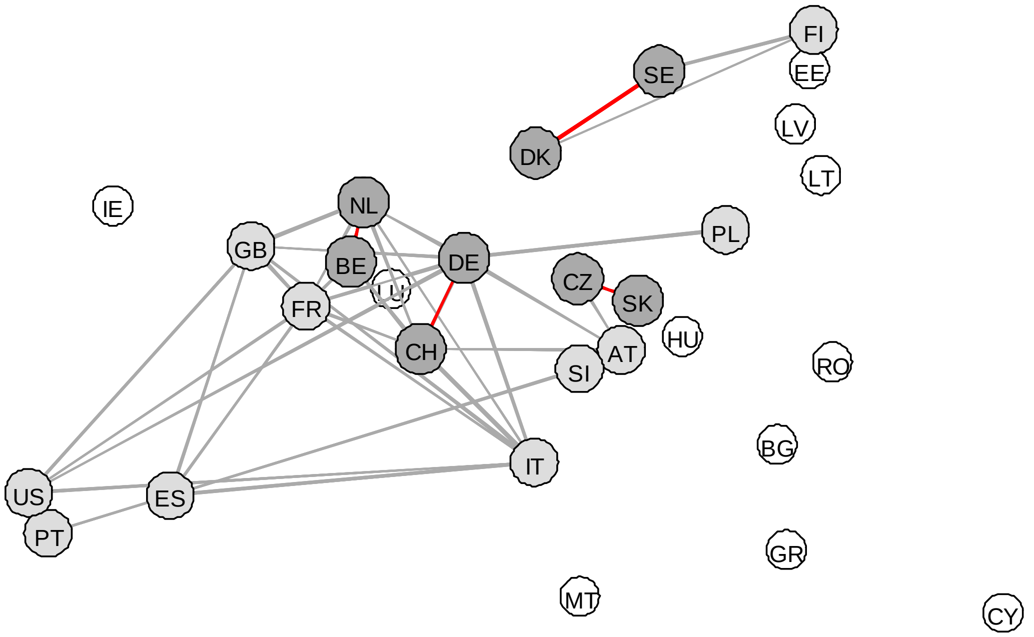
Figure 4-26: Cooperation network based on all publications in the period of 2004-2006



Source: SCI (STN), calculations Fraunhofer ISI, positions using Fruchterman-Rheingold algorithm

Finland acts as a bridge from the Scandinavian countries to the north east of Europe. The link from Scandinavia to these countries is established mostly based on the geographical locations. The countries of Finland, Estonia, Latvia and Lithuania are arranged like pearls on a string, i.e. there are links between the countries that are direct geographical neighbours (see Figure 4-28). In some cases links also disappear over time. Here it has to be noted, that in some cases, especially for smaller countries the absolute number of pair wise co-publications on country level are rather small. Even though we can partly control for such erratic effects using appropriate methods of complexity reduction like the Jaccard Index, there is no method available the fully can eliminate the effects of small numbers on the statistics performed.

Figure 4-27: Cooperation network based on all publications in the period of 1994 to 1996 using geographical locations

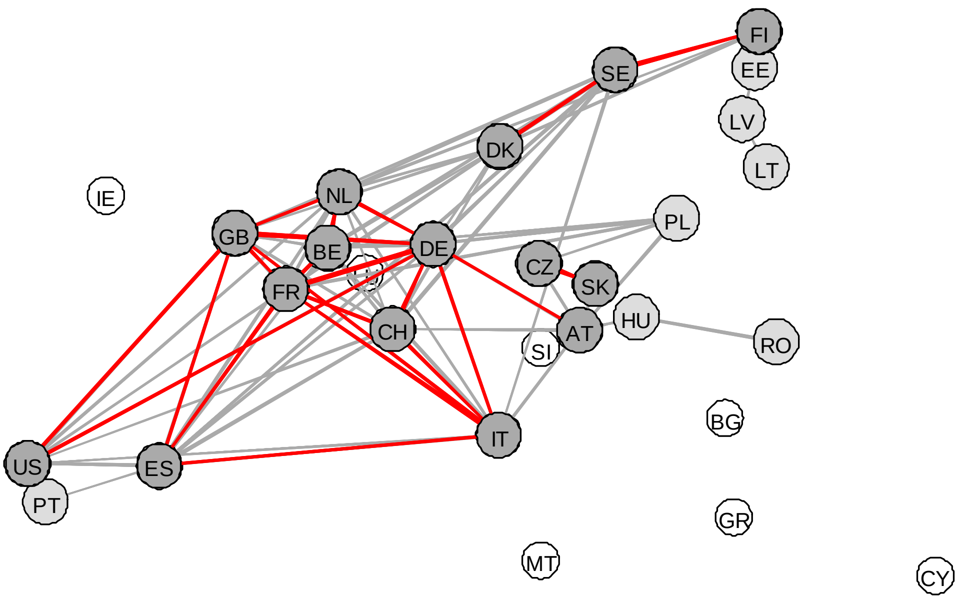


Source: SCI (STN), calculations Fraunhofer ISI, positions using geographical locations

As in principle the network structures from a mathematical standpoint represent graphs, the position of the nodes is contingent, i.e. the position as such in a visualization of a graph can only be a means for orientation but do explicitly not represent a general mathematical principle. Some positioning algorithms, like the commonly applied Fruchterman-Rheingold algorithm, can help to visualize relations and distinguish heavily linked nodes in a network from more isolated ones. This method can be deceptive in some respects as it poses no hard evidence of the true evolution in terms of positions and roles the countries play in the evolution of a network on a hard quantitative basis. The depth of interpretation is limited to fuzzy gut-feeling interpretations of the positions and the relevance. Also, they are prone to misinterpretation due to rotation of the network. Even though there are modifications to the original Fruchterman-Rheingold algorithm, the so called RBFR (Rubber Band modified Fruchterman-Rheingold) there is still a strong erratic character to the change in position of nodes with low connectedness and low degree values. Such nodes tend to "jump" around making a purely visual analysis both cumbersome and pointless, one might even say "dangerous" if used for large scale decisions on policy level. As from a graph-theoretical standpoint the position of nodes does not hold any particular information, in fact the math behind graph theory does ignore such aspects completely, we chose to use a mixed method that highlights distance and geographical neighbourhood as criterion in the visualization and in the later part of this chapter uses more reliable statistical measures that leave less leeway for misinterpretation. This method highlights the geographical aspects of scientific and technical evolution of networks among neighbouring countries but poses the trade-off that the "core" countries are visualized solely by their amount of linkage. The visualizations therefore have the analytical function to show the evolution of the network relative to geographical distances; the statistical measures presented later in this chapter have the function to pinpoint the roles of the countries.

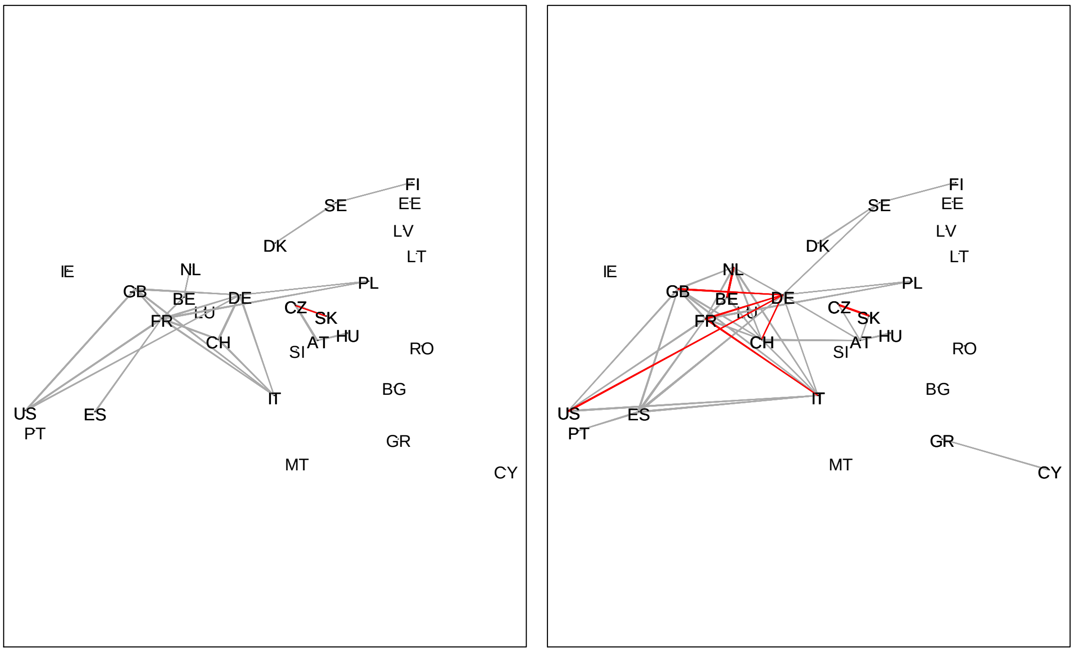
Focusing more on the geographical locations of countries we can also see that the amount of only loosely connected countries that are below the threshold of a Jaccard Index of .1 has significantly decreased. We used a white circle in Figure 4-27 and Figure 4-28 to visualize those countries that bear only weak connections. The number of those isolated countries has decreased over time. Apart from the already mentioned countries of Estonia, Latvia and Lithuania we have a moderate integration of two other eastern European: Hungary and Romania. Still, this integrative development of the research system does not seem to span to the south eastern countries like Greece, Malta or Cyprus. Also Ireland remains mostly isolated. This is mostly due to the fact that co-operations in Ireland seem to be largely focused on co-operations with only one other EU-27 country, namely the United Kingdom.

Figure 4-28: Cooperation network based on all publications in the period of 2004 to 2006 using geographical locations



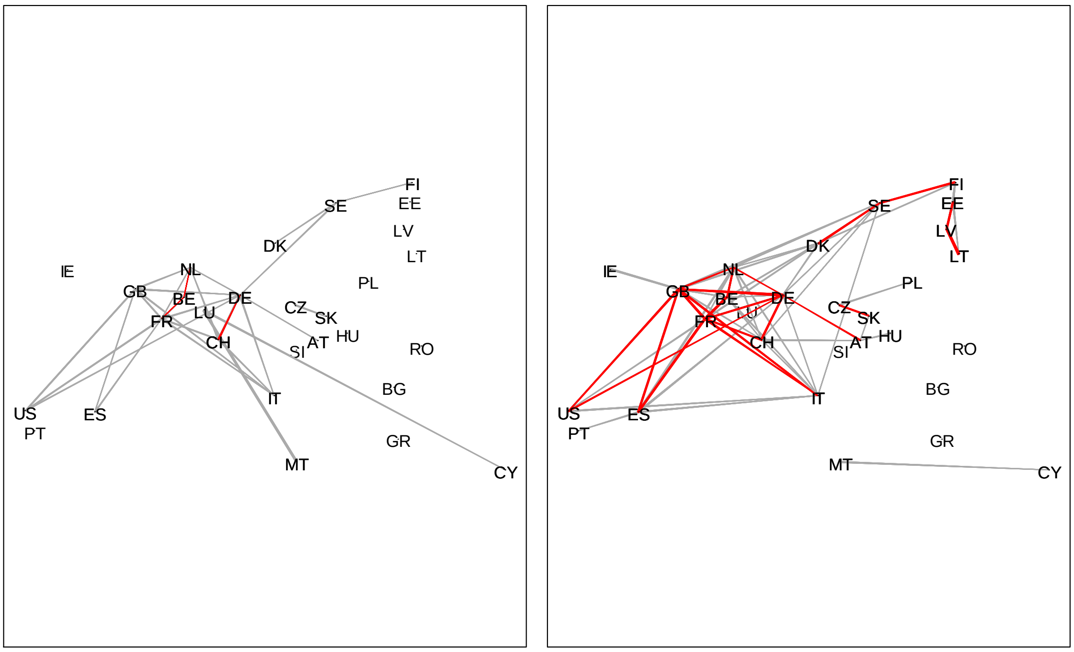
Source: SCI (STN), calculations Fraunhofer ISI, positions using geographical locations

Figure 4-29: Cooperation network based on publications in the field of engineering for the periods of 1994-1996 and 2004-2006 using geographical locations



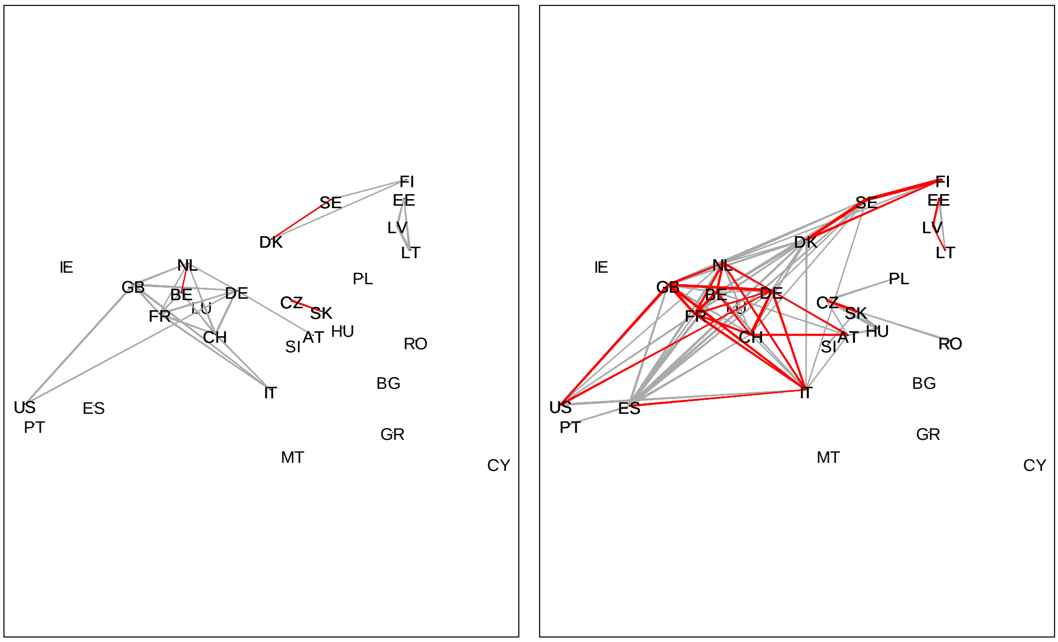
Source: SCI (STN), calculations Fraunhofer ISI positions using geographical locations

Figure 4-30: Cooperation network based on publications in the field of Life Sciences for the periods of 1994-1996 and 2004-2006 using geographical locations



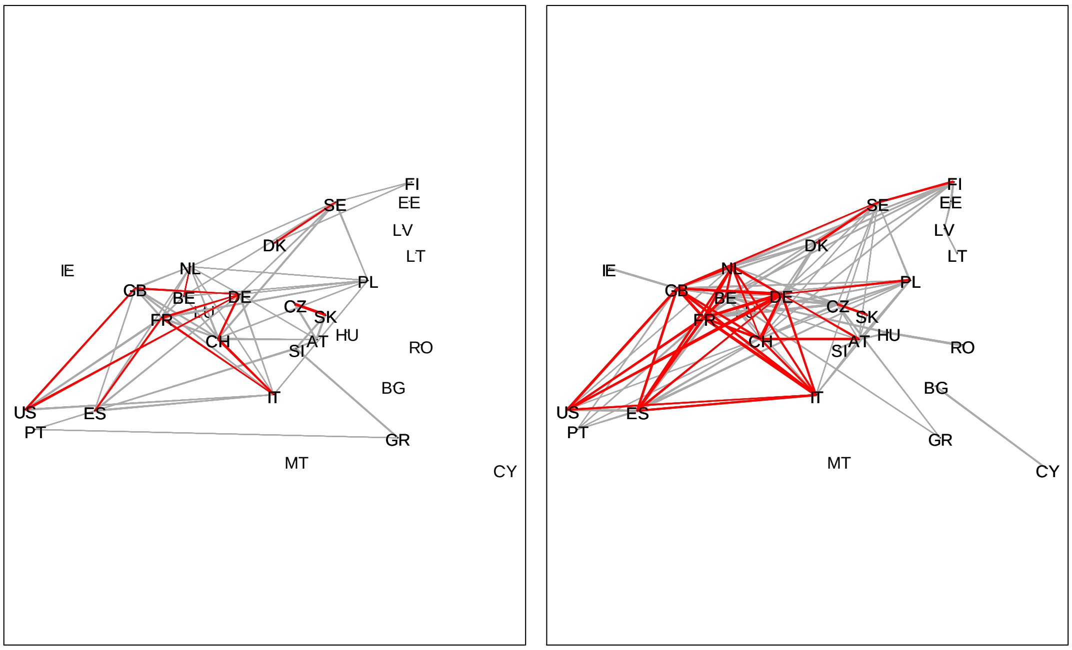
Source: SCI (STN), calculations Fraunhofer ISI positions using geographical locations

Figure 4-31: Cooperation network based on publications in the field of Medicine for the periods of 1994-1996 and 2004-2006 using geographical locations



Source: SCI (STN), calculations Fraunhofer ISI positions using geographical locations

Figure 4-32: Cooperation network based on publications in the field of Natural Sciences for the periods of 1994-1996 and 2004-2006 using geographical locations



Source: SCI (STN), calculations Fraunhofer ISI positions using geographical locations

4.3.3.3 Analysis of co-operation portfolios in publications

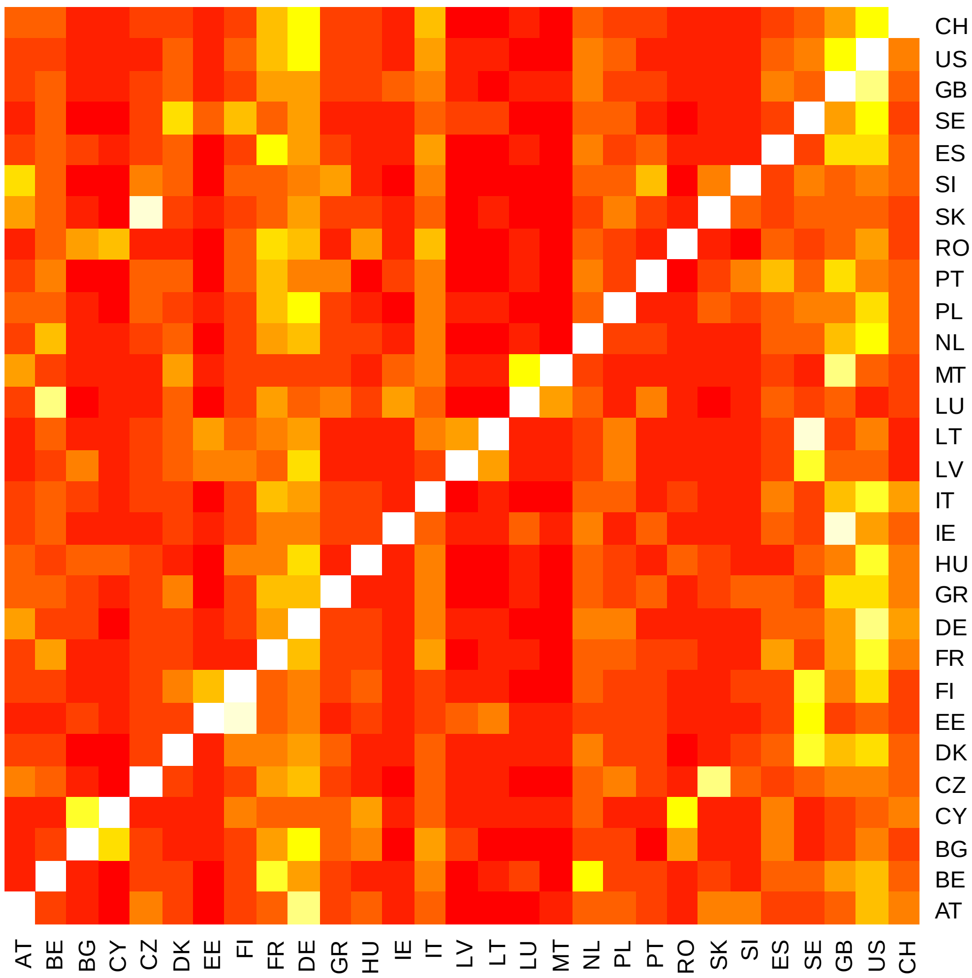
Apart from visualizing the networks and using the density measure we can also analyze the co-operations in terms of portfolios of countries as to their co-operations with other countries. The idea behind this approach is that each country will have more or less stronger ties to other countries which in total form a pattern of co-operations in terms of the shares of the total amount of co-operations. For a complete overview of the whole system these shares have to be interpreted holistically, i.e. for each dyad of countries A and B we can assess the share of A in portfolio B and also the share of B in portfolio A. A bilateral increase in shares over time can then means that the countries have increased the intensity from both perspectives. These values can be represented in tables (see Table 4-2 for Germany). A complete representation as tables is beyond the volume of this report as it would require 29 tables each to represent the total amount of data for each field and period.

Table 4-2: Cross-Impact Assessment table for all publications in the German cooperation portfolio for the periods of 1994-1996 and 2004-2006

DE	A>B(9496)	B>A(9496)	A>B(0406)	B>A(0406)
AT	4,27	24,93	4,46	23,81
BE	2,89	10,35	2,91	10,83
BG	0,84	20,40	0,74	18,54
CY	0,08	8,55	0,08	8,14
CZ	1,89	15,52	1,80	15,16
DK	2,50	11,36	2,23	12,18
EE	0,20	14,66	0,14	9,37
FI	1,50	9,23	1,71	11,29
FR	10,21	12,51	9,80	13,27
GR	1,44	11,94	1,29	10,94
HU	1,73	16,42	1,50	15,76
IE	0,47	9,65	0,76	9,92
IT	6,48	11,07	7,20	12,31
LV	0,16	21,32	0,14	17,08
LT	0,14	15,32	0,22	13,93
LU	0,06	10,35	0,10	15,29
MT	0,00	2,35	0,01	5,00
NL	5,72	13,52	6,36	15,16
PL	3,72	17,03	3,28	16,51
PT	0,70	8,39	1,04	9,82
RO	0,56	14,33	0,71	14,75
SK	0,83	12,91	0,66	13,73
SI	0,49	10,52	0,39	10,53
ES	3,58	10,61	4,69	11,51
SE	3,58	10,74	3,63	12,24
GB	10,92	12,12	12,03	13,23
US	27,49	18,02	24,72	18,44
CH	7,57	17,87	7,40	19,28

To cope with the amount of data relevant we use heatmaps that can represent asymmetrical matrices in a convenient way (see Figure 4-33 and Figure 4-34). The figure can be interpreted in both directions. Moving along the rows we can determine the important countries for the country the row represents. Analogously we can move through the columns and determine the importance of the country described by the column for all the other countries. The importance is depicted by color moving from dark red (low important) to bright yellow or even white (high importance). The diagonal in this case bears no information. The first fact to notice is the strong position of the large European countries France, Germany and Great Britain as well as the United States as important actors in the whole system. The position of these countries has remained strong in the system as a whole.

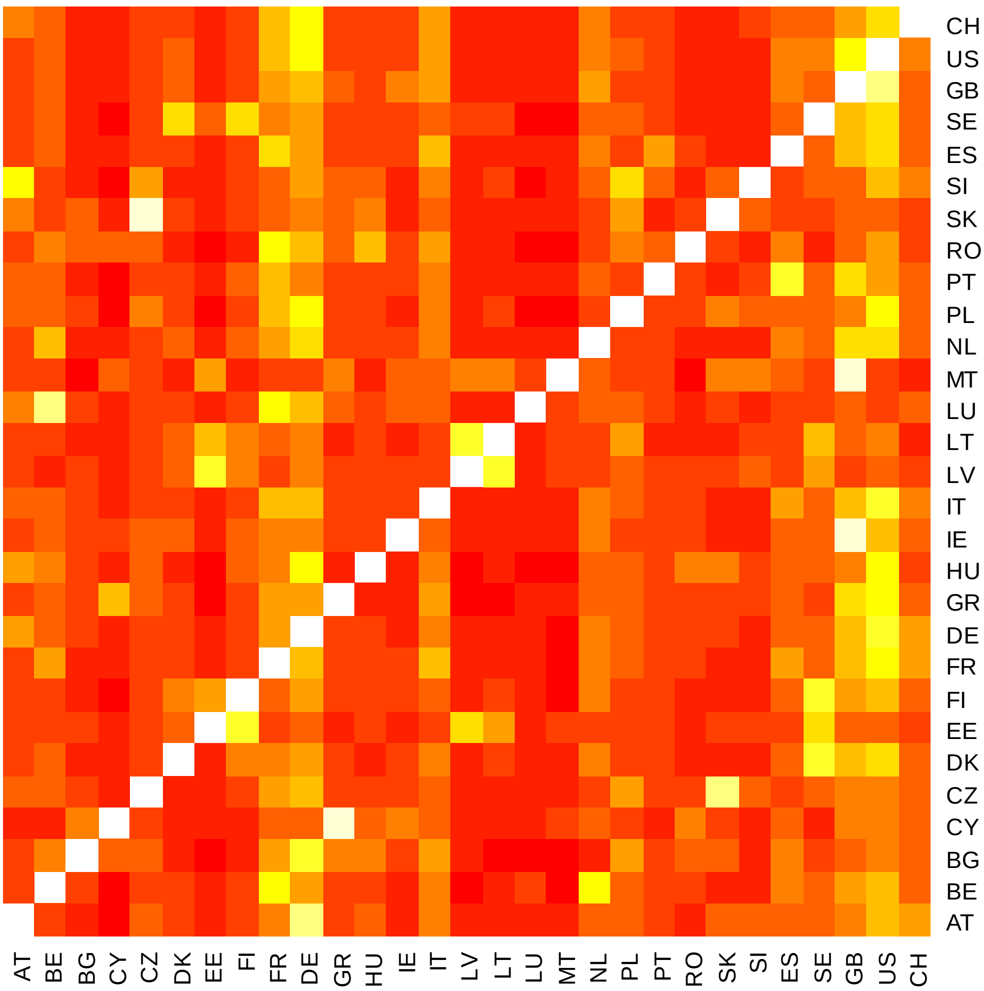
Figure 4-33: Heatmap of country cooperation portfolios for all publications in the period of 1994-1996



Source: SCI (STN), calculations Fraunhofer ISI, normalized by rows

We can also see that also smaller countries have gained in importance, like Slovakia or Romania. We also find a tendency of a cluster forming that spans the Scandinavian and North-East European countries. Overall the later heatmap features a lighter tone which means that there has been an overall levelling effect in the smaller countries as well as the large columns. This tendency should also be reflected in the results of the Shannon Entropy and betweenness measures.

Figure 4-34: Heatmap of country cooperation portfolios for all publications in the period of 2004 to 2006



Source: SCI (STN), calculations Fraunhofer ISI, normalized by column

The measures of betweenness and Shannon's Entropy are in a way complementary. If the country portfolios become more diverse the Shannon Entropy will increase. In contrast the betweenness measure will capture if this has an effect on the dominant players. Their role should thereby decrease overall. Taking both together an increase in Entropy coupled with a decrease in betweenness can provide a good picture about how the European Research Area has changed over the last ten years in terms of dominance of the large European players in research and the change in diversity of cooperation structures.

4.3.3.4 Analysis of breadth of co-operation portfolios in publications

If we analyze the Entropy values over time, i.e. the change in the diversity of the countries cooperation portfolios, we find that almost all countries have increased in diversity of cooperation. We also find that the large increases in Entropy are mostly found in the fields of Natural Science, Life Science and Medicine; a result that fits the results of the visual analysis of the network structures above. We also find that the strongest increases in Entropy can be found in the smaller Eastern countries. This suggests that the increase in diversity of cooperation is stronger for smaller countries and poses the question if cross-country cooperation might has an inherent decreasing return to scale similar to findings about Foreign Direct Investment. We also find that in the field of Engineering the increases in Entropy is rather low. What can proven up to now is that there is a general tendency for all countries in all fields to become more diverse. This puts the increase of relevance of co-publications into a new perspective, namely that this increase is not limited to an increase in co-operations among or with major players but rather that the system itself becomes increasingly coherent but does so in specific patterns of co-operations among larger clusters of countries. This is also reflected if we account for the distribution of Entropy for the different fields in the different periods (see Table 4-3). Here we again see that the increase in Entropy is coherent for all fields between the two periods.

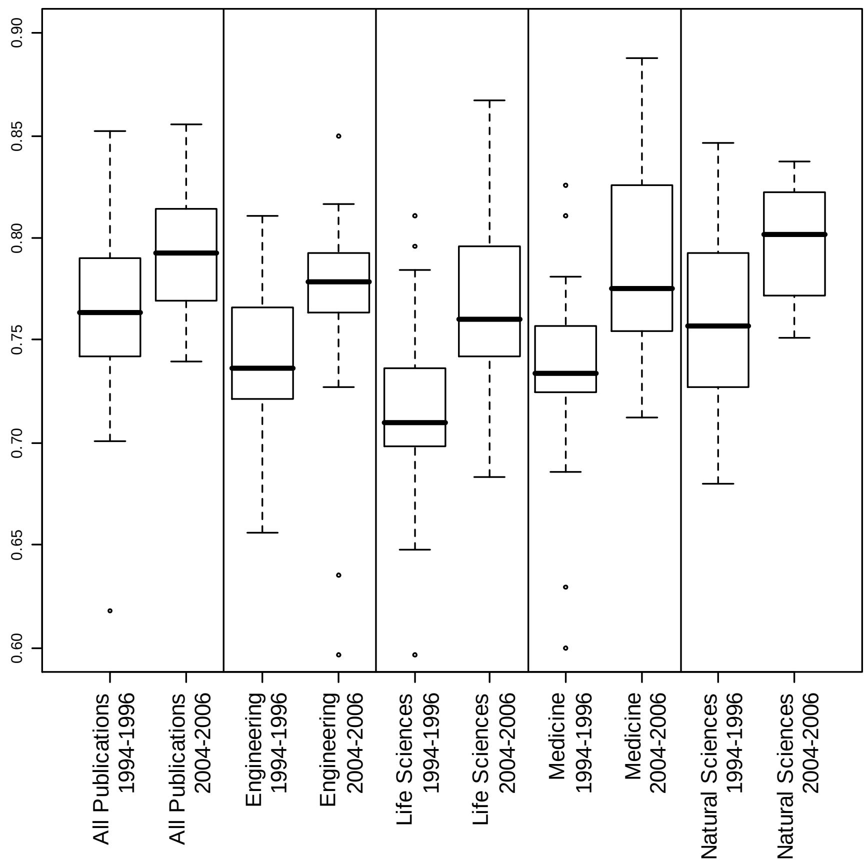
Table 4-3: Shannon Entropy Measures for selected research fields in the periods of 1994-1996 and 2004-2006

	All Publications 1994-1996	All Publications 2004-2006	Change	Engineering 1994-1996	Engineering 2004-2006	Change	Life Sciences 1994-1996	Life Sciences 2004-2006	Change	Medicine 1994-1996	Medicine 2004-2006	Change	Natural Sciences 1994-1996	Natural Sciences 2004-2006	Change
AT	0,763	0,778	0,02	0,728	0,778	0,07	0,698	0,751	0,08	0,686	0,754	0,10	0,793	0,805	0,02
BE	0,772	0,784	0,02	0,763	0,790	0,04	0,716	0,769	0,07	0,731	0,763	0,04	0,793	0,805	0,02
BG	0,790	0,832	0,05	0,737	0,787	0,07	0,811	0,796	-0,02	0,757	0,826	0,09	0,742	0,835	0,12
CY	0,772	0,784	0,02	0,443	0,636	0,44	0,647	0,704	0,09	0,454	0,546	0,20	0,695	0,811	0,17
CZ	0,817	0,835	0,02	0,784	0,814	0,04	0,772	0,817	0,06	0,781	0,840	0,08	0,817	0,838	0,03
DK	0,769	0,775	0,01	0,737	0,766	0,04	0,710	0,760	0,07	0,737	0,775	0,05	0,775	0,781	0,01
EE	0,701	0,820	0,17	0,656	0,751	0,14	0,701	0,814	0,16	0,600	0,817	0,36	0,683	0,817	0,20
FI	0,805	0,808	0,00	0,811	0,817	0,01	0,701	0,781	0,11	0,734	0,784	0,07	0,835	0,829	-0,01
FR	0,757	0,769	0,02	0,769	0,793	0,03	0,719	0,748	0,04	0,728	0,757	0,04	0,757	0,772	0,02

	All Publications 1994-1996	All Publications 2004-2006	Change	Engineering 1994-1996	Engineering 2004-2006	Change	Life Sciences 1994-1996	Life Sciences 2004-2006	Change	Medicine 1994-1996	Medicine 2004-2006	Change	Natural Sciences 1994-1996	Natural Sciences 2004-2006	Change
DE	0,760	0,772	0,02	0,784	0,808	0,03	0,731	0,754	0,03	0,725	0,745	0,03	0,763	0,787	0,03
GR	0,799	0,796	0,00	0,731	0,769	0,05	0,737	0,775	0,05	0,763	0,757	-0,01	0,811	0,826	0,02
HU	0,754	0,814	0,08	0,763	0,808	0,06	0,710	0,790	0,11	0,740	0,811	0,10	0,731	0,823	0,13
IE	0,701	0,748	0,07	0,686	0,728	0,06	0,704	0,683	-0,03	0,689	0,722	0,05	0,680	0,772	0,14
IT	0,742	0,757	0,02	0,748	0,763	0,02	0,701	0,740	0,06	0,695	0,740	0,06	0,757	0,766	0,01
LV	0,731	0,855	0,17	0,716	0,784	0,10	0,597	0,867	0,45	0,725	0,864	0,19	0,722	0,832	0,15
LT	0,742	0,838	0,13	0,692	0,799	0,15	0,671	0,811	0,21	0,754	0,870	0,15	0,701	0,811	0,16
LU	0,808	0,793	-0,02	0,538	0,597	0,11	0,728	0,742	0,02	0,826	0,826	0,00	0,558	0,778	0,39
MT	0,618	0,799	0,29	0,258	0,413	0,60	0,665	0,760	0,14	0,630	0,772	0,23	0,398	0,802	1,02
NL	0,754	0,754	0,00	0,766	0,763	0,00	0,719	0,740	0,03	0,728	0,748	0,03	0,757	0,763	0,01
PL	0,772	0,802	0,04	0,754	0,781	0,04	0,683	0,772	0,13	0,748	0,808	0,08	0,778	0,802	0,03
PT	0,817	0,796	-0,03	0,722	0,778	0,08	0,701	0,742	0,06	0,811	0,808	0,00	0,811	0,796	-0,02
RO	0,775	0,811	0,05	0,728	0,781	0,07	0,775	0,835	0,08	0,772	0,835	0,08	0,728	0,802	0,10
SK	0,826	0,832	0,01	0,745	0,772	0,04	0,796	0,820	0,03	0,760	0,858	0,13	0,826	0,823	0,00
SI	0,852	0,852	0,00	0,790	0,849	0,08	0,784	0,835	0,06	0,769	0,888	0,15	0,846	0,835	-0,01
ES	0,754	0,763	0,01	0,725	0,772	0,07	0,707	0,742	0,05	0,725	0,757	0,05	0,748	0,769	0,03
SE	0,781	0,793	0,02	0,781	0,802	0,03	0,742	0,766	0,03	0,740	0,778	0,05	0,805	0,808	0,00
GB	0,731	0,751	0,03	0,760	0,775	0,02	0,698	0,734	0,05	0,725	0,751	0,04	0,731	0,751	0,03
US	0,757	0,763	0,01	0,766	0,784	0,02	0,740	0,751	0,02	0,748	0,754	0,01	0,751	0,763	0,02
CH	0,734	0,740	0,01	0,728	0,740	0,02	0,662	0,698	0,05	0,698	0,713	0,02	0,745	0,766	0,03

Source: SCI (STN), calculations Fraunhofer ISI

Figure 4-35: Boxplots of the Entropy distribution for selected fields for the periods of 1994-1996 and 2004-2006



Source: SCI (STN), calculations Fraunhofer ISI

4.3.3.5 Analysis of the changing role of dominant players in publications

The final measure we want to analyze before turning to a similar analysis of the realm of innovation, i.e. the cooperation structures in the patenting system, is the measure of betweenness. The increase in Entropy already gave a hint at how the betweenness measure might behave. As diversity increases the dominant role of the larger players should decrease. This decrease of the dominant players can be different between the fields which might produce different results. Also, not all major players might be affected in the same way by the increase in overall diversity.

The most striking fact is that there has been a strong decrease in the relative position of the United States from a European perspective (see Table 4-4). While in the period of 1994-1996 the United States was the most dominant player regarding the network of all publications, we find that this role is now covered by Germany. The same is also true in the field of Engineering where Germany and the United Kingdom were less affected by the overall increase in diversity compared to the United States. It is also notable that Germany remained rather stable in their dominant role and seems to be largely unaffected and has not lost it's role as an important player in the field of engineering.

Table 4-4: Betweenness Centrality Scores for selected research fields for the periods 1994-1996 and 2004-2006

	All Publications 1994-1996	All Publications 2004-2006	Engineering 1994-1996	Engineering 2004-2006	Life Sciences 1994-1996	Life Sciences 2004-2006	Medicine 1994-1996	Medicine 2004-2006	Natural Sciences 1994-1996	Natural Sciences 2004-2006
AT	0,420	0,040	0,296	0,537	0,695	0,202	0,242	0,145	1,464	0,155
BE	0,630	0,180	2,141	0,699	1,838	0,760	1,022	0,227	3,166	0,549
BG	0,064	0,013	0,030	0,010	0,177	0,009	0,000	0,001	0,019	0,043
CY	0,001	0,002	0,000	0,000	0,003	0,001	0,000	0,000	0,000	0,004
CZ	0,074	0,034	0,122	0,199	0,025	0,032	0,053	0,020	0,450	0,195
DK	0,604	0,031	0,763	0,022	0,317	0,230	1,069	0,059	1,768	0,062
EE	0,001	0,002	0,000	0,003	0,009	0,035	0,003	0,002	0,000	0,046
FI	0,818	0,071	0,916	0,185	0,449	0,348	1,899	0,104	0,492	0,093
FR	3,175	1,147	16,177	8,503	5,246	4,112	3,191	1,159	8,303	2,221
DE	5,950	1,467	15,729	12,688	7,870	3,711	11,924	1,702	12,571	3,177
GR	0,120	0,130	0,410	0,500	0,189	0,421	0,247	0,921	0,228	0,263
HU	0,075	0,030	0,067	0,005	0,126	0,073	0,139	0,012	0,029	0,072
IE	0,013	0,032	0,000	0,027	0,093	0,044	0,037	0,025	0,000	0,068
IT	2,515	0,495	2,288	1,326	2,360	1,940	2,873	0,751	5,699	1,241
LV	0,000	0,001	0,016	0,004	0,000	0,001	0,000	0,003	0,000	0,000
LT	0,000	0,001	0,002	0,006	0,000	0,000	0,003	0,008	0,000	0,000
LU	0,002	0,000	0,000	0,000	0,019	0,000	0,016	0,001	0,000	0,000
MT	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
NL	0,739	0,163	1,695	1,400	1,802	0,353	0,944	0,318	0,832	0,321
PL	0,170	0,090	0,766	0,605	0,032	0,295	0,206	0,086	0,653	0,319
PT	0,014	0,017	0,010	0,052	0,009	0,076	0,060	0,011	0,018	0,053
RO	0,019	0,006	0,001	0,009	0,001	0,000	0,003	0,000	0,004	0,015
SK	0,000	0,017	0,002	0,121	0,006	0,022	0,000	0,065	0,002	0,037
SI	0,004	0,006	0,000	0,014	0,004	0,001	0,017	0,018	0,000	0,022
ES	0,645	0,232	0,467	0,531	0,856	0,868	0,424	0,136	0,478	0,673
SE	1,017	0,121	2,354	0,789	4,138	0,720	4,524	0,303	1,864	0,173
GB	7,454	1,252	29,959	14,580	11,617	5,460	20,208	6,681	17,458	2,372
US	7,902	1,291	24,250	7,929	24,700	5,081	23,391	5,150	17,913	2,468
CH	0,574	0,128	0,537	0,258	0,418	0,205	1,504	0,091	0,589	0,356

Source: SCI (STN), calculations Fraunhofer ISI

We can therefore conclude that there is not just an increase in diversity of co-operations in the European Research Area, but also that this led to a "Europeanization" as well. The major European Players now are mostly en par with the United States in terms of dominant network positions and diversity of co-operation portfolios of smaller countries has increases most. In some fields this Europeanization is far less pronounced like in the field of Medicine and Life Sciences where the United Kingdom and the United States still dominate the research network.

4.3.4 Innovation and Cooperation in the European Research Area

Before we commence with an in-depth analysis of the structures of the patenting networks in the European Research Area we might have to spend a few words on the differences between the realm of science and research and the realm of innovation. First, the reader should be aware that co-operations across borders in science in research are by far more common than in the competitive realm of innovation in general and regarding issues of IPR in particular. The fact that patents are property rights that have a potential direct economic value reduces the incentive of filing co-patents. Sometimes companies might more inclined to use patent pools to deal with the output of collaborative R&D. Reasons for the difference between the realms have already been discussed to appropriate length in the literature survey, but should be called to mind as to prevent puzzlement over the differences in the numerical values of the measures for both realms. In short: Most measures have to be interpreted in their context and one has to be aware of the fundamental differences between the two realms.

In this chapter as in the other chapters we use direct applications to the EPO plus the PCT applications that have entered the regional phase at the EPO as a basis of analysis using the PATSTAT database as source of the data. The timeframes are based on priority dates of patents, i.e. we use the years of the first application at a Patent Office. The basis for counting the co-operations are the inventor addresses. We use a full counting scheme. Regarding the fields we use aggregations of IPC classes which are defined to form five technical fields: Electrical engineering, ICT, Instruments, Chemistry and Mechanical engineering. Due to restrictions based in the patent system, we can only be sure to cover all the patents for a given priority year after roughly 18 months. Data therefore can only be used up to the point of priority year 2004 retaining a considerable level of certainty of full coverage. Again we use two periods. The timeframes however differ slightly from those used in the bibliometric analysis in the realm of research. The first period includes patents filed between 1994 and 1996, the second period includes the patents filed between 2002-2004.

4.3.4.1 Analysis of overall network density measures in patents

Table 4-5: Overall network density measures of co-patents in the periods of 1994-1996 and 2002-2004

	Min	1st Qu.	Median	Mean	3rd Qu.	Max
Electrical Engineering (1994-1996)	0,00	0,00	0,00	3,03	0,00	170
Electrical Engineering (2002-2004)	0,00	0,00	0,00	4,38	1,00	249
ICT (1994-1996)	0,00	0,00	0,00	12,38	1,00	744
ICT (2002-2004)	0,00	0,00	0,00	32,63	5,00	1688
Instruments (1994-1996)	0,00	0,00	0,00	10,76	1,00	581
Instruments (2002-2004)	0,00	0,00	0,00	20,32	3,00	988
Chemistry (1994-1996)	0,00	0,00	0,00	31,00	4,00	1678
Chemistry (2002-2004)	0,00	0,00	1,00	51,71	10,00	1857
Mechanical Engineering (1994-1996)	0,00	0,00	0,00	15,06	1,00	818
Mechanical Engineering (2002-2004)	0,00	0,00	0,00	23,73	4,00	1675

Source: PATSTAT, calculations Fraunhofer ISI

As a first measure of evolution of the cooperation in the realm of innovation we have a look at the measures of density already provided above. The median, the value that splits the lower part of the distribution of number of country-based co-patents in half is 0 over all observations. Also the third quartile is comparably low. Lower even than the mean which suggests that differences in this measure are driven by changes in the patterns of the large and dominant countries.[45]

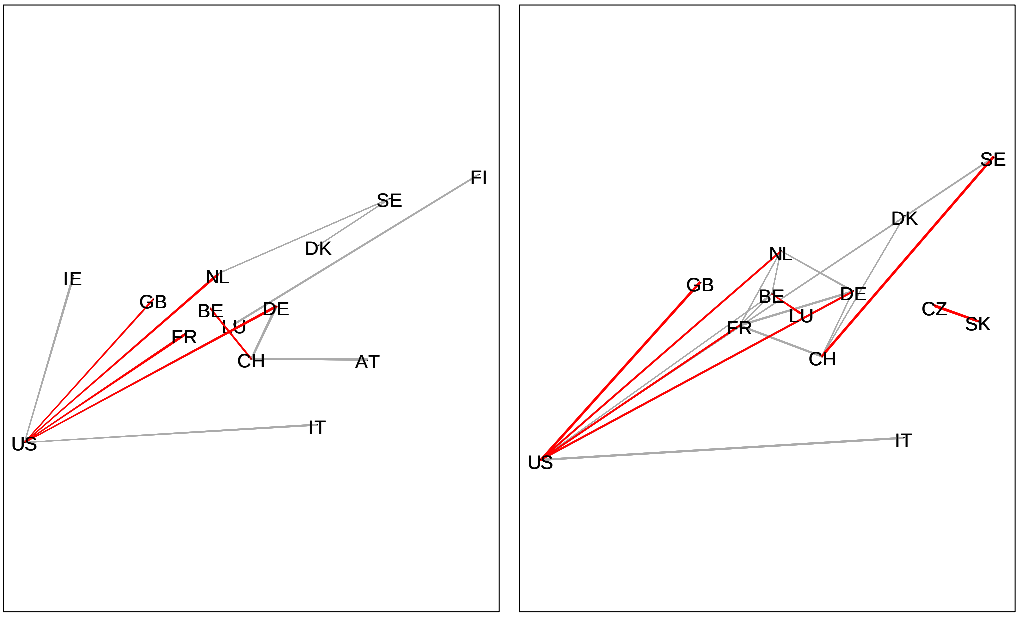
Based on the mean of the co-publications the overall density of the networks has increased. The strongest increase we find in the realm of ICT where the average number of co-patents has increased from 12.4 to 23.6 over all countries. The fields with the lowest overall density are those that have the lowest shares in compound international co-patenting. The lowest density we find in the field of Electrical Engineering where the average number of co-patents is 3 in 1994-1996 and increased to a mere 4.4 in 2002-2004. The field that has potentially increased most in density is Chemistry. Here we find only a very low change in the maximum of the number of co-patents from 1678 to 1857 for the two periods and, considering the circumstances, a strong increase both in the values for the 3rd Quartile and the mean. This increase should also be reflected in an increase in the diversity of the country portfolios. As argued before, these aggregate

45 There is unfortunately neither a trivial way to control for this fact and also nor a perfect solution that is without problems so we have to take it for granted.

measures have to be put into perspective by taking a closer look at the evolution of the networks (see Figure 4-36 to Figure 4-40).

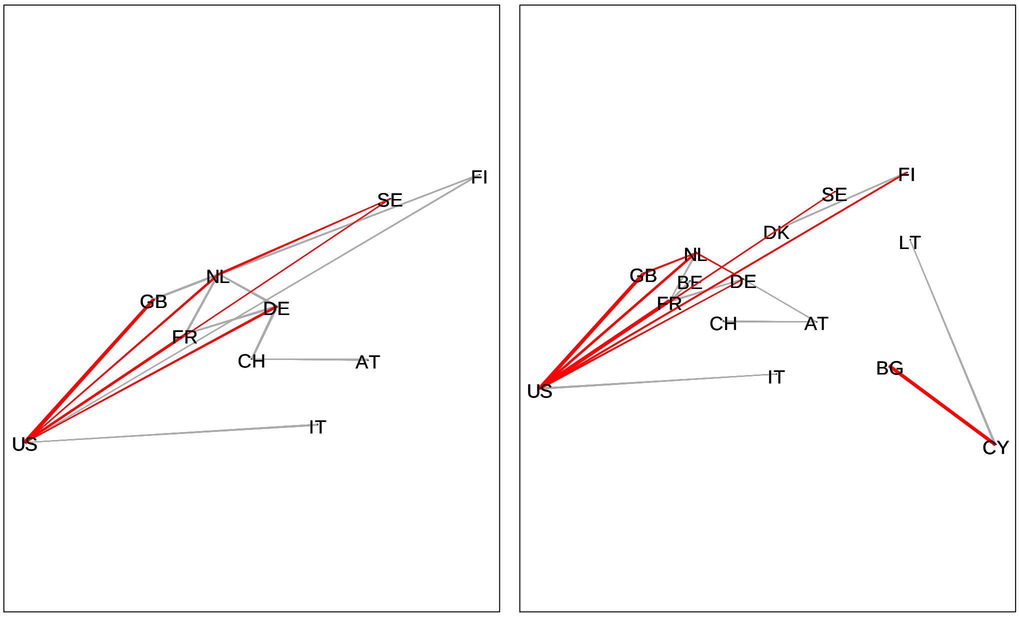
4.3.4.2 Visualualisation of network structures for patents

Figure 4-36: Cooperation network based on patents in the field of Electrical Engineering for the periods of 1994-1996 and 2002-2004 using geographical locations



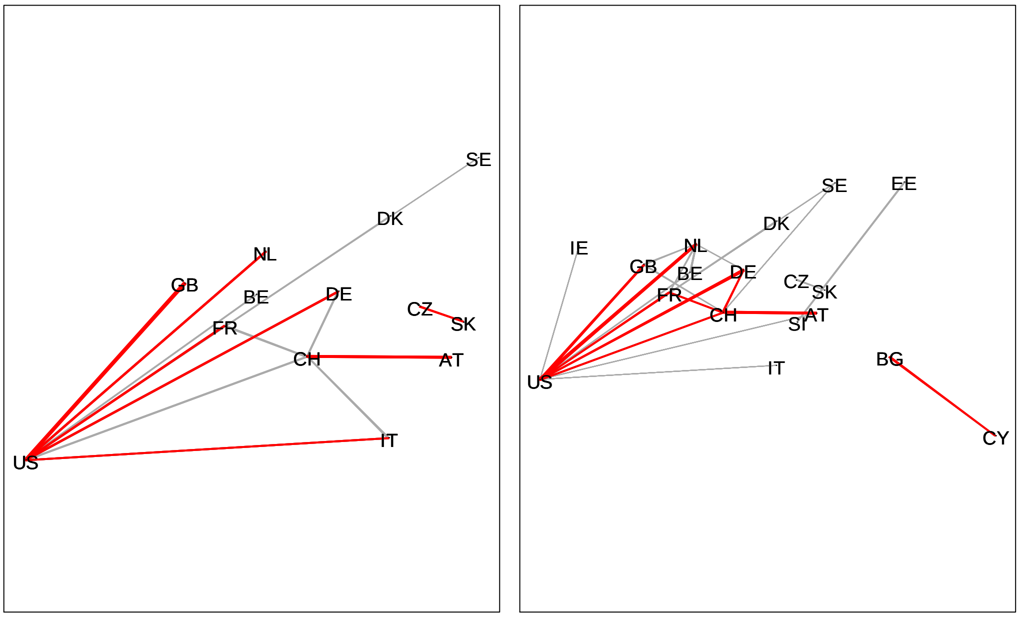
Source: PATSTAT, calculations Fraunhofer ISI, positions using geographical locations

Figure 4-37: Cooperation network based on patents in the field of ICT for the periods of 1994-1996 and 2002-2004 using geographical locations



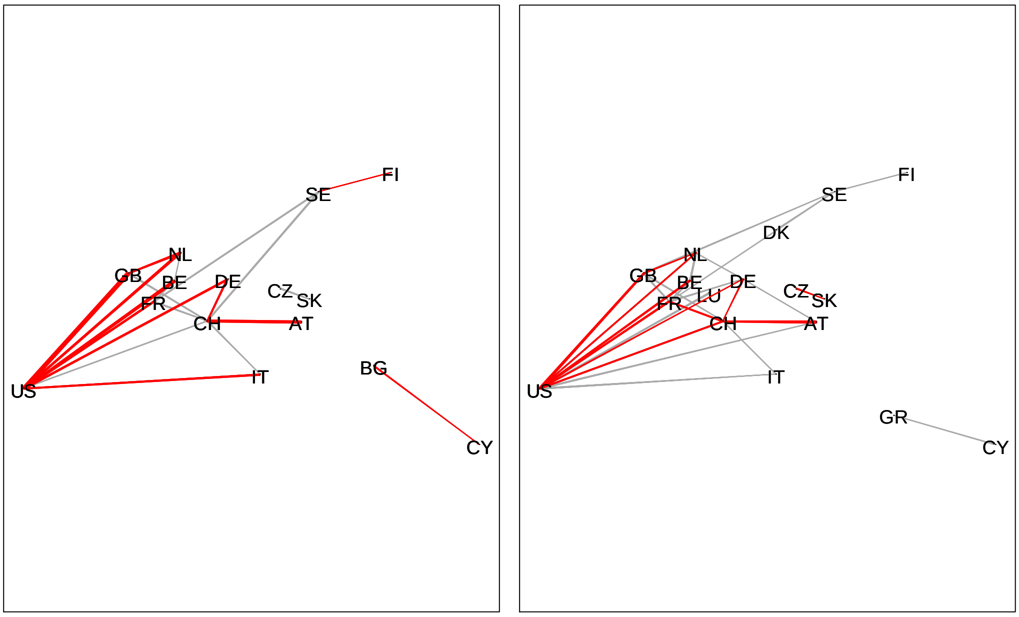
Source: PATSTAT, calculations Fraunhofer ISI, positions using geographical locations

Figure 4-38: Cooperation network based on patents in the field of Instruments for the periods of 1994-1996 and 2002-2004 using geographical locations



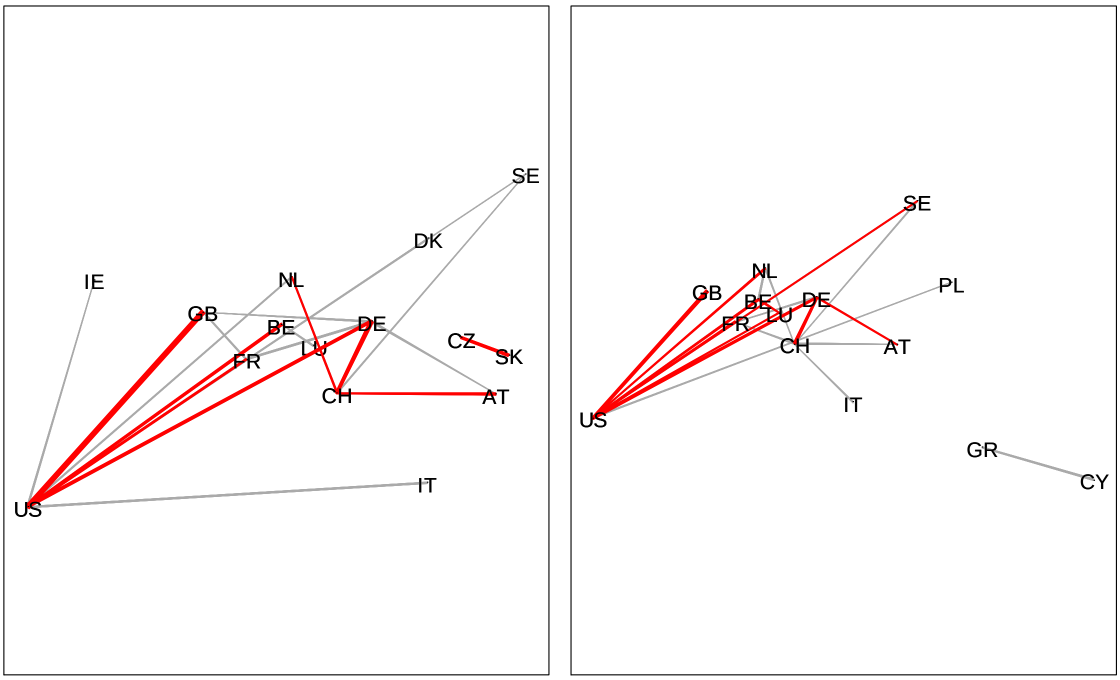
Source: PATSTAT, calculations Fraunhofer ISI, positions using geographical locations

Figure 4-39: Cooperation network based on patents in the field of Chemistry for the periods of 1994-1996 and 2002-2004 using geographical locations



Source: PATSTAT, calculations Fraunhofer ISI, positions using geographical locations

Figure 4-40: Cooperation network based on patents in the field of Mechanical Engineering for the periods of 1994-1996 and 2002-2004 using geographical locations



Source: PATSTAT, calculations Fraunhofer ISI, positions using geographical locations

Overall, there is less integration of the smaller countries. We see much less formation of clusters compared to the realm of research.[46] Many of the smaller eastern European countries do not feature high absolute counts of international co-patents which can be seen as a reason as to why the network is, both from the visual analysis as well as the network measures, less integrated. We also find that the United States play a more important role in both periods compared to the publication networks. There are slight shifts in the dominant role of the US in terms of network positions but this is mostly limited to changes in the links to the larger European countries. The most important players in the EU-27 are Austria, France, Germany, the United Kingdom and to some extent the smaller countries of Switzerland or Belgium.

In Electrical Engineering we can detect a moderate increase in connectivity among the major players. Also we see an increase in the links to the Eastern European countries. Still, this increase is mostly driven by links to the large countries and less by links between smaller countries. We also find that the Scandinavian countries become less connected to continental Europe in terms of number of moderate links. This is counterbalanced by an increase in the linkage between Sweden and Switzerland. Moreover the importance of Germany and France has increased in terms of the network as they link the United States to the rest of the large European countries and have at the same time increased their connections to the other European countries. In ICT we find a cluster of countries forming in the southern east region of Europe including Cyprus, Bulgaria and Lithuania. Still, this cluster is relatively volatile and based on rather low total number of patents. Apart from that we can see that the connections between the continental European countries have somewhat decreased over time. There are overall fewer connections in ICT between the European countries compared to Electrical Engineering in the period of 2002-2004. In the field of Instruments we find that the linkage between the larger European countries has increased in the later period forming one closer connected group of Switzerland, Germany, France and Austria. The United States connects this group to the Netherlands and the United Kingdom both of which are only moderately connected. Switzerland also became closer integrated by strong links to France and Germany. In the field of Chemistry we find roughly the same structural changes as in the field of Instruments. Again the larger countries are grouping together over time. In contrast to the field of Instruments, in which the United States connected the large European countries, this function is in Chemistry performed by Germany and France. In Mechanical Engineering we find the most clear cut structures as the co-operations are considerably low. As with the other fields we find a dominance of the United States in terms of cooperation. As to the fields of Electrical Engineering or

46 This is also reflected in the heatmaps that can be found in Annex 7.

Chemistry, Germany forms a bridge between the US and a number of large countries connected to the US but unconnected among each other except a cluster formed by countries like the Netherlands, Austria and Switzerland.

4.3.4.3 Analysis of breadth of co-operation portfolios in publications

In terms of diversity of the country co-patenting portfolios we find less clear patterns than in the analysis of publications. In general diversity in co-patenting is lower than in the realm of research. We even find a considerable amount of countries that feature an Entropy of 0, i.e. either all co-publications are limited to one other country or there are simply no co-publications for a given country in a field and period. Those countries are mostly the small countries as might also be expected by the previous results. We also find no evidence for differences between large and small countries as to their level of diversity in cooperations. Aggregated measures of Entropy show an increase over time that closely reflects the overall level of co-patenting in the fields (see Table 4-6). Some of the volatility of the Entropy measures could eventually be explained by the strong star-like character of the networks and the low level of co-patenting as a whole. As most of the smaller countries are connected to the larger countries and the larger countries are strongly connected to the US, the changes in co-patenting of these large countries might affect the network as a whole producing lower Entropy values in total and erratic movements of this measure over time.

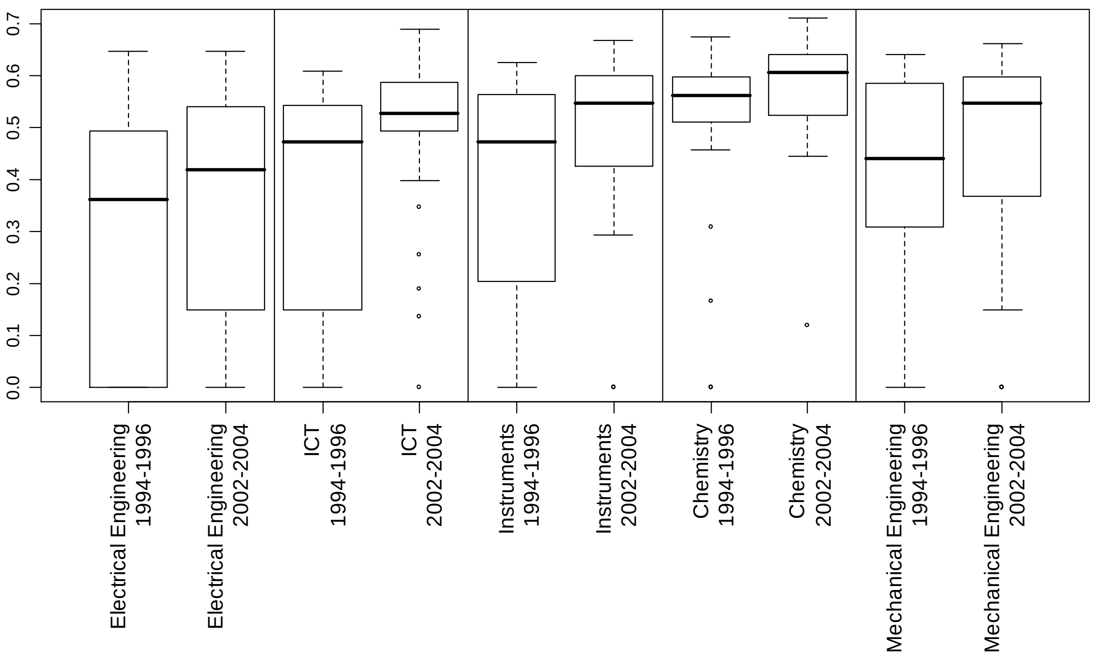
Table 4-6: Shannon Entropy Measures for selected technical fields in the periods of 1994-1996 and 2004-2006

	Electrical Engineering 1994-1996	Electrical Engineering 2002-2004	Change	ICT 1994-1996	ICT 2002-2004	Change	Instruments 1994-1996	Instruments 2002-2004	Change	Chemistry 1994-1996	Chemistry 2002-2004	Change	Mechanical Engineering 1994-1996	Mechanical Engineering 2002-2004	Change
AT	0.38	0.36	-0.05	0.40	0.40	0.01	0.45	0.44	-0.03	0.47	0.52	0.11	0.39	0.37	-0.06
BE	0.42	0.59	0.39	0.55	0.59	0.07	0.53	0.62	0.17	0.53	0.61	0.14	0.59	0.63	0.08
BG	0.00	0.00		0.00	0.50		0.20	0.61	1.96	0.57	0.45	-0.21	0.20	0.29	0.39
CH	0.46	0.53	0.14	0.57	0.61	0.07	0.59	0.55	-0.08	0.59	0.59	0.01	0.53	0.55	0.04
CY	0.00	0.00		0.31	0.53	0.70	0.33	0.40	0.21	0.53	0.60	0.13	0.28	0.66	1.35
CZ	0.40	0.48	0.23	0.33	0.59	0.80	0.42	0.51	0.21	0.67	0.71	0.05	0.36	0.33	-0.08
DE	0.61	0.65	0.06	0.61	0.65	0.07	0.60	0.60	0.00	0.63	0.66	0.05	0.63	0.64	0.02
DK	0.42	0.54	0.29	0.60	0.56	-0.06	0.47	0.55	0.16	0.61	0.65	0.07	0.56	0.64	0.16
EE	0.00	0.00		0.00	0.44		0.00	0.42		0.00	0.51		0.00	0.00	
ES	0.36	0.48	0.31	0.45	0.62	0.38	0.56	0.55	-0.03	0.62	0.60	-0.03	0.49	0.54	0.11
FI	0.52	0.63	0.22	0.53	0.56	0.05	0.61	0.62	0.03	0.58	0.64	0.10	0.59	0.57	-0.03
FR	0.51	0.57	0.12	0.54	0.50	-0.07	0.58	0.61	0.06	0.60	0.62	0.03	0.54	0.60	0.11
GB	0.42	0.50	0.18	0.47	0.50	0.07	0.50	0.58	0.15	0.53	0.61	0.14	0.48	0.54	0.13
GR	0.00	0.41		0.55	0.69	0.25	0.28	0.49	0.73	0.56	0.60	0.06	0.33	0.55	0.67

	Electrical Engineering 1994-1996	Electrical Engineering 2002-2004	Change	ICT 1994-1996	ICT 2002-2004	Change	Instruments 1994-1996	Instruments 2002-2004	Change	Chemistry 1994-1996	Chemistry 2002-2004	Change	Mechanical Engineering 1994-1996	Mechanical Engineering 2002-2004	Change
HU	0.31	0.26	-0.14	0.47	0.52	0.11	0.36	0.40	0.09	0.55	0.62	0.14	0.33	0.37	0.11
IE	0.29	0.30	0.04	0.48	0.52	0.09	0.48	0.49	0.02	0.46	0.56	0.22	0.59	0.61	0.04
IT	0.56	0.55	-0.03	0.54	0.63	0.15	0.52	0.64	0.23	0.62	0.65	0.05	0.64	0.65	0.02
LT	0.00	0.00		0.00	0.14		0.00	0.00		0.00	0.12		0.00	0.00	
LU	0.51	0.42	-0.19	0.51	0.59	0.14	0.48	0.58	0.20	0.59	0.51	-0.14	0.59	0.55	-0.07
LV	0.00	0.00		0.00	0.19		0.00	0.00		0.17	0.46	1.75	0.00	0.00	
MT	0.20	0.00		0.00	0.00		0.00	0.00		0.00	0.52		0.20	0.37	0.80
NL	0.49	0.51	0.04	0.56	0.53	-0.05	0.53	0.52	-0.03	0.54	0.59	0.09	0.61	0.59	-0.03
PL	0.20	0.43	1.12	0.46	0.50	0.09	0.57	0.48	-0.16	0.58	0.64	0.09	0.32	0.45	0.38
PT	0.20	0.00		0.51	0.54	0.06	0.20	0.55	1.70	0.51	0.66	0.29	0.33	0.44	0.35
RO	0.00	0.15		0.00	0.49		0.00	0.36		0.31	0.50	0.63	0.00	0.15	
SE	0.65	0.56	-0.13	0.54	0.61	0.12	0.62	0.65	0.05	0.64	0.64	0.00	0.64	0.64	-0.01
SI	0.00	0.23		0.15	0.35	1.34	0.31	0.56	0.80	0.54	0.69	0.27	0.44	0.29	-0.33
SK	0.00	0.39		0.00	0.26		0.20	0.29	0.43	0.56	0.61	0.10	0.31	0.56	0.80
US	0.53	0.59	0.10	0.60	0.63	0.06	0.63	0.67	0.07	0.63	0.68	0.08	0.57	0.58	0.03

Source: PATSTAT, calculations Fraunhofer ISI

Figure 4-41: Boxplots of the Entropy distribution for selected fields for the periods of 1994-1996 and 2004-2006



Source: PATSTAT, calculations Fraunhofer ISI

4.3.4.4 Analysis of the changing role of dominant players in patents

An analysis of the betweenness measures also reflects this star-like character of the networks (see Table 4-7). Noteworthy levels of betweenness are almost completely concentrated on the large European countries and the US. The betweenness levels in co-patenting are, due to the star-like topology of the networks, also significantly higher compared to the betwenness levels found in co-publications. The changes in betweenness are reflected by the changes in patterns we found through the analysis of Figure 4-36 to Figure 4-40.

In Electrical Engineering we find an increase of both Germany and the United States and France as gatekeepers. In ICT, Germany is increasingly connecting the major European countries which in turn lose some of their betwenness character. For the field of Instruments the United States became more important as to connecting the other countries affecting most European countries excluding Italy and Germany. In chemistry we find changes similar structures as in ICT with an increase in betweenness levels for Germany and a decrease for the United Kingdom. The betweenness values for US are stable over time in both fields. In contrast to ICT, the relevance of Switzerland and France has increased in Chemistry rather than decreased. Mechanical Engineering is in terms of gatekeeper positions of countries clearly dominated by Germany and the US. The position of the US has changed over time though and lost some of it's dominance over the field.

Table 4-7: Betweenness Centrality Scores for selected research fields for the periods 1994-1996 and 2004-2006

	Electrical Engineering 1994-1996	Electrical Engineering 2002-2004	ICT 1994-1996	ICT 2002-2004	Instruments 1994-1996	Instruments 2002-2004	Chemistry 1994-1996	Chemistry 2002-2004	Mechanical Engineering 1994-1996	Mechanical Engineering 2002-2004
AT	1.000	0.028	0.009	1.434	1.762	0.447	1.316	2.408	2.043	0.199
BE	0.000	6.737	0.554	2.212	22.837	1.063	2.267	5.244	3.958	4.023
BG	0.000	0.000	0.000	0.028	0.000	0.010	0.018	0.000	0.000	0.000
CH	3.965	9.580	9.868	2.229	16.364	3.650	4.839	8.195	1.690	8.439
CY	0.000	0.000	0.000	0.130	0.000	0.001	0.049	0.016	0.000	0.011
CZ	0.000	0.122	0.000	0.009	1.245	0.019	0.175	0.114	0.020	0.000
DE	68.673	94.714	45.013	96.336	64.937	63.262	52.679	70.331	109.645	124.155
DK	0.005	0.021	0.033	0.207	0.009	0.012	0.309	0.075	0.009	0.066
EE	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.002	0.000	0.000

	Electrical Engineering 1994-1996	Electrical Engineering 2002-2004	ICT 1994-1996	ICT 2002-2004	Instruments 1994-1996	Instruments 2002-2004	Chemistry 1994-1996	Chemistry 2002-2004	Mechanical Engineering 1994-1996	Mechanical Engineering 2002-2004
ES	0.000	0.035	0.014	0.746	0.000	0.001	0.818	0.470	0.001	0.143
FI	0.182	0.235	7.535	4.289	2.767	1.013	0.042	0.059	0.004	0.000
FR	10.376	20.609	12.458	2.763	27.525	6.862	5.064	10.612	9.242	1.732
GB	9.261	7.868	11.342	7.525	29.517	9.504	35.292	12.434	5.504	3.613
GR	0.000	0.000	0.000	0.164	0.000	0.000	0.111	0.071	0.000	0.013
HU	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.017	0.001	0.000
IE	0.000	0.000	0.045	0.206	0.006	0.103	0.000	0.013	0.036	0.038
IT	0.592	3.279	0.338	0.374	0.952	8.178	5.411	2.599	7.891	0.561
LT	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000
LU	0.081	0.000	0.000	0.000	0.000	0.000	0.007	0.004	0.005	0.004
LV	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NL	0.934	0.341	3.193	2.088	0.309	1.025	5.784	4.584	3.055	1.727
PL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.000	0.001
PT	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.000
RO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SE	1.772	0.601	1.104	0.899	5.181	2.829	2.828	3.946	1.194	1.976
SI	0.000	0.000	0.000	0.000	0.000	0.011	0.000	0.023	0.000	0.000
SK	0.000	0.021	0.000	0.000	0.002	0.000	0.000	0.040	0.001	0.003
US	27.160	37.809	72.492	74.355	69.587	91.009	58.984	57.736	50.702	34.295

Source: PATSTAT, calculations Fraunhofer ISI

4.3.5 Conclusions

Looking at the data and taking everything we found into account: Can we speak of an integrated European Research Area? Do we find something what might even be called an "ERA-effect"? This depends on what we essentially understand by an "ERA-effect". If by Era-effect we mean an integration of the smaller countries, both in terms of connections to the large dominant countries and among each other and we only consider the realm of research the answer to both questions is: Yes! If by ERA-effect we also mean that there should be more integration internally compared to externally the answer must be: Maybe! Some measures in the realm of research point at a decrease in the gate-keeping role of the US if we focus on EU-27. So much we can say for the realm of research as to the results of our analysis. In the realm of innovation we find much less conclusive evidence for such an ERA-effect. One might even be inclined to say that there isn't such a thing as an ERA effect in co-patenting. Still, there are tendencies, small and partly inconclusive at best, that point at an increase of the connections among the larger players. The smaller players though are not part of the large picture of co-patenting. What might be reasons for this lack of integration in co-patenting? Some reasons might be found in the aim of appropriability of knowledge, rent-seeking behaviour or motives for patenting as a strategic instrument. These might produce an incentive to fraction potentially patentable content into the least patentable units in a collaborative R&D activity if different companies are involved. What remains are co-patents that involve at least two countries in terms of inventors involved but those inventors belong to one economic unit: A multinational enterprise. Unfortunately, we can not tell if co-patenting is dis-proportionally driven by multinational companies compared to overall patenting activity using the data at our disposal. It would be critical though to find an answer to this question in foreseeable future as to understand the results generated by country-based analyses of co-patenting and also to maybe provide some frame of interpretation for the results we found in this chapter.

5 The Impact of Collaboration on Europe's Scientific and Technological Performance

5.1 Introduction

5.1.1 Objectives of the ERA

After the approval by Council and Parliament of the 7^{th} Framework Programme for Research and Technological Development, the focus in European research policy-making has shifted back to the idea of the European Research Area (ERA). A Green Paper re-launching the debate on the issue has been published in 2007[47]. Following a debate with stakeholders, several actions are/will be launched.

The idea of the ERA was first launched in the year 2000 via a Commission Communication on the issue[48]. The concept was also referred to in the 2000 Lisbon European Council Presidency Conclusions, in which Europe was urged to turn itself into a knowledge-based economy through more and better investment in the knowledge triangle of research, education and innovation[49].

The ERA was launched in response to three perceived S&T weaknesses: insufficient funding; lack of an environment to stimulate research and exploit results; and the fragmented nature of activities and dispersal of resources. Improved (cross-border) co-operation and co-ordination among key players in the EU was seen as one key ingredient to remove these deficiencies. Indeed, according to the EC's Communication of 2002, the ERA aimed for:

- the creation of an **"internal market"** in research, an area of free movement of knowledge, researchers and technology, with the aim of **increasing cooperation**, stimulating competition and achieving a better allocation of resources;
- a restructuring of the European research fabric, in particular by **improved coordination of national research activities and policies**, which account for most of the research carried out and financed in Europe;

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47 European Commission, The European Research Area: New Perspectives, Green Paper, Presented by the Commission (SEC(2007) 412), COM(2007) 161 final, Brussels, 4 April 2007; European Commission, Commission Staff Working Document Accompanying the Green Paper 'The European Research Area: New Perspectives' (COM(2007) 161), SEC(2007) 412/2, Brussels, 4 April 2007.

48 European Commission, Towards a European Research Area, Communication from the Commission to the Council, the European Parliament, the Economic and Social Committee and the Committee of the Regions, COM(2000) 6 final, Brussels 18 January 2000.

49 Presidency Conclusions Lisbon European Council 23 and 24 March 2000.

- the development of a European research policy which not only addresses the funding of research activities, but also takes account of all relevant aspects of other EU and national policies[50].

In particular, the recent (2007) Green paper on the ERA emphasised once again the importance of improved collaboration and co-operation with / between the key actors of Europe's research systems. According to the Green Paper, *"the ERA that scientists, companies and citizens need should have the following 6 key features":*

1. **An adequate flow of competent researchers** with high levels of mobility between institutions, disciplines, sectors and countries;
2. **World-class research infrastructures**, integrated, networked and accessible to research teams from across Europe and the world, notably thanks to new generations of electronic communication infrastructures;
3. **Excellent research institutions** engaged in effective public-private cooperation and partnerships, forming the core of research and innovation 'clusters' including 'virtual research communities', mostly specialised in interdisciplinary areas and attracting a critical mass of human and financial resources;
4. **Effective knowledge-sharing** notably between public research and industry, as well as with the public at large;
5. **Well-coordinated research programmes and priorities**, including a significant volume of jointly-programmed public research investment at European level involving common priorities, coordinated implementation and joint evaluation; and
6. **A wide opening of the European Research Area to the world** with special emphasis on neighbouring countries and a strong commitment to addressing global challenges with Europe's partners[51].

Improved coordination and cooperation with / between the key actors of the ERA are not only instrumental to increase the flows of people (pt 1) or knowledge (pt 4), or to achieve economies of scale (pt 2), they are also a mean to step up the quality of research towards world-class excellence through *"effective participation in innovation clusters including virtual research communities"* (pt 3).

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50 European Commission, The European Research Area: Providing New Momentum. Strengthening –Reorienting – Opening up New Perspectives, Communication from the Commission, COM(2002) 565 final, Brussels, 16 October 2002

51 European Commission, *The European Research Area: New Perspectives*, Green Paper, Presented by the Commission (SEC(2007) 412), COM(2007) 161 final, Brussels, 4 April 2007, p.2-3.

5.1.2 Objectives and implementation of the survey

One main reason for the setup of the ERA is the intended stimulation and facilitation of international cooperation in research. It is therefore interesting to understand the patterns of international collaboration, to understand how international collaboration influences S&T performance and even more so to understand which underlying motives stimulate this collaboration. Insight into these motives may lead to more efficient support (through adequate policy support measures) of future international cooperation.

Moreover, the motives of international cooperation may differ from the motives for domestic cooperation and may therefore be at the base of differences in impacts of international cooperation on S&T performance. For example, if international cooperation is motivated by increasing one's knowledge and expertise by working together with appropriate partners and in more appropriate infrastructure, then it can be expected that research quality increases and that publications or inventions resulting from it have a greater impact in the academic and/or industry community (read: may receive a higher number of citations).

In view of this, a survey is conducted to detect and uncover motivations and barriers, incentives and disincentives for international cooperation. It concerns a small scale pilot survey aiming to touch on several of the issues related to international cooperation. A unique feature of this survey is that the panel was directly composed from co-authored papers and co-inventoried patents. Especially the latter source of information appeared to be very difficult to access as patent databases do not (always) contain precise contact information like an e-mail address and/or a telephone number. As a consequence, the research team had to manually look up e-mail addresses over the internet.

In total a panel of 483 researchers (inventors and/or authors) was asked to cooperate on the survey. 46 of them filled out the questionnaire completely, resulting in a response rate of almost 10%[52]. It took respondents about 11 minutes on average to complete the questionnaire. It was our initial intention to split up the analysis of the survey by grouping answers and thus respondents on the basis of:

52 As we will indicate later, 49 responses were valid in total but 3 of them were neither co-author nor co-inventor and were therefore unable to answer the remaining questions of the survey. These 3 respondents are not considered in the analysis.

- Country

  In each country there is a different kind of multi-actor and multi-faceted approach for stimulating international S&T cooperation[53]*. Drivers can thus differ substantially between countries due to these different policies and actions.*

  Moreover, literature[54] *suggests that country size matters greatly as well. Researchers in small countries may feel greater need to cooperate internationally than researchers in larger countries, in order to find appropriate partners or infrastructure, …*

- Area of expertise

  Previous research[55] *has shown that international cooperation differs greatly among research fields.*

- Co-inventor and co-author

  The motives for cooperation between these groups may differ, as well as the stimulating instruments in the context of different supportive programmes.

However, the number of responses is too small in each of these cases (strata) to apply a completely detailed analysis and to draw significant conclusions. We will however present some more detail by referring to differences in the responses between co-authors and co-inventors, as these groups do have more substantial sizes. Moreover, they differ in opinion, because collaboration motives and practices are driven differently. We emphasize, however, that any reference to differences between these subgroups is indicative and not tested for significance in view of their limited size.

Finally, as a follow-up to this online survey we have conducted 6 in-depth telephone interviews with a number of respondents (inventors and authors). The purpose of these interviews was to validate the survey (interpretation of the questions, further explanation of answers deviating from the mean etc.) and to elaborate further on a number of interested findings.

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53 Boekholt et al. 2008.

54 Hinze 1999; Katz 2000; Luukkonen et al. 1992.

55 Edler et al. 2007.

5.2 Profile analysis of the respondents

5.2.1 General Characteristics

As this was a pilot survey, the approach used to select our potential respondents was novel as well. After a screening of a series of scientific publications in the science fields of interest (cf. supra), we have identified collaborating authors and traced their contact information. A similar approach was used for the patents, however, here it appeared to be much more difficult to identify the contact information of individual inventors (through manual internet searches). Based on these premises, 46 respondents have cooperated to our survey. In Table 5-1 we present the geographical origin of our respondents. About 46% of all respondents are either Belgian, British, German or Italian. In line with the objective of this survey, we see that most nationalities occur only once in our group of respondents (wide spread group).

Table 5-1: Distribution of the respondents over nationality

Number of respondents	Nationality
1	Austrian; Canadian; Danish; Finnish; French and British; Hungarian; Icelandic; Indian; Lithuanian; Polish; Spanish; Swedish; Turkish
2	Chinese; Czech; Dutch; French; Portuguese; Romanian
5	Belgian; British; German
6	Italian

Often international collaboration is the result of networks of individual research and is thus linked to their geographical roots, i.e. home country versus working country. We investigated to what extent our respondents work in a different country than in their home country. Table 5-2 shows the matrix of working country (rows) versus home country (columns). The yellow cells are the cells on the diagonal, where home country and working country are the same. The orange cells are those observations that deviate from the diagonal, thus where researchers work outside their home country. Although most of the respondents that are internationally active work in their home country, a large group (about 26%) is not. This may suggest that international collaboration does to some extent coincide with the underlying mobility patterns of the researchers in questions.

The group that works in another country than their home country, does not show however a different collaboration pattern (or intensity) than the others. We thus find no evidence here that researcher mobility stimulates frequency of collaboration (take into account the small samples). In our follow-up interviews however, respondents indicate that researcher mobility is important for opening up (enabling) collaboration with other countries, just as it is for building up a network.

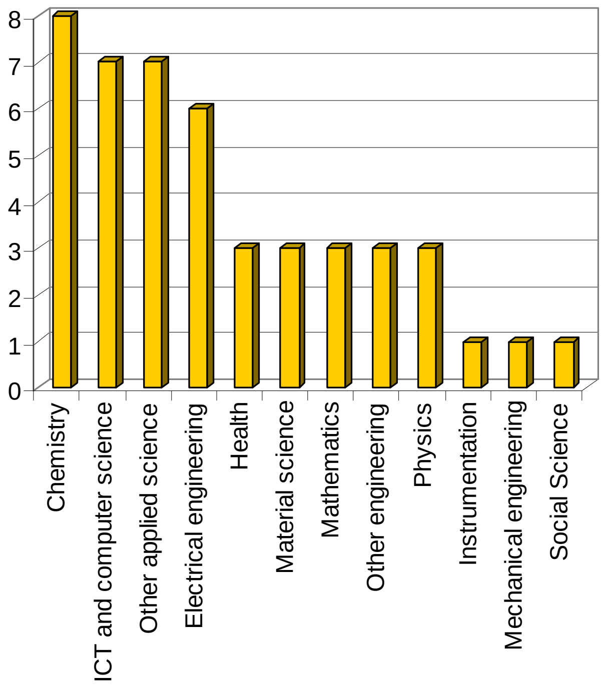
Table 5-2: Comparison between the home country (nationality) and the working place of the respondents

Nationality \ Work place	AT	BE	CA	CN	CZ	DK	FI	FR	FR & GB	DE	HU	IS	IN	IT	LT	PL	PT	RO	ES	SE	NL	TR	GB	*TOT*
BE		5												2										*7*
CA			1																					*1*
CN				2																				*2*
CZ					2																			*2*
DK						1																	1	*2*
FR										1													1	*2*
DE										4				1			1							*6*
HU											1													*1*
IS												1												*1*
IN													1										1	*2*
IT														3										*3*
LT															1									*1*
PL																1								*1*
PT																	1							*1*
RO																		2						*2*
SG								1																*1*
ES																			1					*1*
SE																				1				*1*
NL																					2			*2*
TR																						1		*1*
GB							1		1														2	*4*
USA	1							1																*2*
TOT	*1*	*5*	*1*	*2*	*2*	*1*	*1*	*2*	*1*	*5*	*1*	*1*	*1*	*6*	*1*	*1*	*2*	*2*	*1*	*1*	*2*	*1*	*5*	*46*

Only 6 of the respondents do not work at a university or (public or private) research institute. 3 work in a large company, 2 in a small or medium size company. This group coincides with the group of inventors. Furthermore, one respondent indicated to work for an NGO. The majority of the respondents has between 11 and 30 years of experience in their field of expertise.

The distribution of the respondents over the different S&T fields is presented in Figure 5-1. Chemistry, ICT and (Electrical) Engineering are the most common fields covered by the respondents. Of course this is no surprise as researchers in these fields were the primary target of the survey.

Figure 5-1: Distribution of the respondents over the different fields of expertise



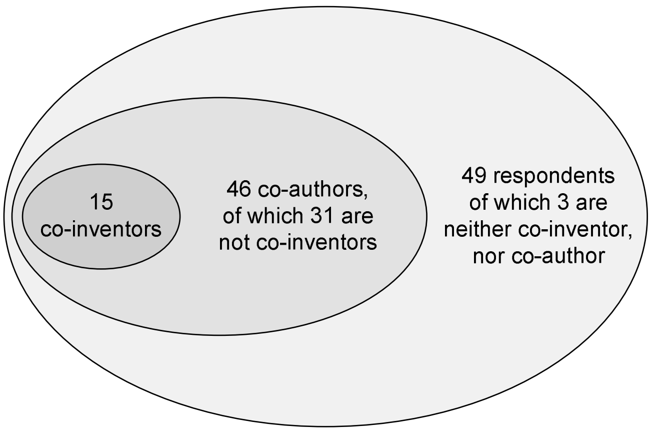
The number of researchers per field, however, is small. Quite some researchers made use of the answering option 'other' and filled in a different field of expertise than the ones in the proposed list (containing the pre-selected S&T fields). Consequently, the number of S&T fields increased substantially and each category contained only a few researchers, with scarcity as a result. It seems that researchers are rather (or consider themselves) multidisciplinary and, for example, do not want to be categorised in the field "Chemistry" or "Mechanical or Electrical engineering" when in fact they are "Chemical engineers".

For the further processing of the results, and in view of the limited number of observations per field, it would be (statistically) incorrect to draw conclusions per S&T field. Therefore, the analysis of the results needs to be performed at the aggregate level in order to obtain more reliable conclusions.

5.2.2 Co-authors and co-inventors

In total, 46 researchers have completely filled out the questionnaire (see Figure 5-2). Only 15 of these respondents (33%) indicate to have been involved in the development of patents together with other inventors from outside his/her country. All of them are at the same time co-author of scientific publications together with other international authors. 3 respondents indicate to be neither a co-inventor nor a co-author. As already indicated, their answers are not taken into account. Here as well, the relatively low number of respondents in each separate category (inventors versus authors) makes it almost impossible to draw differentiated in-depth conclusions. The main analyses will therefore be performed at the aggregate level. However, where remarkable differences exist in the answering pattern of both, we will mention them for the reader's information.

Figure 5-2: Overview of the co-authors and co-inventors in the responses of the survey



In the literature, co-publications and co-invented patents are frequently used as proxies for international collaborations. The setup of the survey has also made use of these indicators as proxies. However, some questions remain on their limitations and characteristics. Therefore, we asked the respondents about their opinion on the use of co-inventoried patents and co-publications as proxies for international collaboration activities. The result is that co-publications are broadly validated as an appropriate indicator by 76% of the respondents, while the opinions on co-inventoried patents are more divided. 30% of respondents considers the latter to be an inappropriate measure for international collaboration, while the majority refers to other indicators as well.

This seems to suggest that pure scientific collaboration (on the 'basic' side of research) is pretty well reflected by co-authored papers. At the same time, this does not seem to be the case for collaboration in a more applied research setting, mainly because collaboration does not always seem to lead to co-inventoried patents. As one respondent indicates in an in-depth interview: "*Publications reflect who you are working with, as they are the aim of each researcher and thus of each research collaboration. For patents, however, this is not the case. People at universities are not really aware of the importance of patenting. Patents rather reflect the interest of industry in research – they are the next step following publications."*

5.3 Results

5.3.1 Collaboration behaviour and intensity

5.3.1.1 Collaboration partners

We have asked the respondents to rank a number of different collaboration partners from very important (1) to less important (5) according to the importance of the type of partners they collaborate with. The types of partners proposed by us are industry, universities, public research institutes, private research institutes, and other (to be defined by the respondent). Subsequently, we have asked the respondents to rank different categories of geographic proximity of collaboration partners from very important (1) to less important (5) according to which type of partners they collaborate with mostly. The categories proposed here are researchers from the own institute, researchers from other institutes in the home country, researchers from neighbouring countries, researchers from other EU countries, researchers from non-EU countries, and other.

The most important type of collaboration partners for our group of respondents are the universities. They are named by 96% of the respondents, of which almost 2/3 of them indicate to be the most frequent collaboration partners. Public research institutes (85%) and industry (63%) are also named. The latter, however, are more often ranked as more important than the former, which suggests that collaboration with industry is very important, possibly in view of related funding streams. This also affirms the findings in the literature on the network model of collaboration (Gibbons et al., 1994) that science and technology are increasingly interwoven. Private research institutes are only indicated by 41% of the respondents and are always given a third place or lower. Remarkably, they are relatively more often named by co-inventors than by co-authors but co-authors assign to them a more important role as partner. Finally, to a smaller extent, collaboration also takes place with consultants, end-users and NGO researchers.

In terms of geographic proximity, partners are rather equally distributed over the categories. For example, collaboration with researchers from the own institution is named as often as researchers from another institution within the country or even as researchers from institutions outside of the EU. This is remarkable, but the picture is nuanced when we take into account the ranking of these types of partners. Even though the own institution is not mentioned by all respondents as a collaboration partner, half of those who did, ranked it as most important. Only institutions within the EU do better; the other categories are substantially lower rated. It thus seems that to some extent (geographical) proximity is important to some, while to others, this does not matter at all. It seem reasonable to assume that the type research and the field involved, do play a role here as well.

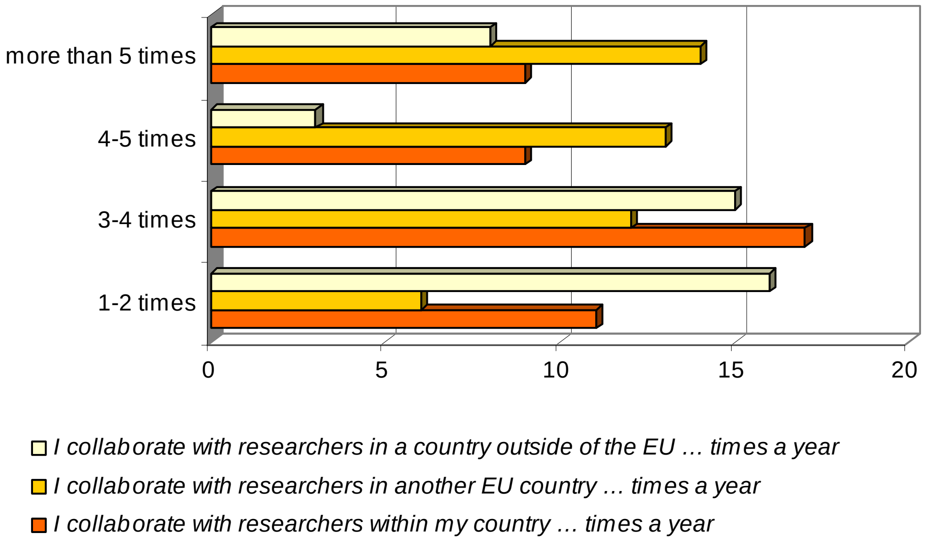
5.3.1.2 Collaboration intensity

On collaboration intensity, we have asked the respondents to indicate how often they collaborate on average per year with each type of partner (according to geographical origin). The answer categories are 1-2 times a year, 3-4 times a year, 4-5 times a year, more than 5 times a year.

Collaboration intensity is approximated by the annual frequency of collaboration. Overall, a frequency of 3 to 4 times per year is cited mostly by the respondents. Yet, for collaboration with partners outside of the EU, 1 to 2 times is the most frequent answer, while for collaboration with research in other EU countries, the most often indicated collaboration frequency is remarkably higher: more than 5 times per year. It seems thus that research in other EU countries are the 'preferred' partners as this type of collaboration is often (and more easily) facilitated by EU-funding (according to one of our respondents). As found in the analysis from co-publishing data, scientific international collaboration is thus increasingly important. Yet, here we see that co-publishing is rather driven by intra-EU collaboration whereas the data suggest extra-EU collaboration to be the main type of collaboration driving growth. Though, this finding is based on he strict definition of intra-EU, while the alternative definition suggests a parallel development of intra- and extra-EU co-publications.

Co-inventors indicate a considerably higher frequency of collaboration with researchers inside the country than authors do (please keep in mind the low number of co-inventors among the respondents). This is in contrast with the analysis of patent data, which suggests that the co-invented patents from international collaboration are the fastest growing group, and even mainly driven by extra-EU collaboration. In the figure below we summarise the answers provided.

Figure 5-3: Frequency of collaboration per geographic type of partners – number of respondents



5.3.1.3 Types of collaboration

We have asked the respondents to indicate which type of collaboration, in terms of arrangement, they are mostly involved in. The answer categories we proposed are formal collaboration, informal agreements, established networks or other more 'loosely coupled' types of collaboration.

Collaboration can take place in the context of formalised contracts or informal and more loosely coupled collaboration formats. Collaboration between researchers seems to often have an informal character. Together, informal agreements and network contacts add up to be most important to 59% of the respondents. Yet collaboration also seems to have a relatively high level of formality, since 39% of the respondents indicates working together on a contractual basis to be most important for them.

Co-inventors, as expected, indicate to be involved in formal collaboration or collaboration through established networks more often than co-authors. This seems logical as IPR division is strongly legally driven and thus most often contractually based. Collaboration leading to co-authorship, seems to be mainly based on informal types of collaboration.

5.3.2 Motives and barriers to collaboration

5.3.2.1 Motives to collaboration

Collaboration in scientific and/or technological work is often driven by a variety of motives (see also literature survey). We have asked the respondents to indicate whether they agree with a number of potential motives for international collaboration and to what extent they do so (on a scale of 1-5 with 1=completely disagree; 2=disagree; 3=neutral; 4=agree; 5=completely agree). The potential motives were identified from literature and presented to our respondents as follows:

- To expand the professional network
- To maintain and/or increase the quality of one's research and/or development
- To further develop one's knowledge and expertise
- To build up, strengthen and/or maintain historical ties among one's research group and other international research groups (cultural/linguistic adequacy)
- To access the expertise and knowledge not available in one's country
- To obtain additional funding
- To access the appropriate research infrastructure (e.g. laboratories, equipment, databases, etc.)
- Because one has been asked by colleague researchers from abroad (academia, research institutes or companies)
- To increase one's career opportunities as a researcher abroad (e.g. get visiting positions abroad, become mobile researchers, etc.)
- To spread and share the 'costs' of research (e.g. purchase of equipment, databases, development of labs, etc.)
- For more general geopolitical reasons (e.g. development objectives, economic collaboration, etc.)
- Because one is obliged to, according to the organisation's policy towards collaboration.

Figure 5-4 and Table 5-3 show that most of the respondents are driven by motives like network expansion and increasing the research quality. More than half of the respondents has indicated to completely agree with these propositions (median=5). From the additional in-depth interviews with some of the respondents, we heard that networking is not only the purpose of collaboration, but also a stimulus for collaboration. This is also an effect identified in literature on network models of collaboration (Gibbons et al. 1994). When one disposes of an extended network, it is easier to collaborate, to find the right partners, one is asked by other researchers in the network to collaborate etc.

Good networking thus leads to more collaboration, and more collaboration again leads to good networking: one reinforces the other.

Figure 5-4: Motives for international collaboration – percentage of respondents that agrees, disagrees, or that is neutral

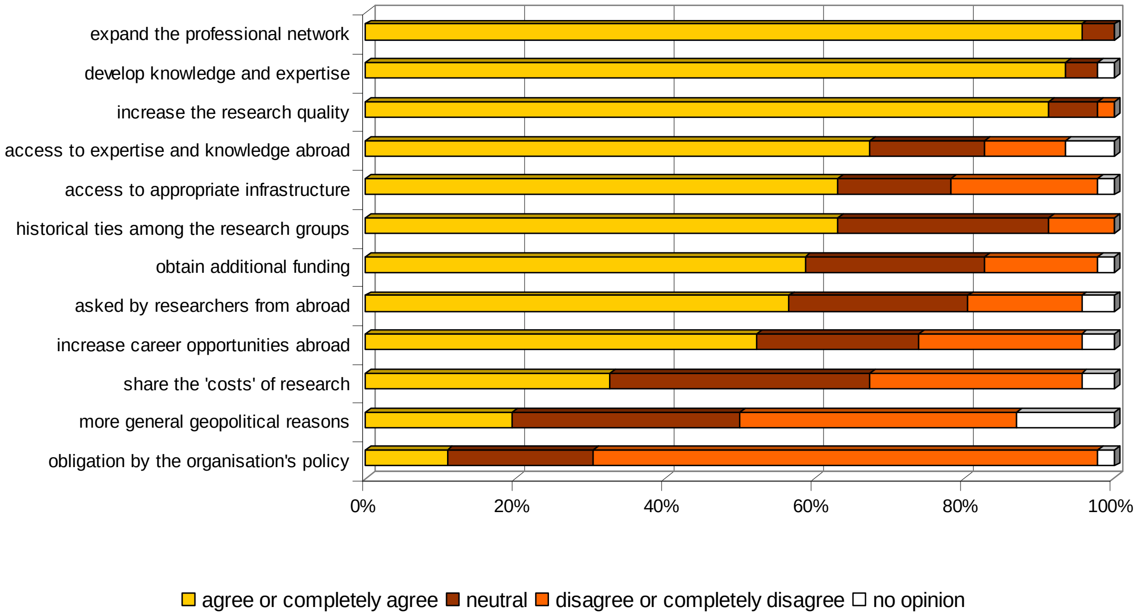


Table 5-3: Motives for international collaboration – median and mean (with 1=complete disagreement to 5=complete agreement)

Potential motives **You engage in international collaboration…**	**Mean**	**Median**
To expand the professional network	4,5	5
To maintain and/or increase the quality of one's research and/or development	4,41	5
To further develop one's knowledge and expertise	4,36	4
To build up, strengthen and/or maintain historical ties among one's research group and other international research groups (cultural/linguistic adequacy)	3,85	4
To access the expertise and knowledge not available in one's country	3,84	4
To obtain additional funding	3,69	4
To access the appropriate research infrastructure (e.g. laboratories, equipment, databases, etc.)	3,58	4

Potential motives You engage in international collaboration…	Mean	Median
Because one has been asked by colleague researchers from abroad (academia, research institutes or companies)	3,55	4
To increase one's career opportunities as a researcher abroad (e.g. get visiting positions abroad, become mobile researchers, etc.)	3,39	4
To spread and share the 'costs' of research (e.g. purchase of equipment, databases, development of labs, etc.)	3,07	3
For more general geopolitical reasons (e.g. development objectives, economic collaboration, etc.)	2,58	3
Because one is obliged to, according to the organisation's policy towards collaboration	2,02	2

To further develop one's knowledge and expertise also scores high as a motive for collaboration: a larger number of respondents has agreed or completely agreed with this proposition than with the one on increase in research quality, but the latter has more respondents completely agreeing (given the higher median). Also access through collaboration to what is not available in the home country is important: in particular specific expertise, knowledge and infrastructure do matter.

International networking with a purpose of strengthening and maintaining historical ties between research groups, or increasing one's career opportunities abroad is also named by the majority of the respondents. On these matters, co-inventors and co-authors seem to differ in opinion. Co-inventors find these to be less important motives for international collaboration than co-authors.

Generally, it is also motivating for researchers to engage in collaboration when they are asked by researchers from abroad or when they can obtain additional funding as a direct or indirect result of it. These are motives as well.

Finally, few respondents consider shared 'costs' of research, general geopolitical reasons and obligations by the organisation's policy to be motives for international collaboration. The number of neutral responses is quite high. The latter proposition is even strongly denied by respondents, as two thirds of them disagree or completely disagree with this proposition. Even more strongly, 80% of co-inventors disagrees or completely disagrees with this proposition, which seems to be counterintuitive in view of the strategic importance of IPR protection.

Through the in-depth interviews we have looked further into this proposition that the organisation's policy can oblige researchers to cooperate internationally. The rejection may either be due to the fact that there is no obligation, or because it is not considered to be a motive even though it happens in reality. The latter may point out that internal (more intrinsic) motives are regarded as more important than external (pressure) factors.

In one case, agreement is explained by the fact that the organisation has set up an indicator-based review system for funding requests. One of these indicators is international cooperation. Consequently, it is clear that the organisation puts great emphasis on international cooperation, and that even assessment and funding depend on it. This of course stimulates international cooperation. However, the respondent has no problem with this way of working and is even in favour of it, as long as the guidelines to the system are clear and objective. This observation shows that the obligation may exist, but is not always viewed in a negative way. Some recognise it as a motive – be it external, others might not. The results must thus be viewed in the right context. The researchers have emphasized moreover that cooperation need to be driven by the content, the intrinsic research questions.

Finally, motives to collaborate seem to be rather universal and do not vary for intra or extra EU collaboration according to 83% of the respondents (cf. infra).

5.3.2.2 Barriers to collaboration

Motives to collaborate often meet several barriers to collaborate as well. To identify barriers to international collaboration, we have applied the same approach as for the motives. Based on our literature survey, we have proposed a number of potential barriers and asked the respondents to indicate their degree of agreement with the proposition (on a scale of 1-5 with 1=completely disagree; 2=disagree; 3=neutral; 4=agree; 5=completely agree).

The potential barriers proposed to our respondents are:

- Lack of funds that stimulate international collaboration
- Potential loss of time because of travelling
- Difficulty of finding the appropriate partners/person(s) to collaborate with
- Challenge of dealing with different cultures and backgrounds
- Language barriers
- No need really to collaborate.

Figure 5-5 shows that only a limited share of respondents recognizes the proposed barriers. Moreover, often the disagreement is larger than the agreement (see also Table 5-4).

Figure 5-5: Barriers to international collaboration – percentage of respondents that agrees, disagrees or is neutral

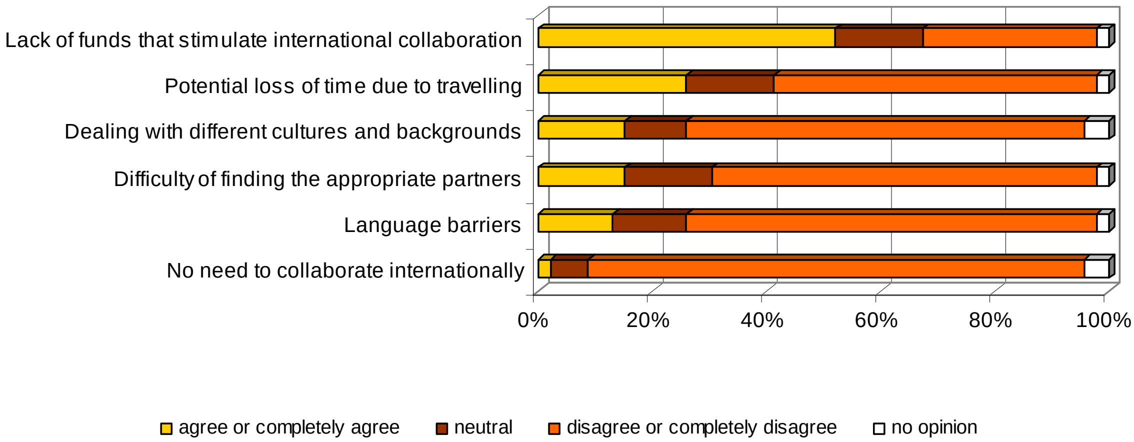


Table 5-4: Barriers to international collaboration – median and mean (with 1=complete disagreement to 5=complete agreement)

Potential barriers **What is keeping you from international collaboration is…**	**Mean**	**Median**
Lack of funds that stimulate international collaboration	3,42	4
Potential loss of time because of travelling	2,42	2
Difficulty of finding the appropriate partners/person(s) to collaborate with	2,16	2
Challenge of dealing with different cultures and backgrounds	2,05	2
Language barriers	2,02	2
No need really to collaborate	1,55	1

A barrier that has been frequently mentioned by the researchers, is the administrative burden (and thus time investment) related to international collaboration. At the same time the lack of funding is also a quite important barrier to international collaboration (3,42 on a scale to 5). Half of the respondents considers this to be an important barrier. This is even more pronounced for the co-authors than for the co-inventors.

Second in importance is the potential loss of time due to travelling, but here already more respondents disagree than agree. Language and other cultural barriers do not seem to bother researchers in their consideration of international collaboration, although they do play a role especially in collaboration with Asian countries. Finally, it is interesting to note that the need to collaborate internationally does exist.

Here as well, the barriers do not seem to vary between intra and extra EU collaboration (according to 74% of our respondents), although compared to the motives for collaboration there is less consensus here (cf. infra).

5.3.3 Value added of collaboration

To measure the results obtained by international collaboration, we have asked the respondents to indicate why, in their opinion, cooperation outside the home country pays off. Again we have proposed a number of potential positive effects of collaboration and have asked for their agreement/disagreement (on a scale of 1-5 with 1=completely disagree; 2=disagree; 3=neutral; 4=agree; 5=completely agree).

The potential effects we have proposed are:

- It increases the quality of the research carried out
- It stimulates and enables the mobility of researchers
- It helps to 'get to know each other' better
- It helps to strengthen the scientific and technological capabilities of a nation
- It helps to establish an international name
- It helps to further align research priorities and programmes and thus to achieve higher levels of efficiency
- It helps to address emerging societal challenges that go beyond the national interest (e.g. climate change, etc.)
- It helps to better valorise the research findings on the market (larger market reach)
- It leads to more frequently cited publications
- It leads to higher value patents

Figure 5-6 and Table 5-5 show that many of the proposed aspects of value added are validated by the majority of the respondents. Most of the respondents tend to agree with these propositions and the possible value added of collaboration. There is little disagreement, but neutral or 'no opinion' answers are rather frequent.

Figure 5-6: Value added of collaboration – percentage of respondents

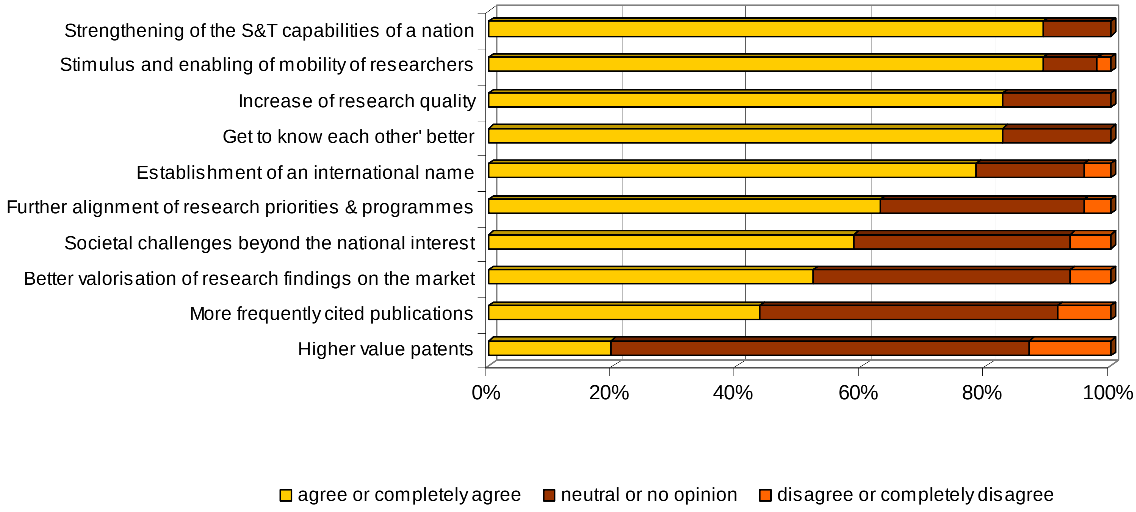


Table 5-5: Value added of international collaboration – median and mean (with 1=complete disagreement to 5=complete agreement)

Potential value added **International scientific and/or technological collaboration pays off because…**	**Mean**	**Median**
It increases the quality of the research carried out	4,26	4
It stimulates and enables the mobility of researchers	4,18	4
It helps to 'get to know each other' better	4,17	4
It helps to strengthen the scientific and technological capabilities of a nation	4,15	4
It helps to establish an international name	4,07	4
It helps to further align research priorities and programmes and thus to achieve higher levels of efficiency	3,93	4
It helps to address emerging societal challenges that go beyond the national interest (e.g. climate change, etc.)	3,92	4
It helps to better valorise the research findings on the market (larger market reach)	3,66	4
It leads to more frequently cited publications	3,60	3
It leads to higher value patents	3,21	3

The main sources of value added coming from international collaboration are the increased strengthening of the science and technology capabilities of a nation and the stimulating and enabling of the mobility of researchers. Also about 80% of the respondents agrees that an increase in the quality of research, the getting to know the partners better and the establishment of an international name, are important results from working together with international partners.

We were able to go into more detail concerning the value added in terms of career development in the additional interviews with some of the respondents. For all of them, career development is an important effect of international collaboration. The emphasis lies on learning from others, both in terms of skills and knowledge and in terms of openness of the mind (getting to know other ways of handling things, other systems, another research focus). Also, researchers confirm that, when collaborating frequently, they receive additional recognition from their colleagues in the academic world, which underlines the importance of the effect of international name establishment.

On the proposition that value added from collaboration comes from addressing emerging societal challenges that go beyond the national interest, co-inventors and co-authors seem to differ in opinion in the survey. Co-inventors tend to agree more with this proposition than co-authors, perhaps because of the more applied nature (more solution driven) of the research of co-inventors.

The only potential sources of value added that less than half of the respondents agrees with, are that resulting publications are cited more frequently and that patents have higher value when they both result from international collaboration. Yet, the latter proposition's rejection is to some extent explained by the fact that two third of the respondents are not co-inventors, and thus feel that they have no opinion on this matter. In fact, all 13 'no opinion' responses were given by co-authors. Of the co-inventors, however, two thirds also responds 'neutral', so we tend to conclude that there is little insight in or believe of higher value patents due to collaboration. This in contrast to recent studies however, which show that internationally co-authored papers receive more international citations than their national 'peer' publications.

5.3.4 Differences in motives, barriers and value added for intra-EU versus extra-EU collaboration

We have also asked the respondents to indicate whether they see a difference in motives, barriers or value added for collaboration within the EU versus outside of the EU. Furthermore, the respondents were given the possibility to elaborate on the causes for these differences in an open question.

Even though we found a difference in collaboration intensity, 83% of all respondents do not believe that the motives are different for intra-EU and extra-EU collaboration. Those who do feel there is a difference, however, attribute this to practical issues as well as to content. The following reasons are brought up in favour of intra-EU research: travel time, the ability to prepare common project proposals for the EU governance, the availability of grants, and more similarities in research interests and complementarity in activities between EU research groups.

Concerning the barriers to international collaboration, 74% of all respondents say there is no difference outside of the EU as compared to within the EU. 20% on the other hand, states that there is a difference. Most of them make reference to the funding possibilities, which appear to be practically non-existing for intra-EU collaboration. Also culture, language and travel time are mentioned as more important barriers for extra-EU collaboration than for intra-EU collaboration. Yet in the opposite direction, one respondent indicates that the administrative burden within the EU is even larger.

The lion's share (93%) of respondents does not regard the value added from extra-EU research collaboration different from that of intra-EU research collaboration. The only remark regarding this question is that good intra-EU research collaboration can lead to access to European research funds, which extra-EU collaboration cannot.

Generally, the differences in motives and barriers for and value added of extra-EU research on the one hand and intra-EU research on the other, are likely to be small and mainly practical in nature.

5.3.5 Role of ERA in collaboration

Finally, we have asked our respondents in an open question to express their ideas on the role of the ERA, and the European Commission's efforts in this respect, in national and/or international scientific and technological collaboration.

21 of the 46 respondents answered the open question of how they relate ERA to national and/or international scientific and technological collaboration. The overall view on the role of ERA tends to be positive. Yet, we should also mention that some of the respondents do not understand what is meant by "European Research Area". Apparently the concept is not that widespread as is assumed in national and European policy maker's circles.

As a first advantage of ERA, it is said that ERA leads to streamlining of international research. This is particularly relevant in common issues like human welfare, drug design, basic science and knowledge base etc. Yet it is also stated that this streamlining is very difficult because countries still have different interests due to their different national backgrounds[56]. Also, what is important for a specific country is not always relevant at the EU level.

The in-depth interviews go into more detail on this matter and confirm that the ERA is indeed important for streamlining certain research topics. There is thus need for this type of high level collaboration to tackle common issues. But it is also emphasized that there remain research topics that are so specific that they are best handled at national or regional level. National or regional collaboration are thus also important and need to be stimulated as well. Furthermore, ERA opens doors for small European countries to find the most appropriate research partners. Without the stimulus of international cooperation, researchers might be inclined to mainly look within the geographic borders of their own country, which is very restricting especially to small countries[57].

Collaboration in general – national, inter-EU or international - tends to improve individual researchers' competencies, because much is to learn from looking at the same problem from a different perspective and by trying to solve it together. Also, collaboration leads in some people's opinion to more efficient use of resources. It is therefore again emphasized that not only international collaboration matters, also national collaboration or collaboration within the same institution is important. Following, the idea that ERA stimulates some form of collaboration –for as far as this is not substituting another form but leads to a real growth in collaboration - is also positive in view of researchers' development, resource allocation and effectiveness of research. In this sense, it is agreed upon that ERA is an important opportunity for researchers to widen their knowledge base and extend their professional network.

Yet, next to the broad scope of advantages from additional collaboration initiatives, it is also emphasized that funding is the main condition for project set-up. Therefore, in some researchers' opinion, it are the funding possibilities at EU level that are vital to international collaboration. However, with these funding possibilities comes administrative work as well. To some, this appears to be heavy bureaucracy and a serious barrier to requesting for this support. Some claim to prefer requesting for bilateral or domestic financial sources for this reason only.

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56 See also a recent study on 'Coordination and cooperation with and between IRO's and RPO's, DG Research' – carried out by a consortium lead by COWI Denmark (in finalization early 2009).

57 As mentioned before, this is confirmed in literature (Hinze 1999; Katz 2000; Luukkonen et al. 1992). Researchers in smaller countries seem to have more difficulties finding adequate partners in their own country, thus, they are forced to look for partners abroad. With increasing differentiation in science and thus smaller scientific comunities, this trend might become increasingly relevant.

Also, we learn from the in-depth interviews that great importance is attached to horizontality of measures – meaning that funding programmes should be open to all disciplines and should only be reviewed based on objective quality criteria, not on nationality or discipline.

Another idea touched upon during one of the interviews, is that EU universities should be stimulated to become more multicultural, which would in turn lead to an increase of international cooperation and knowledge diffusion. Not only short-period research mobility is important, also the number of permanent positions for foreign professors should increase. Nowadays, it is found difficult to work outside of one's country on a permanent basis. This is much easier in the USA, where universities are truly multicultural. Therefore, the ERA has a role in stimulating the creation or opening of permanent positions for foreign researchers.

5.3.6 Preliminary conclusions

General

- Collaboration in general is important to the respondents. Any instrument stimulating any form of collaboration is therefore welcomed.
- Data analysis has shown a growing pattern in co-publishing and co-patenting. According to the survey results, it is expected that international collaboration will continue increasing in the future, thanks to the further development of mobility and communication possibilities and thanks to the growing acknowledgement of the importance of international collaboration.
- Co-publications are regarded as a good indicator for international collaboration. Co-inventions are accepted to a much lesser extent. This is in line with the literature findings.

Motives, barriers and results

- The intrinsic scientific and research drivers as identified from the literature (Wagner et al. 2001; Katz/Martin 1997) as endogenous motives, tend to be the most important drivers for international cooperation. These include quality of research, network expansion, access to infrastructure, knowledge, partners that are not available in the home country etc. Some of these are also named to be the most important results of cooperation, thus the expectations/motives seem to come true.
- Quality of research is high on top of the motives list, but is not proven to be a result of international cooperation, as higher patent value and/or more citations are not expected by the respondents.
- Next to intrinsic and to some extent idealistic motives, however, funding also takes up an important place in the considerations regarding international collaboration.

Even more, a lack of funding is the only barrier largely accepted by respondents. Also, it tends to drive researchers to intra-EU collaboration – cf. infra – which shows that is a powerful driver for researchers.

- National competitiveness and global challenges are not the main value added of international research, but do tend to matter.
- Furthermore, the development and mobility of researchers and the building up of an international name as a researcher are seen as value added from international co-operation. Personal career paths seem to benefit from it.

Intra-EU research & funding

- On the importance of the proximity of collaboration partners, opinions differ. For some it matters, for other it doesn't.
- It seems though, that intra-EU cooperation is very important compared to extra-EU and even domestic cooperation. Both the type of partners and the frequency of collaboration point this out. Yet, there is no evidence that motives or barriers differ much from extra-EU or domestic cooperation. Furthermore, the data analysis does not suggest that intra-EU collaboration plays such a dominant role either.
- Therefore it is likely that funding plays a great role in the importance of intra-EU co-operation and is emphasized by respondents therefore. Funding is also mentioned as an important motive for intra-EU cooperation and as a barrier for extra-EU cooperation.
- Value added of good and visible intra-EU research, is according to some also a way of obtaining additional EU funding, and thus has an advantage over other (geographic) forms of research collaboration.

The role of ERA

- ERA is not known to all respondents.
- Yet, as already suggested by the network analysis, it does seem to play an important role in international cooperation. In the survey results, it is attributed growing streamlining of research, increasing development possibilities for researchers and the provision of an important source of funding for international cooperation.
- The objectives of ERA are thus to a large extent mirrored in these results: ERA stimulates international cooperation, which in turn – according to the response pattern of this survey - leads to improved coordination of national research activities and policies, better allocation of resources by streamlining of research and increasing the mobility of researchers, the expansion of researcher's networks and knowledge sharing.

- And as ERA stimulates and streamlines funding for research cooperation, the results of the survey learn that it provides researchers with a very basic incentive that leads them to engage in international cooperation: funding.
- However, an objective of ERA is also to open up to the rest of the world. In this view, respondents have the opinion that ERA could be more open towards e.g. the USA.
- Also, public-private cooperation is still much below the public-public cooperation. Even though industry is indicated to be an important collaboration partner, and literature suggests that scientific and technological research are becoming increasingly interwoven, respondents of the survey believe that more could be done to stimulate public-private cooperation.

Questions for future research:

In this survey analysis, the number of respondents was too limited to draw significant conclusions on the different sub-groups of the sample of researchers. However, country size, area of expertise and co-inventors vs. co-authors remain interesting subgroups to analyse international cooperation behaviour in more detail in future research.

6 Policy relevant reflections

6.1 The European Research Area

The „European Research Area" (ERA) was launched in the year 2000, aiming at further integration of the European research system and achieving a higher degree of coordination and cooperation among the various players at all policy levels aiming at improved efficiency and effectiveness of still fragmented research efforts in order to strengthen Europe’s international competitiveness. ERA is a vision about coordinating national research activities and policies and creating an internal market for research with the free circulation of researchers, ideas and technologies. The Lisbon European Council urged Europe to turn itself into a knowledge-based economy through more and better investment in the knowledge triangle of research, education and innovation. The ERA was initiated to overcome three weaknesses: insufficient research funding; inadequate framework conditions to stimulate research and its exploitation; and finally the fragmentation of activities and resources. Improving the co-operation and co-ordination among key players within the European Union is a key factor to overcome these shortcomings. As re-defined in the EC’s 2007 Green paper on the future of the ERA, the ERA as such covers the following key features:

1. An adequate flow of competent researchers with high levels of mobility between institutions, disciplines, sectors and countries;
2. World-class research infrastructures, integrated, networked and accessible to research teams from across Europe and the world, notably thanks to new generations of electronic communication infrastructures;
3. Excellent research institutions engaged in effective public-private cooperation and partnerships, forming the core of research and innovation 'clusters' including 'virtual research communities', mostly specialised in interdisciplinary areas and attracting a critical mass of human and financial resources;
4. Effective knowledge-sharing notably between public research and industry, as well as with the public at large;
5. Well-coordinated research programmes and priorities, including a significant volume of jointly-programmed public research investment at European level involving common priorities, coordinated implementation and joint evaluation;
6. A wide opening of the European Research Area to the world with special emphasis on neighbouring countries and a strong commitment to addressing global challenges with Europe's partners.

Even though the term “ERA” is not known to all our respondents (it is a rather abstract concept), ERA seems to play an important role in international cooperation. It is attributed to streamline research, increase development possibilities for researchers and the provision of an important source of funding for international cooperation. The objectives of ERA are thus to a large extent mirrored in the results of our (small scale) survey: ERA stimulates international cooperation, which in turn – according to the response pattern of the survey – leads to improved coordination of national research activities and policies, better allocation of resources by streamlining of research and increasing the mobility of researchers, the expansion of researcher's networks and knowledge sharing. And on top, ERA provides researchers with a very basic incentive that leads them to engage in international cooperation: funding.

6.2 Collaboration from the researcher’s perspective

Collaboration, in all forms, is an important instrument for opening up boarders and stimulating interaction among researchers. This was clearly emphasized by the respondents involved in our small-scale survey. In general, respondents are aware of the importance of collaboration, nationally as well as internationally, and recognise the importance of the European Research Area (ERA) in that respect. The observed trend of increasing international collaboration is expected to continue in the future, thereby facilitated by the further development of (researcher) mobility support schemes and communication possibilities.

The importance of international collaboration for respondents is mainly reflected by the intrinsic elements and drivers for doing research. These include quality of research, network expansion, access to infrastructure, knowledge, partners that are not available in the home country etc. Some of these elements also clearly benefit from cooperation and are thus also a motive. Even though quality of research (both in terms of good quality publications and high-value patents) is high on the top of the motives list, researchers are not fully convinced about the correlation between the two. As illustrated in our literature review however, internationally co-authored publications do result in high citations indicators. Apparently though, researchers do not recognise this fully or do not experience this as such.

Mobility of researchers and also the establishment of an international name as a researcher (personal career path), are clearly seen as benefits of international cooperation. Funding also takes up an important place in the considerations regarding international collaboration. Even more, a lack of funding is the only proposed barrier largely accepted by respondents. Lack of (national) funding tends to drive researchers to increasingly engage in intra-EU collaborations, thus being a powerful driver for researchers to become more international.

On the importance of the proximity of collaboration partners, no clear conclusion could be derived. For some it matters a lot, for others it does not. This is more or less in line with the findings that geographic proximity tends to lead to more integration in research and innovation, but that extra-EU research is also important and even more strongly growing than intra-EU research. Contrary, from the survey results, we find that intra-EU cooperation is very important compared to extra-EU and even domestic cooperation. Both the type of partners and the frequency of collaboration point this out. Still, there is no evidence that motives or barriers differ much for intra-EU or domestic cooperation, except for one: funding. Funding is mentioned both as an important motive for extra-EU cooperation and as a barrier for intra-EU cooperation. According to some researchers, good and visible extra-EU research also has the added value of possibly obtaining additional EU funding (catalytic effect).

6.3 Higher levels of collaboration?

6.3.1 The 'science' sphere

Our data analyses show that the shares of international collaborations, as a part of total collaboration in research captured by scientific publications, have been increasing considerably over time. This opposed applies to the 'pure' national publications, where we hardly have seen any evolution since the mid 1990s until recent years (where a small increase can be noted). Research is increasingly becoming internationalised, which is to some extend due to the intrinsic nature of science, which has become more network, and thus also socially, embedded. A large part of the increase in international co-publications is accounted for by collaboration with partners outside the EU.

There are some indications in our data that larger countries have lower shares of international collaborative publications, which might be the result of sufficient 'internal' research capabilities. Some of these countries show considerable exchange with third countries outside the EU, among which Switzerland, North-America, but also other countries and areas like China, Japan or South-America play an important role. Undoubtedly, international S&T cooperation strategies with so-called Third Countries play a role here. The analysis of co-publications in 26 science fields, have lead to the insight that the EU is less strongly engaged in international collaboration where it has strong capabilities (high scientific output). This may suggest that international collaboration is sought for getting access to complementary knowledge and expertise, which is also confirmed to a large extend in our survey.

Another finding is that more applied fields are less internationally oriented, perhaps due to higher sensitivity to competitive forces, while basic research areas seem to reach higher shares of international co-authorship. Chemical Engineering or Food and Nutrition are rather nationally oriented fields, while Nuclear Technology, Geology and Physics are quite internationally oriented. Though, trilateral collaborations – between at least two EU member countries and one non-EU country – are rather frequent in Nuclear Technology research and in Physics. Indeed, these fields are also known for their highly international profile.

Concerning the geographical characteristics, an additional analysis of EU-15 collaborations revealed similar trends like in the case of all EU-27 countries, though on a slightly lower level, of course. This may point out that New Member States (NMS) are not yet operating fully within the spirit and the possibilities within the ERA (however, potential publication biases have to be taken into account here). Some indications were also found to support the relevance of geographical proximity. The discussions we had with researchers indeed refer to this issue, and even confirmed that proximity does matter when it comes to 'partnering'.

6.3.2 The 'technology' sphere

On the technology side, by analysing and studying patters of co-patenting, it became clear that since the 1990s, there has been an increase in the share of technology developed among international partners for the EU as a whole, and amongst most individual EU countries. This increase is mainly the result of collaborations with extra-EU countries (or Third Countries), just as has been the case for scientific collaborations.

Interesting to note is that the share of intra-EU collaboration has increased as well, but much less than the extra-EU shares. At the same time we see concentrations around specific EU countries, which is the result of the industrial structure/sectoral specialisation pattern of a nation and in a broader sense the so-called 'propensity to patent'. Moreover, there are indications that country size (whether technological or economic) may be a factor in explaining inter-country differences in the levels and trends of the share of international technological collaborations. The three countries that appear amongst the innovation leaders in the EU (based on the European Innovation Scoreboard) namely Finland, Sweden and Germany have a relatively low share of technology developed on the basis of international collaborations. On the other hand some of the countries with the largest shares are below average in terms of the innovation scoreboard rankings: Latvia and Lithuania. Most like this clearly links to the national capabilities concerning technology development.

Here as well, we find the NMS to be less present than the 'old' MS. The most important co-operation partners for the EU countries are the US and Switzerland. However, the largest increases in technological collaborations, albeit for a small base, have been with China and India, the Third Countries. For sure, one also has to acknowledge the role of the internationalisation strategies of large MNC's, for example in the area of chemicals (and pharmaceuticals). The technical field with the largest share of international collaborations for the EU countries as a whole is Chemistry. This is indeed traditionally an area of EU technological strength. The other field where the share of internationally developed technology is relatively high is Instruments. In all technology areas, we see that extra-EU collaborations are relatively more important than those with other EU-15 countries. It has to be kept in mind thought that these patterns are based on patented inventions, and that only a fraction of all inventions (and thus potential collaborations) is patented.

6.3.3 Network analysis

The aim has been to analyze the evolution of the fields as a whole, as well as the emergence of new structures in the ERA based on the formation of agglomerations of countries. In our network images and analysis over different periods, we see that large countries play an (increasingly) central role. Small countries are more integrated, both in terms of connection to the large dominant countries but also among each other (in the realm of research). Furthermore, we see that the gate-keeping role of the US has decreased over time, if we focus on EU27. In short, we do see an integrative effect, but whether this can be fully or even partially attributed to ERA, and to which feature, is not evident. In our discussion with the researchers, and derived from the survey, it is clear that the availability of more funding for international collaboration, and the policy awareness to this end, have played a positive role. Also the openness of the FP-programs towards Third Countries has played an important role in this respect.

Based on co-patenting, a different image occurs. One might be inclined to say that there is not such a thing as an ERA effect in co-patenting. However, there are tendencies, small and partly inconclusive at best, that point at an increase of the connections among the larger players. The smaller players though are not part of the larger picture of co-patenting. Reasons for this lack of integration in co-patenting might be found in the aim of appropriability of knowledge, rent-seeking behaviour or motives for patenting as a strategic instrument. These might produce an incentive to fraction potentially patentable content into the least patentable units in a collaborative R&D activity if different companies are involved. What remains are co-patents that involve at least two countries in terms of inventors involved but those inventors belong to one economic unit: a multinational enterprise.

6.4 Indications of increasing 'integration'?

Much has been achieved in the recent decade in terms of progress (since the concept was endorsed at the Lisbon European Council in 2000, and the European Research Area has become a key reference for research policy in Europe) towards the ambitious objectives, but only a few achievements can directly be quantified and measured, especially those achievements relating to integration and far reaching cooperation in research and development (and mainly in relation to progress on features 5 and 6 – cf. supra). Certainly, the above discussed indicators and patterns do suggest increasing 'openness' to cross-border collaboration, and mainly extra-EU collaboration.

At the same time, no firm conclusions can be drawn as far is 'integration' movements in the context of the ERA is concerned. The fact that respondents acknowledge the advantages of intra-EU research, suggests that they are also prepared to engage to a growing extent in intra-EU collaborations, which in turn will lead to increased integration. However, an objective of ERA is also to open up to the rest of the world (extra-EU collaboration). In this view, respondents are of the opinion that ERA could be more open towards e.g. the USA, China and Japan. Also, public-private cooperation is still much below the public-public cooperation.

Indications of 'integration'? Yes, but at the same time it is hard to attribute this progress to specific initiatives and efforts undertaken under the ERA umbrella, just as it is to plead that there is no interrelation at all. Next to supporting measures like funding, frameworks and networking activities, also geographical as well as cultural (especially language) proximities matter and contribute to the cohesion of the ERA. The latter can hardly be directly influenced by policy action, but the knowledge on these matters can be used to better tailor future policy tools. Regional focuses as well as using certain member states as "bridges" to integrate others could be meaningful means especially towards the further integration of the New Member States, which are less integrated so far – at least according to our empirical findings. As smaller countries tend to collaborate more often "by nature", fostering the larger member states to collaborate more would have larger effects – both directly and indirectly as they will seek collaborators also from smaller countries.

6.5 Future monitoring of progress

To measure and monitor this circulation and cohesion, several indicators could/should be employed, but only a few are at hand at the moment and are ready for direct use. Scientific publications and patent applications are examples of these ready-to-use indicators, where international co-publications and co-patents are an output-measure of international collaborations. The scientific literature confirms this adequateness, though one has to be aware of the technical but also interpretational limitations of these indicators. Moreover, as discussed above, they are not the only indicators that capture collaboration. ERA also encompasses additional instruments, means and infrastructures, which foster the exchange of knowledge and ideas, but which cannot be covered by the analysis of patents and publications only.

What does this imply?

- A better and more integrated logical framework (intervention logic) is essential in order to being able to systematically 'connect' the expected effects of ERA to its features and support measures, and as such to claim for a certain degree of causality between integration and policy measures.
- It is important to develop and use various complementary indicators to measure progress on the specific features (dimensions) of the ERA.
- A feature specific monitoring instrument is needed, as the 'ERA' as such is a rather heterogeneous concept; each feature should be measured by a set of specific indicators (fulfilling the SMART criteria) in combination with more general indicators.
- In several cases, it might even be needed to develop field-specific (topical) indicators as a result of the specificity of respective science fields. It is clear that co-patents and co-publications belong into this set of indicators, but also that they should be complemented by other indicators like FP participation information, Webometric indicators that capture website citations (cf. infra), conference participation information etc.
- Another categorisation of monitoring indicators distinguishes the project-level integration from the programme-level and policy-level integration. Project-level collaboration leads to increased integration among researchers or researchers' teams. Programme-level collaboration (coordination) leads to integration and alignment among public R&D programmes in regions and countries (e.g. which part of the budget of national programmes is actually 'open' to foreign participation?). Finally, policy-level collaboration (coordination) leads to strategic integration, co-developed global research agenda's and thematic priorities. The take-off of ERA-Net schemes since FP6, the appearance of Technology Platforms, Art 169, JTI's etc as reinforcement of the means to foster the European integration of research, as well as the increased coordination of national policies therefore need to be better monitored at the EU-level. For instance, some studies have already assessed the level of openness of some regional / national R&D programmes to foreign participation, but there is a need to pursue the monitoring in a more structured way. No need to mention that such a monitoring at pro-

gramme- or policy-level needs to be developed in close cooperation with the Member States.

- The monitoring system should be institutionalised and ‘broadly’ supported. Fiches of indicators should be developed where each indicator is well described methodologically, but also in terms of its interpretational limitations. The monitoring system should be made public.
- The need for novel indicators capturing and measuring the ‘flow’ concept is emphasized. A promising field in this respect is the field of Webometrics, where website citation analysis seems to be useful for measuring more informal types of knowledge transfer; however, here as well, the stability of the potential indicators just as the interpretational limitations are important.
- Finally, monitoring is an ongoing process: it is important to repeat analysis over time and as such to build a longitudinal perspective.

6.6 Future research

Although this study has shed some light on important aspects relating to S&T collaboration in the context of the ERA, more research questions remain in relation to the indicators used here.

1. First of all, is co-patenting disproportionally driven by multinational companies compared to overall patenting activity? It would be critical though to find an answer to this question in the foreseeable future as to understand the results generated by country-based analyses of co-patenting and also to maybe provide some frame of interpretation for the results we found.

2. Furthermore, the statistical analysis provided here covers a period of the accession that is too short to prove the integrating effects from a geographical perspective. Future studies might find more evidence for this.

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8 Appendices

Appendix 1: Overview of relevant studies

ADL (2005): The internationalisation of R&D in the UK. ADL with Prof R Veugelers. Report for the DTI/OST, November 2005, Ref. 20547, 117 pages.	Consultancy report that draws on a variety of indicators, incl. co-patenting, to describe the internationalisation of research and development and it implications for the UK. The study reports for 1999-2000 that 6.6% of OECD-resident patents filed at the EPO resulted from international collaboration, compared with 4.1% in 1991-2. When intra-EU co-operation is netted out, international collaboration in patenting is lower in the EU (7%) than in the US (11%). The study also points out that internationalisation tends to be lower in larger OECD countries and argues that this is largely driven by the need for researchers in smaller countries need to look abroad for collaborators. Having said this, there are also outliers. The UK is one such example with around 20% of its EPO patents linked to foreign co-inventors.
Calero, C.; van Leeuwen, T.N.; Tijssen, R.J.W (2005): Research networks of pharmaceutical firms: Geographical patterns of research collaboration within and between firms. Proceedings of the 10th International Conference of the International-Society-for-Sciento-metrics-and-Informatrics, July 24-28, 2005, Stockholm, Sweden, pp. 310-315.	Industry's scientific output in terms of research articles are one of industry's collaborative quantifiable research outcomes. Large-scale systemic measurements of worldwide trends and sectoral patterns can be disclosed from scientific and technical articles that are (co)authored by industrial researchers and published in the peer-reviewed international scientific journals. Co-authored research papers are assumed to signal research cooperation and associated knowledge flows and exchanges. We focus our attention on the large science-based Pharmaceuticals multinational enterprises (MNEs) that are active in many countries and produce many research articles – either with partners both within the MNE and/or with external partners within the private sector. The study is based on research articles jointly written by corporate researchers and published in peer-reviewed scientific and technical journals during 1996-2001. The network analyses of co-publication linkages indicate structural differences between types of Pharmaceuticals MNEs and geographical regions. A general typology is developed of MNEs in terms of their patterns of research cooperation linkages. Separate aggregate analyses are conducted for exemplars of each type broken down by the geographical region in which the partnering companies are located. Some patterns indicate a centralized research cooperation profile; others reflect geographical dispersion of research partners - both within and outside the NINE.

Cantner, U.; Graf, H. (2004): Cooperation and specialization in German technology regions, Journal of Evolutionary Economics, 14 (5), pp. 543-562.	In this paper we focus on the technological knowledge of a region and the pattern of cooperative behavior of the innovative actors within that region as a means of transferring this knowledge. In particular, we are concerned with the relationship between the kind and level of knowledge and/or the degree of specialization within a region, the propensity to cooperate and the kind of cooperation. Based on a theoretical discussion of research cooperation we derive appropriate hypotheses and provide an econometric analysis based on data of co-patenting. We find that technologically moderately specialized regions show the highest number of research cooperations, and the higher a regions specialization, the more cooperations take place with partners inside that region.
Fontana, R.; Geuna, A. (2008): The Nature of Collaborative Patenting Activities. Unpublished manuscript, draft 16 May 2008.	The paper investigates why different governance structures are used in a sample of successful collaborative patenting activities in Europe. First we show that collaborative innovative activities are present in the patenting process much more that was known before on the basis of co-assignment data. Overall collaborative patenting activity can be estimated to be present in more than a quarter of all patents, this is about eight times more than what one can expect from co-assignment data (used till now to assess cooperation in patenting). We then examine what is the impact of organizational, project and individual factors on the decision to chose which of the three possible modes of governance: co-assignment, co-invention, collaborative agreement. We find that higher project complexity and technological scope are associated to tighter modes of governance. We also find a weak negative relationship between licensing and co-ownership, this result provide some support to the view that some licensing can be the result of ex-ante legal agreements more than a market for technology. Finally, inventor specific characteristics matter too. In particular, experience increases the probability of choosing less hierarchical governance modes while better education is associated to tighter modes.

Glänzel, W.; Debackere, K.; Meyer, M. (2008): 'Triad' or 'tetrad'? On global changes in a dynamic world, Scientometrics, 74, pp. 71-88.	The US-EU race for world leadership in science and technology has become the favourite subject of recent studies. Studies issued by the European Commission reported the increase of the European share in the world's scientific production and announced world leadership of the EU in scientific output at the end of the last century. In order to be able to monitor those types of global changes, the present study is based on the 15-year period 1991-2005. A set of bibliometric and technometric indicators is used to analyse activity and impact patterns in science and technology output. This set comprises publication output indicators such as (1) the share in the world total, (2) subject-based publication profiles, (3) citation-based indicators like journal-and subject-normalised mean citation rates, (4) international co-publications and their impact as well as (5) patent indicators and publication-patent citation links (both directions). The evolution of national bibliometric profiles, 'scientific weight' and science-technology linkage patterns are discussed as well. The authors show, using the mirror of science and technology indicators, that the triad model does no longer hold in the 21(st) century. China is challenging the leading sciento-economic powers and the time is approaching when this country will represent the world's second largest potential in science and technology. China and other emerging scientific nations like South Korea, Taiwan, Brazil and Turkey are already changing the balance of power as measured by scientific production, as they are at least in part responsible for the relative decline of the former triad.
Guellec, D.; Pluvia Zuniga, M. (2007): Globalisation of technology captured with patent data. A preliminary investigation at the country level, in Statistics Sweden, Productivity Yearbook 2006, 109-126. Downloaded from: http://w41.scb.se/statistik/_publikationer/OV9999_2007A01_BR_06_X76BR0801.pdf.	This paper uses patent data to investigate the globalisation of technological activities as led by multinational enterprises since the early 1990s. Three questions are addressed: i) what are the major patterns in te globalisation of inventive activities? ii) what are the motivations of technological globalisation? and iii) what is the impact of globalisation on the inventive performance of the countries investing abroad in R&D and of those receiving the investment? Patent data give meaningful and rich insights into the globalisation of technology. Major findings are as follows. The share of cross border inventions in total inventions is increasing, reflecting the globalisation of R&D and technology. However, there is substantial variability across countries regarding the characteristics, motives and effects of cross-border R&D in terms of knowledge transfer. The dominant motive of MNEs in most countries for developing R&D abroad is to acquire lacking and complementary technological competences, expanding their knowledge base – while adapting products to local characteristics comes second only. Knowledge transfers from cross border inventions, both to the owner and to the inventor country, are high and rising steadily, in most countries.

Guellec, D.; van Pottelsberghe de la Potterie, B. (2001): The internationalisation of technology analysed with patent data, Research Policy, 30, pp. 1253-1266.	This paper presents three new patent-based indicators of internationalisation of technology reflecting international cooperation in research and the location of research facilities of multinational firms. They witness both an increasing trend towards the globalisation of technology in the OECD area and large cross-country differences in the extent of internationalisation. An empirical analysis shows that the degree of technological internationalisation is higher for small countries and for countries with low technological intensity. Finally, two countries are more likely to collaborate if they are geographically close to each other, if they have a similar technological specialisation and if they share a common language. Being member of the European Union involves more cross-border ownership but does not entail more research co-operation than it is implied by the above factors. Nordic countries have a particularly high propensity to collaborate together.
Hanel, P. (1994): R&D, Inter-Industry and International Spillovers of Technology and the Total Factor Productivity Growth of Manufacturing Industries in Canada, 1974-1989.	The paper offers new econometrics evidence on the relationship between total factor productivity and the R&D expenditures of Canadian manufacturing industries in the presence of inter-industry and international spillovers of technology. The construction of spillover proxies is based on a matrix of Canadian patent counts. The normalized distributions of inventions patented in Canada by each country of the G-7 group are weighted by their respective R&D expenditures to generate estimates of R&D expenditures in other industries in Canada and abroad, creating spillovers that can be used by each Canadian industry. The results confirm Griliches' (1994) finding that the TFP-R&D nexus is strongly influenced by the inclusion or exclusion of the computer industry, whose TFP has been adjusted for quality improvement. They also suggest that the process-related R&D activity appears to have a statistically more significant effect on TFP than the product-related R&D. Federal grants to R&D do not appear to enhance TFP. The estimated effect of spillovers from R&D in other industies in Canada varies over time and, in contrast to former studies, is smaller than the effect of the industry's own R&D. The estimated effect of international spillovers of R&D on TFP is mostly statistically significant. Its magnitude, however, varies over time and is smaller than the effect of industry's own R&D.
Hu, A.G.; Jaffe, A.B. (2001): "Patent Citations and International Knowledge Flow: The Cases of Korea and Taiwan": Cambridge, MA: NBER Working Paper No. W8528, 2001.	This paper examines patterns of knowledge diffusion from US and Japan to Korea and Taiwan using patent citations as an indicator of knowledge flow. We estimate a knowledge diffusion model using a data set of all patents granted in the U.S. to inventors residing in these four countries. Explicitly modeling the roles of technology proximity and knowledge decay and knowledge diffusion over time, we have found that knowledge diffusion from US and Japan to Korea and Taiwan exhibits quite different patterns. It is much more likely for Korean patents to cite Japanese patents than US patents, whereas Taiwanese inventors tend to learn evenly from both US and Japanese inventors. The frequency of a Korean patent citing a Japanese patent is almost twice that of the frequency of a Taiwanese patent citing a Japanese patent. We also find that a patent is much more likely to cite a patent from its own technological field than from another field.

Klitkou, A.; Nygaard, S.; Meyer, M. (2007): Tracking techno-science networks: A case study of fuel cells and related hydrogen technology R&D in Norway, Scientometrics 70 (2), pp. 491-518.	This study explores boundary-crossing networks in fuel-cell science and technology. We use the case of Norwegian fuel cell and related hydrogen research to explore techno-science networks. Standard bibliometric and patent indicators are presented. Then we explore different types of network maps-maps based on co-authorship, co-patenting and co-activity data. Different network configurations occur for each type of map. Actors reach different levels of prominence in the different maps, but most of them are active both in science and technology. This illustrates that to appreciate fully the range of science-technology interplay, all three analyses need to be taken into account.
Lee, Y.G.; Lee, J.H.; Song, Y.I.; Kum, H.J. (2007): Collaborative strategies and open innovation in the mobile telecommunications industry. Proceedings of the 4th International Conference on Innovation and Management, Dec 5-6, 2007, Ube, Japan, pp. 521-525.	This study deals with the issue of open innovation in the mobile phone industry, especially focusing oil the fact that mobile firms have increasingly become engaged in external capabilities to extend the knowledge boundaries of firms. As an open innovation strategy, the collaboration efforts have been especially important due to the rapid speed of external environment change. The authors confirm that the number of co-patenting in US patents, which indicates strong collaborative research of leading mobile firms (Nokia, Motorola, Samsung and LG), is not so high. This paper also confirms that current industry leader have high the cross-country patents compare to others with increasing strategic activity.
Maggioni, M.A.; Nosvelli, M.; Uberti, T.E. (2007): Space versus networks in the geography of innovation: A European analysis, Papers in Regional Science, 86 (3), pp. 471-493.	This paper provides an original framework for the interpretation of innovative activity among European regions according to traditional 'geographical' spillovers and 'relational' spillovers. The focus is on two knowledge-based relational phenomena: participation in the same research networks (within the EU Fifth Framework Programme) and EPO co-patent applications. Using two econometric techniques, we investigate the factors that determine patenting activity, distinguishing structural features, geographical and relational spillovers. In this way, we are able to test whether hierarchical relationships based on a-spatial networks between geographically distant excellence centres prevail over diffusive patterns based on spatial contiguity.
Meyer, M.; Bhattacharya, S. (2004): Commonalities and differences between scholarly and technical collaboration - An exploration of co-invention and co-authorship analyses, Scientometrics, 61 (3), pp. 443-456.	Co-authorship analysis is a well-established tool in bibliometric analysis. It can be used at various levels to trace collaborative links between individuals, organisations, or countries. Increasingly, informetric methods are applied to patent data. It has been shown for another method that bibliometric tools cannot be applied without difficulty. This is due to the different process in which a patent is filed, examined, and granted and a scientific paper is submitted, refereed and published. However, in spite of the differences, there are also parallels between scholarly papers and patents. For instance, both papers and patents are the result of an intellectual effort, both disclose relevant information, and both are subject to a process of examination. Given the similarities, we shall raise the question as to which extent one can transfer co-authorship analysis to patent data.

OECD (2007): Compendium of Patent Statistics. Paris: OECD.	The Compendium of Patent Statistics 2007 provides the latest available internationally comparable data on patents. Patent indicators presented in this publication are specifically designed to reflect recent trends in innovative activities across a wide range of OECD member and non-member countries. Patent-based statistics reflect the inventive performance of countries, regions and firms, as well as other aspects of the dynamics of the innovation process (e.g. co-operation in innovation or technology paths). Patent indicators, along with other science and technology indicators, thus contribute to our understanding of the innovation system and the factors that support economic growth. For example, using the inventors' address, indicators can be developed to monitor the internationalisation of and international collaboration in science and technology (S&T) activities. The results presented in this document reflect the efforts of the OECD, the European Patent Office (EPO) and the OECD task force on patent statistics to improve the quality and availability of patent statistics for researchers and policy makers. Furthermore, OECD activity on patent statistics benefited from strong support from the Japan Patent Office (JPO). The focus of OECD work in this area is not only limited to the development of patent indicators; efforts are also made to develop methodologies and guidelines for compiling and interpreting patent indicators, and to improve accessibility of such information for users. Statistics reported in this compendium differ from data published in other sources, such as patent office data. This is mainly due to methodology. OECD's patent indicators are designed to reflect inventive activity, whereas patent data reported in annual reports of patent offices are designed to reflect their own activity and are primarily for administrative purposes (e.g. budget planning). Therefore, the data reported here should not be compared with those published by patent offices. The 2007 edition is the fifth edition in an annual series. With each edition, there is a continuing effort to provide new or improved patent indicators for international comparisons. The 2007 edition has made extended use of the EPO's the World-wide Statistical Patent Database and the comprehensive data set on JPO applications set up by the JPO and the University of Tokyo (IIP database). A series of new indicators was drawn to highlight patenting activities in key technology fields such as nanotechnologies. A new section presents patenting activity by regions. The electronic version of this document, together with spreadsheets containing the data used in charts and graphs, plus a glossary of terms and a brief note on patenting procedures, is available on the OECD patent statistics web site: www.oecd.org/sti/ipr-statistics

Tsuda, K.; Rinaldo, F.J.; Kryssanov, V.V.; Thawonmas, R. (2006): The structure of patent authorship networks in Japanese manufacturing companies. Proceedings of the International Conference on e-Business (ICE-B 2006), Setubal, Portugal, Aug 7-10, 2006, pp. 289-293.	Technological and research strategies are becoming more significant as they create future value in the market. The core of these strategies is the creation of patents, which help eliminate or contain competition. Companies seek to learn the research strategies of their competitors. At the same time, all companies try to hide their own strategies but they generally cannot, because patents have to be filed and therefore exposed at a patent office and even made globally (e.g. via the WWW) accessible on-line. Part of the technological strategy of a company can be determined by observing the patents it files, their timing and their authors. There have been many studies about patents reported in the literature, with most of them focusing on the connectivities existing in co-citation, co-patent networks. In the presented work, the focus is on the inventors. Given the patent files of a company, one could possibly predict the company's current and future research and production strategies. Furthermore, if the inventors are known, the human resources of the corresponding companies could naturally be scrutinized. The latter would allow to estimate the mechanism prevailing in the process of patent creation at a specific company. A novel approach to analyze the professional activities of company inventors is proposed and applied to determine the inventive strategy of Japanese manufacturing companies. The presented results can be used to optimize knowledge and recourse management within a company.
Zamin, M.; Otto, J. (2004): Patterns of knowledge flows and MNE innovative performance. Journal of International Management, 10 (2), pp. 239-258.	This paper examines the influence of inter-and intra organisational knowledge flows on innovative performance in multinational enterprises. It employs a theoretical framework relating to organisational differentiation within multinational enterprises to generate a number of hypotheses linking knowledge flows to innovate performance. The hypotheses are tested in the biopharmaceutical context. Patent citations and co-patenting are utilised to capture knowledge flows. The findings support suggestion in the literature that subsidiary embededdness in external knowledge stimulates innovation in MNEs.
Frietsch, R.; Schmoch,U. (2006) :Technological Structures and Performance as Reflected by Patent Indicators. Chapter 3.2. In: Schmoch, U., Rammer, C., Legler, H. (eds.): National Systems of Innovation in Comparison. Structure and Performance Indicators for Knowledge Societies. Dordrecht: Springer.	This chapter uses patent applications as an innovation indicator and compares the trends and structures of twelve countries, analysing so-called triadic patents as a first concept. According to this approach, the Scandinavian countries, the Netherlands, and Switzerland are the top countries in relative terms, whereas the USA, Japan, and Germany are the leading countries in absolute terms. As a second concept, applications at the European Patent Office (EPO) were investigated with regard to filings in R&D-intensive areas. At the EPO, an upsurge in the second half of the 1990s can be observed which is triggered by all countries in a similar way, but with some new players. This development caused the largest applicants to re-shape their portfolios. Finally, looking at international technology co-operations of German inventors, this mode of knowledge production proves to have gained importance. Common languages, local proximity, and technological competence of the partners distinctly support technology co-operation.

Edler, J. (2004): International research strategies of multinational corporations: A German perspective, Technological Forecasting & Social Change, 71 (2004), pp. 599–621.	This paper explores the international research activities of multinational corporations that are related to Germany. It analyzes what role German companies and Germany as a host of foreign companies play in the growing specialization of global exploitation and generation of knowledge. The paper covers application oriented as well as strategic research for two company samples – German and non-German – on the basis of a complex indicator-based analysis (patents and publications) and microdata from business reports. The paper shows that internationalization of research and development (R&D) has increased and broadened in scope. It highlights the strong and growing differences existing between technological and scientific areas as well as between different sectors. Apparently, while the market adaptation of products is still the major driver for German companies, international knowledge seeking has become more and more important, especially in technological areas that are linked very closely to basic research. While Germany as a host of international industrial R&D is much more attractive for applied research (mechanical engineering) than for basic research, the country has still established attractiveness in selected knowledge-intensive technological areas and shows a high intensity of international cooperation. There is a high level of reciprocity in knowledge intensive areas pointing towards a global specialization and division of labor.

Appendix 2: Differences between patents and scientific papers

Substantive Requirement	**Applicable to**	**for patents**	**for journals**
Subject matter	Patents as well as Research papers	an invention must fall into one of the categories that the patent law divides patentable subject matter into	should fall within the scope of a journal. But is not a very stringent criteria like patents.
Utility	Patents	An invention must meet the requirement of 'utility'. The utility doctrine requires only a minimum level of applicability: An invention must perform a designed function or achieve some minimum human purpose.	Not applicable to research papers
Novelty	Patents as well as research papers	An invention has to be novel, depending on the circumstances, prior art constitutes of anything previously published, patented, known, used, or sold by an inventor or anyone else that is relevant to an invention.	A research paper has to be novel and should indicate novelty, for example in the in selection of the problem, or methodology or in analysis of the data.
Non-obviousness	Patents as well as research papers	The knowledge in the technological skill should not be obvious to one of ordinary skill in that area. A patent application will be rejected if the examiner can show that a researcher with ordinary skill in the technological field in question would see the invention as an obvious next step.	True for a research paper also. The problem/findings or other analytical steps should not be obvious.
Definiteness	Patents	A skilled artisan must understand the limits of the invention based on the claim language. If the claim language is not definite or clear, the patent can be rejected. This type of rejection also applies to specifications.	Not applicable to research papers

Appendix 3: Example of co-patenting analysis: nanotechnology

Co-inventions

We calculated the number of co-inventions for both US as well as European patent data. A total of 246 US nano-patents (1992-2001) are the outcome of collaborations with inventors from different countries as, corresponding to a total of 226 European patent applications. Table A.1 contains an overview of co-inventions for US patents. Table A.2 reflects the situation for European patent applications.

Not surprisingly, the US, Germany, Japan, France and the UK are among the most collaborative countries with respect to US nano-patents. The European patent data also reflect the collaborative strength of the US, Germany and France. Japan.

Belgium and Flanders are included as separate entities. If considered as strictly separate entities, both Belgium and Flanders have a high rate of co-inventivity. However, if one excludes the within-country links (between Flemish and non-Flemish Belgian inventors), the number of (international) inventions is considerably reduced. Yet Belgium and Flanders have a similar level of co-inventive activity as Italy (US data) or Israel (EPO data).

Co-assignations

Co-assignations are still relatively uncommon, at least if one compares them to of co-inventions. We shall not present detailed data in this place. A total of 25 co-assignations could be identified in the USPTO data (1992-2001). The corresponding number for European application data is 66.

Source: Excerpt from Glänzel et al. (2003a)

Table A.1: Country Co-invention Matrix (based on USPTO data application years 1992-2001)

	US	**DE**	**JP**	**BE**	**FR**	**GB**	**CA**	**CH**	**IL**	**NL**	**IT**	**AU**	**KR**	**CN**	**MC**	**ES**	**NO**	**AT**	**RU**	**SA**	**SG**	**TR**	**Others**	**Total**
US		30	25	8	14	18	27	9	11	6	4	3	8	6	3	2	3	1	2	2	2	1	22	212
DE	30		5	1	1	1		4		3		1			3			1	1			3	3	57
JP	25	5			2	2		1	3		4	1					1				1		1	46
BE	8	1			1	3				3													1	39(17)
FR	14	1	2	1				8	3	3	3				1	1		1						38
GB	18	1	2	3				1		1	2	1											3	34
CA	27							1									1		1					30
CH	9	4	1		8	1	1											1					1	26
IL	11		3		3						2													19
NL	6	3		3	3	1																		19
IT	4		4		3	2			2															15
AU	3	1	1			1															1		1	8
KR	8																							8
CN	6																						1	7
MC	3	3			1																			7
ES	2				1															2				5
NO	3		1				1																	5
AT	1	1			1			1																4
RU	2	1					1																	4
SA	2															2								4
SG	2		1									1												4
TR	1	3																						4
Others	22	3	1	1		3		1				1		1										33
Total	212	57	46	39 (17)	38	34	30	26	19	19	15	8	8	7	7	5	5	4	4	4	4	4	33	660

Source: SooS (2003)

Table A.2: Country Co-invention Matrix (based on EPO data application years 1992-2001)

	US	DE	BE	V	FR	CH	JP	GB	IT	NL	CA	IL	AT	RU	SE	AU	NO	KR	LU	TR	CN	DK	ES	ID	Others	Total
US		32	7	5	6	6	16	9	4	7	6	9	1	1	3	2	2	4	2	1	1		1		12	137
DE	32		6	3	11	12	7	5	2	3	1		5	5	1	1			2	4	1	1			2	104
BE	7	6		(36)	3					2	1								1					1	2	59 (23)
V	5	3	(36)		2					2	1														1	50 (14)
FR	6	11	3	2		4	1	1	2	1	1	3	1	1									2		4	43
CH	6	12			4		4	1			2		1												3	33
JP	16	7			1	4							1			1	1					1		1		33
GB	9	5			1	1			4	1		1				1	2					1		1	2	29
IT	4	2			2			4				2		1											2	17
NL	7	3	2	2	1			1																		16
CA	6	1	1	1	1	2								1											2	15
IL	9				3			1	2																	15
AT	1	5			1	1	1																			9
RU	1	5			1				1		1															9
SE	3	1																							3	7
AU	2	1					1	1													1					6
NO	2						1	2														1				6
KR	4																				1					5
LU	2	2	1																							5
TR	1	4																								5
CN	1	1														1		1								4
DK		1					1	1									1									4
ES	1				2																				1	4
ID			1				1	1																	1	4
Others	12	2	2	1	4	3		2	2		2				3								1	1		35
Total	137	104	59 (23)	50 (14)	43	33	33	29	17	16	15	15	9	9	7	6	6	5	5	5	4	4	4	4	35	654

Source: SooS (2003)

Appendix 4: List of collected data / indicators

Indicator	Period
1a. Total number of publications, co-publications intra-EU (EU-27) and extra-EU (where at least one author is from a third country)	1995-2006
1b. Total number of publications, co-publications intra-EU (where at least one collaborating author is from an EU member country) and extra-EU; this is the alternative definition of intra-EU	2006
1c. Total number of publications, co-publications intra-EU (EU-15) and extra-EU (where at least one author is from a third country)	1995-2006
2. Total number of co-patents (co-inventor) intra-EU (EU-27) vs. number of co-patents where at least one author is from a third country	1995-2004
3a. Total number of publications, co-publications intra-EU (EU-27) and extra-EU (where at least one author is from a third country) broken down by the countries of the authors	2000 + 2006
3b. Total number of publications, co-publications intra-EU (where at least one collaborating author is from an EU member country) and extra-EU broken down by the countries of the authors; this is the alternative definition of intra-EU	2006
4a. Total co-patents (EPO) with at least one author from the EU-27 broken down by the countries of the authors	1990-2004
4b. Total co-patents (EPO) with at least one author from the EU-15 broken down by the countries of the authors	1990-2004
4c. Total co-patents (USPTO) with at least one author from the EU-15 broken down by the countries of the authors	1990-2004
5. Indicator 3a broken down in main scientific fields	2006
6. Indicator 4 broken down in main industrial sectors	2004

Appendix 5: Classification scheme for the SCI

Table A.3: List of 26 Scientific Fields

No.	Field name
1	Electrical engineering
2	Computers
3	Optics
4	Measuring, control
5	Medical engineering
6	Nuclear technology
7	Organic chemistry
8	Polymers
9	Pharmacy
10	Biotechnology
11	Food, nutrition
12	Basic chemistry
13	Chemical engineering
14	Materials research
15	Environmental engineering
16	Mechanical engineering
17	Thermal processes
18	Civil engineering
19	Physics
20	Medicine
21	Biology
22	Ecology, climate
23	Mathematics
24	Geosciences
25	Multidisciplinary
26	Other

Source: Fraunhofer ISI

Table A.4: Search Strategies

No.	Key terms of SCI Category Codes
1	electrical & electronic engineering; telecommunications
2	computer science
3	optics; photographic technology
4	instruments; spectroscopy; remote sensing; automation; control; robotics; photogrammetry
5	engineering, biomedical; medical laboratory technology; radiology; neuroimaging
6	nuclear science & technology
7	chemistry, organic
8	polymer science
9	pharmacy; chemistry, clinical; drugs
10	biochemistry; biochemical; genetics; biotechnology; cell biology
11	food science; nutrition
12	chemistry *not* (organic, clinical, medicinal); electrochemistry
13	engineering, chemical
14	mineralogy; metallurgy; materials science *not* (paper, textiles)); crystallography
15	engineering, environmental
16	engineering *and* (industrial, manufacturing, marine, mechanical, aerospace, agricultural; multidisciplinary; ocean; petroleum (from basic chemistry)); mechanics; material science *and* (paper, textiles); transportation; aeronautics
17	thermodynamics; energy
18	engineering, civil; mining; construction and building technology
19	astronomy; physics *and* (particles, atomic, condensed, fluids, mathematical, applied, nuclear, multidisciplinary); microscopy; acoustics;
20	cytology; surgery; ophthalmology; orthopedics; otorhinolaryngology; dentistry; odontology; ergonomics; rehabilitation; critical care; emergency medicine; public health; anatomy; histology; pathology; medicine; allergy; andrology; anesthesiology; oncology; cardiovascular; vascular; dermatology; endocrinology; gastroenterology; geriatrics; hematology; immunology; infectious; mycology; pediatrics; psychiatry; respiratory; rheumatology; toxicology; virology; urology; tropical; transplantation; clinical neurology; gynecology; abuse; physiology; neurosciences; parasitology; veterinary; health care; medical informatics; biomaterials; nursing
21	biology ; biomethods; botany; zoology; ornithology; plant; entomology; reproductive; freshwater; microbiology; biophysics (from materials)
22	meteorology; ecology; environmental sciences; water resources; limnology; oceanography; aquatic; biodiversity
23	mathematics; statistics
24	geography; geology; geological; geophysics; geosciences
25	multidisciplinary sciences (*not* engineering, physics)
26	paleontology; archaeology; agriculture; agricultural; horticulture; fisheries; forestry; agronomy

Source: Fraunhofer ISI

Appendix 6: Classification scheme for patents based on IPC

No	Description	IPC codes
A	**Electrical engineering**	
01	Electrical machinery, apparatus, energy	B60M, B61L, F21H, F21K, F21L, F21M, F21P, F21Q, F21S, F21V, G08B, G08G, G10K, G21C, G21D, H01H, H01K, H01M, H01R, H01T, H02B, H02H, H02K, H02M, H02N, H02P, H05C
02	Electronic components	B81B, B81C, G11C, H01C, H01F, H01G, H01J, H01L
B	**ICT**	
03	Telecommunications	G09B, G09C, H01P, H01Q, H01S, H02J, H03B, H03C, H03D, H03F, H03G, H03H, H03M, H04B, H04J, H04K, H04L, H04M, H04Q, H05K
04	Audio-visual electronics	G03H, H03J, H04H, H04N, H04R, H04S
05	Computers, office machinery	B41J, B41K, B43M, G02F, G03G, G05F, G06C, G06D, G06E, G06F, G06G, G06J, G06K, G06M, G06N, G06T, G07B, G07C, G07D, G07F, G07G, G09D, G09G, G10L, G11B, H03K, H03L
C	**Instruments**	
06	Measurement, control	F15C, G01B, G01C, G01D, G01F, G01H, G01J, G01K, G01L, G01M, G01N, G01R, G01S, G01V, G01W, G04B, G04C, G04D, G04F, G04G, G05B, G08C, G12B
07	Medical equipment	A61B, A61C, A61D, A61F, A61G, A61H, A61J, A61L, A61M, A61N, A62B, B01L, B04B, C12M, G01T, G21G, G21K, H05G
08	Optics	G02B, G02C, G03B, G03D, G03F, G09F
D	**Chemistry**	
09	Basic chemicals, paints, soaps, petroleum products	B01J, B09B, B09C, B27K, C01B, C01C, C01D, C02F, C07B, C07C, C07F, C07G, C09B, C09C, C09D, C09F, C09K, C10B, C10C, C10G, C10H, C10J, C10K, C10L, C11D, C12S, D06L, F17C, F17D, F25J, G21F, A01N, C05B, C05C, C05D, C05F, C05G, A62D, C06B, C06C, C06D, C08H, C09G, C09H, C09J, C10M, C11B, C11C, C14C, D01C, F42B, F42C, F42D, G03C, G21J
10	Polymers, rubber, man-made fibres	A45C, B29B, B29C, B29D, B60C, B65D, B67D, C08B, C08C, C08F, C08G, C08J, C08K, C08L, D01F, E02B, F16L, H02G
11	Non-polymer materials	B21C, B21G, B22D, B22F, B24D, B28B, B28C, B32B, C01F, C01G, C03B, C03C, C04B, C21B, C21C, C21D, C22B, C22C, C22F, C23C, C23D, C23F, C23G, C25B, C25C, C25D, C25F, C30B, C25B, D07B, E03F, E04B, E04C, E04D, E04F, E04H, F27D, G21B, H01B
12	Pharmaceuticals	A61K, A61P, C07D, C07H, C07J, C07K, C12N, C12P, C12Q
E	**Mechanical engineering**	
13	Energy machinery	B23F, F01B, F01C, F01D, F03B, F03C, F03D, F03G, F04B, F04C, F04D, F15B, F16C, F16D, F16F, F16H, F16K, F16M, F23R
14	General machinery	A62C, B01D, B04C, B05B, B61B, B65G, B66B, B66C, B66D, B66F, C10F, C12L, F16G, F22D, F23B, F23C, F23D, F23G, F23H, F23J, F23K, F23L, F23M, F24F, F24H, F25B, F27B, F28B, F28C, F28D, F28F, F28G, G01G, H05F
15	Machine-tools	B21D, B21F, B21H, B21J, B23B, B23C, B23D, B23G, B23H, B23K, B23P, B23Q, B24B, B24C, B25D, B25J, B26F, B27B, B27C, B27F, B27J, B28D, B30B, E21C

No	Description	IPC codes
16	Special machinery	A01B, A01C, A01D, A01F, A01G, A01J, A01K, A01M, A21C, A22B, A22C, A23N, A24C, A41H, A42C, A43D, B01F, B02B, B02C, B03B, B03C, B03D, B05C, B05D, B06B, B07B, B07C, B08B, B21B, B22C, B26D, B27L, B31B, B31C, B31D, B31F, B41B, B41C, B41D, B41F, B41G, B41L, B41N, B42B, B42C, B44B, B65B, B65C, B65H, B67B, B67C, B68F, C13C, C13D, C13G, C13H, C14B, D01B, D01D, D01G, D01H, D02G, D02H, D02J, D03C, D03D, D03J, D04B, D04C, D05B, D05C, D06B, D06G, D06H, D21B, D21D, D21F, D21G, E01C, E02D, E02F, E21B, E21D, E21F, F04F, F16N, F26B, H05H, F41A, F41B, F41C, F41F, F41G, F41H, F41J
17	Transport	B60B, B60D, B60G, B60H, B60J, B60K, B60L, B60N, B60P, B60Q, B60R, B60S, B60T, B62D, E01H, F01L, F01M, F01N, F01P, F02B, F02D, F02F, F02G, F02M, F02N, F02P, F16J, G01P, G05D, G05G, B60F, B60V, B61C, B61D, B61F, B61G, B61H, B61J, B61K, B62C, B62H, B62J, B62K, B62L, B62M, B63B, B63C, B63H, B63J, B64B, B64C, B64D, B64F, B64G, E01B, F02C, F02K, F03H, B63G
F	**Other**	
18	Metal products	A01L, A44B, A47H, A47K, B21K, B21L, B25B, B25C, B25F, B25G, B25H, B26B, B27G, B44C, B65F, B82B, E01D, E01F, E02C, E03B, E03C, E03D, E05B, E05C, E05D, E05F, E05G, E06B, F01K, F15D, F16B, F16P, F16S, F16T, F17B, F22B, F22G, F24J, G21H
19	Textiles, wearing, leather, wood, paper, domestic appliances, furniture, food	A21B, A41B, A41C, A41D, A41F, A41G, A42B, A43B, A43C, A44C, A45B, A45D, A45F, A46B, A46D, A47B, A47C, A47D, A47F, A47G, A47J, A47L, A63B, A63C, A63D, A63F, A63G, A63H, A63J, A63K, B01B, B27D, B27H, B27M, B27N, B41M, B42D, B42F, B43K, B43L, B44D, B44F, B62B, B68B, B68C, B68G, C06F, D04D, D04G, D04H, D06C, D06F, D06J, D06M, D06N, D06P, D06Q, D21C, D21H, D21J, E04G, E06C, F23N, F23Q, F24B, F24C, F24D, F25C, F25D, G10B, G10C, G10D, G10F, G10G, G10H, H05B, A01H, A21D, A23B, A23C, A23D, A23F, A23G, A23J, A23K, A23L, A23P, A24B, A24D, A24F, C12C, C12F, C12G, C12H, C12J, C13F, C13J, C13K

Source: based on Schmoch and Gauch (2004); Fraunhofer ISI

The analysis was conducted based on the level of 6 technological areas:

A – Electrical Engineering

B – Information and Communication Technologies (ICT)

C – Instruments

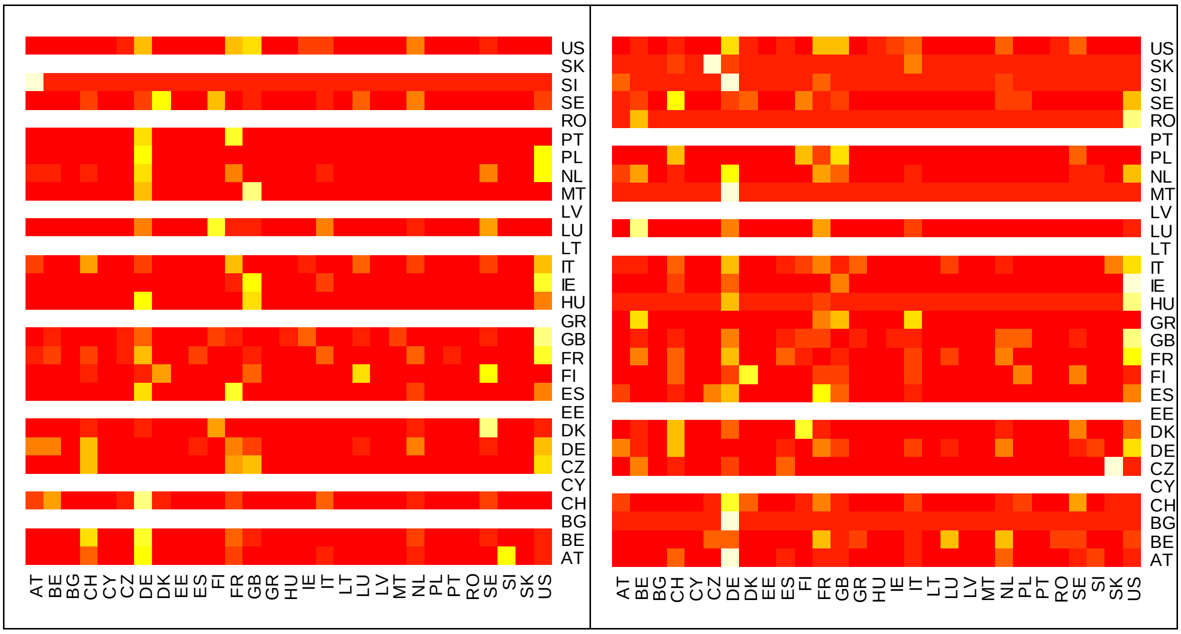
D – Chemistry

E – Mechanical Engineering

F – Other

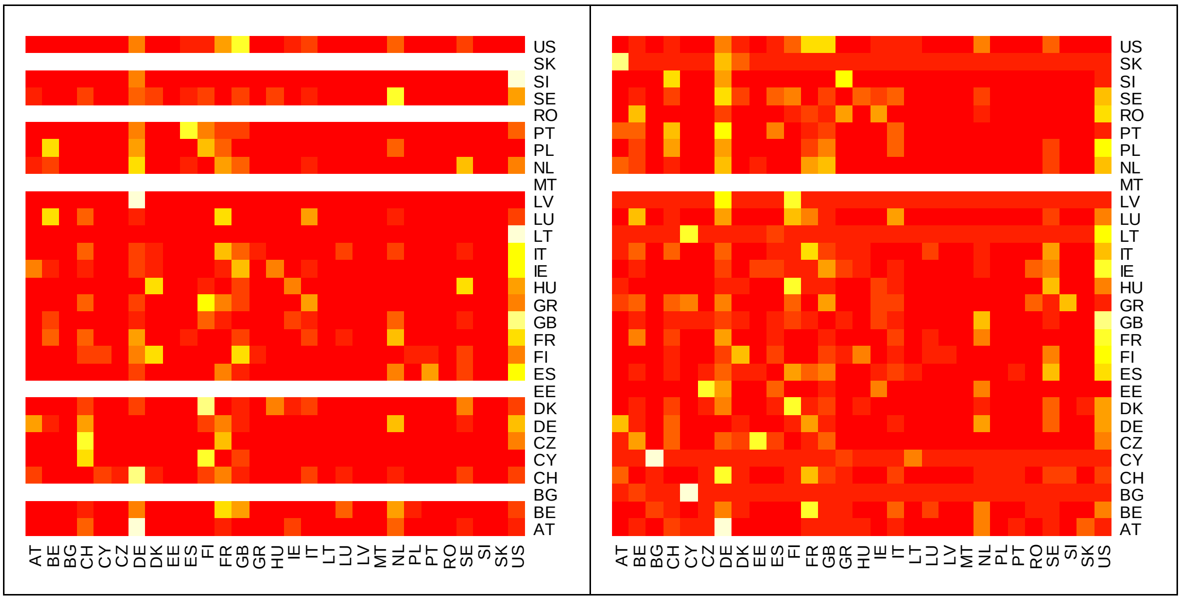
Appendix 7: Heatmaps of the cross-impact assessment tables in patents

Figure A.1: Heatmap of country cooperation portfolios in Electrical Engineering for the period of 1994-1996 and 2002-2004



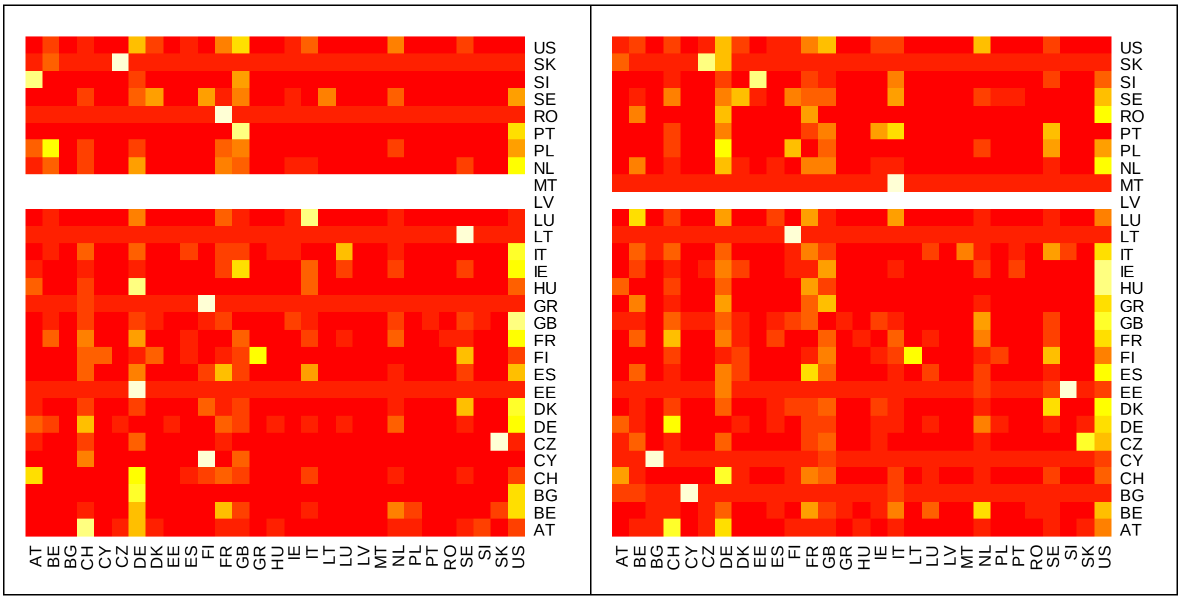
Source: PATSTAT, calculations Fraunhofer ISI

Figure A.2: Heatmap of country cooperation portfolios in ICT for the period of 1994-1996 and 2002-2004



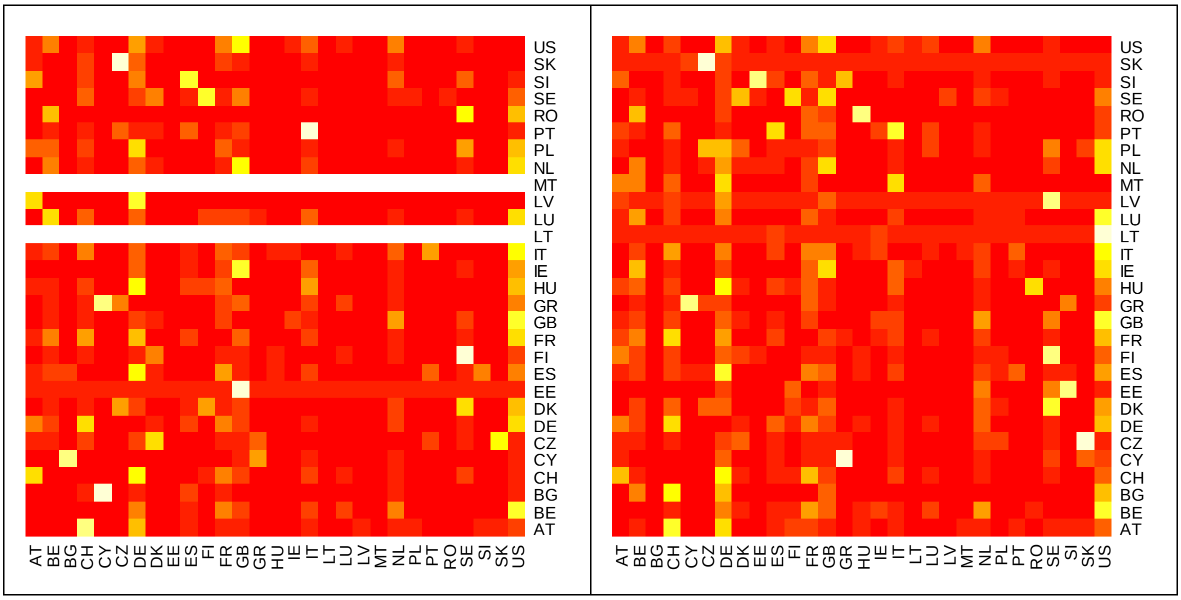
Source: PATSTAT, calculations Fraunhofer ISI

Figure A.3: Heatmap of country cooperation portfolios in Instruments for the period of 1994-1996 and 2002-2004



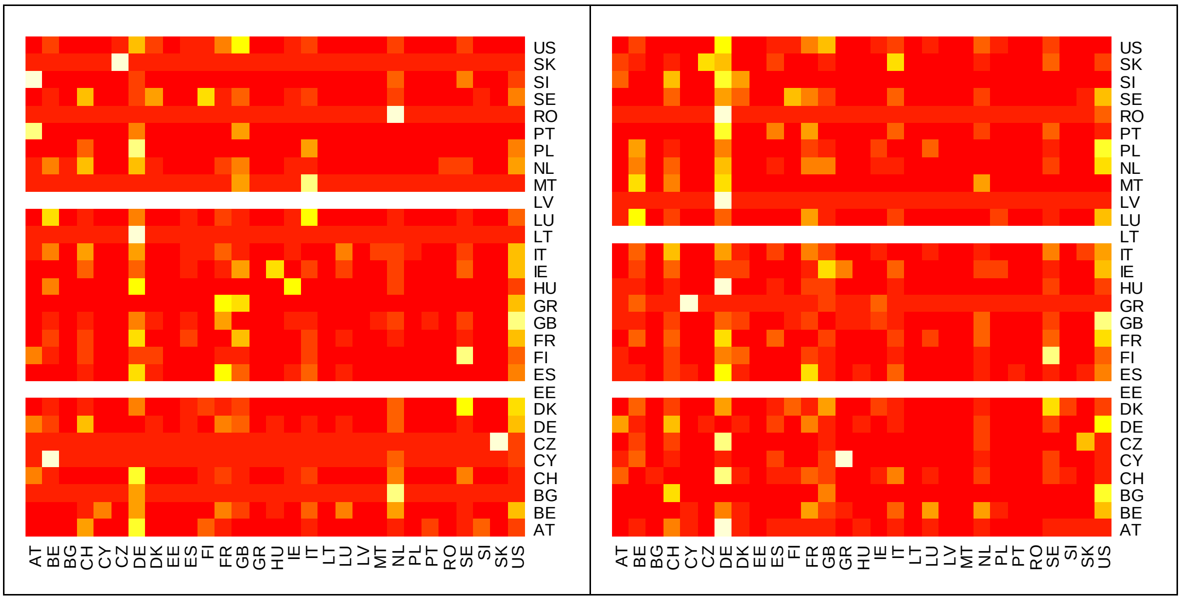
Source: PATSTAT, calculations Fraunhofer ISI

Figure A.4: Heatmap of country cooperation portfolios in Chemistry for the period of 1994-1996 and 2002-2004



Source: PATSTAT, calculations Fraunhofer ISI

Figure A.5: Heatmap of country cooperation portfolios in Mechanical Engineering for the period of 1994-1996 and 2002-2004



Source: PATSTAT, calculations Fraunhofer ISI