

# Knowledge spillovers through R&D networking

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## 1. Introduction

In spite of the abundant research on the relation between spillovers and the optimal outcome of cooperation in R&D versus non-cooperative set-ups, and the well-acknowledged increasing occurrence of cooperative agreements, the fact that firms might manage spillovers within and through R&D cooperation has hardly been addressed empirically.

One of the most basic and popular mechanisms with which collaborative research is performed in Europe during the last 15 years, is the European Framework Programmes (FWPs). The EU launched the ambitious 1<sup>st</sup> Framework programmes in 1984, in order to promote transnational interorganizational collaboration in 'pre-competitive' R&D. The aim was to strengthen the competitive position of EU firms and help them keep up with the technological race, since they were generally regarded as lagging their US and Japanese counterparts in technological and economic performance.

In this paper, we will show that the rationale for a policy of promoting R&D cooperation depends on the theoretical perspective that is endorsed, and on the magnitude and (a)symmetry of spillovers, a matter that is still open to empirical scrutiny.

Public policies that are entirely based on conclusions from analysing existing national value-added linkages may be more inward- and backward looking than those which also consider (inter)national collaborative patterns, that will partly shape the future economic and technological space.

Input/output-based network and cluster policies could also run the risk of sustaining and even reinforcing inefficient and collusive lock-in situations.

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Up to now, previous studies on the proxy measurement of spillovers focused mainly on supplier-buyer linkages or on patent data.

We have computed knowledge spillovers using the interfirm linkages that have been established in Europe through collaborative R&D.

We have found that the pattern of intra- and intersectoral spillovers is country specific, more so for user sectors than for supplier sectors, and can not simply be fitted in the value added chain.

Low-tech industries like food and beverages and textiles benefit from considerable spillovers in a number of countries.

We also computed science-industry spillovers and these were found to be very important for *food and beverages* in almost all countries and *textiles* in some countries.

This again seems to suggest that a classification, based on R&D intensity, is probably not very distinctive in the analysis of networking, above all since the results concern pre-competitive R&D networking and not innovative networking for which non-technical issues are even more considerable.

We argue that the mapping of R&D collaboration allows for a rather straightforward measurement of knowledge spillovers, that can complement or readjust some of the conclusions that have resulted from other methodologies.

## **2. How embodied are knowledge spillovers ?**

Technological or R&D spillovers are most often defined as externalities, with agents unable to fully appropriate all benefits from their own R&D activities.

*“ By technological spillovers, we mean that (1) firms can acquire information created by others without paying for that information in a market transaction, and (2) the creators (or current owners) of the information have no effective recourse, under prevailing laws, if other firms utilize information so acquired.”* (Grossman and Helpman, 1992: p.16)

However they are sometimes defined in a broader sense.

*“ R&D spillovers refer to the involuntary leakage, as well as, the voluntary exchange of useful technological information.”* (Steurs, 1994: p. 2)

Llerena and Matt (1999) also distinguish between involuntary and voluntary spillovers and state that the latter are probably the most considerable.

In his review of preceding research on R&D spillovers, Griliches (1992) concludes that, in spite of a considerable number of methodology and data constraints, studies generally seem to confirm the presence and relative magnitude of R&D spillovers.

Griliches makes the distinction between two notions of R&D spillovers.

He qualifies spillovers to be 'embodied' if they relate to the purchase of equipment, goods and services. Embodied spillovers can also be defined as rent spillovers to the extent that improvements- which are the results of a firm's efforts- in the products that are sold to other firms are not fully absorbed by a concurring price increase.

Embodied spillovers are generally measured through input-output tables- amplified with survey data or data on R&D expenditures- or flows of international trade (Terleckyj 1974; Coe and Helpman 1995; OECD 1999,a).

Although the importance of supplier-buyer linkages for innovation is well established (Debresson et al. 1997 ; Christensen, Rogaczewska and Vinding 1999; OECD 1999,b) innovative networks are also often found to be too complex to be reduced to value-added chains.

Because, as pointed out by Debresson (1999), innovative networks often straddle nations and encompass foreign partners, the use of available R&D collaboration data can broaden the framework of inter-firm networking by focusing both on national and international linkages whereas I/O analysis is mostly confined to national or regional networking.

Debresson and Hu (1999) find that I/O-based methods are in general not very reliable for small, open economies.

Another limitation of an I/O-based analysis is : *«The first measurement problem is how to fit the « new » innovation into categories of the « old » economic structure represented in the I/O matrices. We must limit our goals to mapping where, within the old economic space, innovative activities arise.»* (Debresson and Hu, 1999 : p.31).

If public policy would only draw conclusions from this kind of analysis, it will probably be more inward- and backward looking than a policy that also considers indications as to the direction in which the international technological space might evolve.

An I/O-based policy may also run the risk of promoting inefficient and collusive lock-in situations.

Disembodied spillovers are seen by Griliches as “ [...] *ideas borrowed by research teams of industry i from the research results of industry j. It is not clear that this kind of borrowing is particularly related to input purchase flows*” (Griliches (1992), p. S36), and are in Griliches view more significant than embodied spillovers.

According to Griliches, the main problem with computing knowledge spillovers is an accurate definition of the technological proximity or closeness between firms, as an inverse relationship between spillovers and technological distance may be expected.

Scherer (1982) constructed a matrix of technology flows by linking data from a 1974 business survey on R&D expenditures to patent data .

Jaffe (1986, 1989) proposes a method to characterize the technological position of a firm based on patent data, which allows for the detection of technologically related firms. In Jaffe's view the magnitude of spillovers is a function of the technological distance between firms.

He uses the distribution of firms' patents over patent classes and defines the spillover pool as the weighed sum of all other firms' R&D, with the weights proportional to the technological proximity, and finds evidence of a positive effect of technologically close firms' R&D on the productivity of own R&D.

Verspagen (1997a) points to the importance of intersectoral spillovers to argue that the magnitude of spillovers between firms is not necessarily related to their 'technological similarity'.

In our view, technological proximity is a better proxy for the absorptive capacity of firms than it is for the spillover between firms. Especially w.r.t. intentional technology transfer or technological collaboration - for which complementarity is often preferred to supplementarity - is concerned, partners are probably more distant technologically than competitors are.

Although the latter have a higher capacity to absorb the knowledge of their competitors, they rely on involuntary spillovers.

Capron et al. (1996) and Verspagen (1997b) compare I-O based matrices to technology matrices based on patent data and conclude that I-O based measures of spillovers do not very well grasp knowledge spillovers.

Veugelers and De Backer (1999), working with alliance matrices, confirm this finding but they also find a relatively high complementarity between technological and economical spillovers, suggesting that research which solely focuses on technological activities neglects complementary channels through which know how can be transferred (e.g. non R&D alliances).

We believe that the mapping of R&D collaboration can complement or readjust the picture of innovative networking that has resulted from the exclusive use of existing I/O linkages to map innovative interfirm networks.

It is obvious that innovative networks entail far more than R&D networks, as the former also relate to the commercial exploitation of the results of R&D activities and innovation does not always imply R&D activities.

The proposed method therefore can only be seen as complementary to others, with as main advantage that it straightforwardly maps existing patterns of collaboration at the network level.

### **3. Rationale for a public policy of promoting R&D cooperation**

Llerena and Matt (1999) show that the rationale for a policy of promoting interfirm cooperation in R&D depends on the theoretical perspective of the policy-maker.

If a market or transaction cost stance is adopted, cooperation is regarded as an (unstable) exception to competition.

The FWP of the EU (see section 4) have been set up as block exemptions- dictated by the specific nature of pre-competitive R&D- to the strict competition rules of the Treaty of Rome.

However, the EC also promotes the follow-up of participation in its FWP by more near-market collaboration in EUREKA projects<sup>3</sup>, and thereby somewhat bends its own competition rules.

From a more evolutionary perspective, interfirm agreements are considered to be a powerful coordination mechanism to create and diffuse knowledge within a vast, complex and rapidly evolving technological space.

Where public policy, following the first traditional perspective, is concerned with adjusting market failures, the latter perspective urges policy makers to consider evolutionary failures, related to learning processes, lock-in and negative externalities (Llerena and Matt, 1999 : p.188-94).

The extensive game-theoretical research that followed from D'Aspremont and Jacquemin (1988) originated the view that co-operation in the R&D stage and competition in the production stage was the social optimum. Because of the nature of R&D activities (non-excludability, uncertainty and inappropriability) market resource allocation will not be socially optimal. Policy can resolve this market failure through co-operation, subsidies and intellectual property rights. These findings were seen as support of the EU FWP and national policies of promoting R&D collaboration.

However, the theoretical support for such policies is not that straightforward.

From the viewpoint of the strategic investment literature, R&D competition is more optimal than collaboration if spillovers are small, and when spillovers are large the private and social welfare optimum coincide and public subsidies will not elicit many additional R&D activities. Publicly subsidized programmes of R&D collaboration are in this case only appropriate if spillovers are asymmetric (i.e. if there is sufficient diversity between firms in research capabilities).

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<sup>3</sup> EUREKA is an intergovernmental initiative which was proposed by the French government in 1985 as an alternative to the American Star Wars programme. EUREKA aims at fostering co-operation between firms. It is not an EU mechanism although as a member the EU finances some large EUREKA projects mainly in the field of ICT like Jessi (microelectronics) and HDTV (high definition television).

If spillovers are differentiated between voluntary (between cooperating firms) and involuntary (between non-cooperating firms) the welfare results, and thus the policy conclusions, are not as clear either (Llerena and Matt, 1999 :p.182-86).

Cassiman and Veugelers (1998) point out that the fact that firms could manage spillovers within and through R&D cooperation, has hardly been addressed empirically.

Nelson (1992) and Teece (1992) have argued that non-codified tacit knowledge does not, contrary to the idea of knowledge as a public good, spill over inexpensively. As knowledge is considered to have become more tacit, this might explain why hybrid forms like cooperative agreements have become so popular. Cooperation may increase knowledge flows between partners and can allow partners to internalize spillovers. In most theoretical models spillovers are exogenous to the decision to cooperate or not. Cassiman and Veugelers (1998) review some of the models that do acknowledge that partners may voluntarily increase spillovers between them. As a consequence the magnitude of spillovers will depend on the decision to cooperate.

Irrespective of which theoretical perspective is endorsed, the magnitude and specificities of spillovers are crucial for the rationale of a public policy towards promoting R&D collaboration, and this matter is still open to empirical scrutiny.

#### **4. EU policy towards promoting R&D cooperation**

The successive Framework Programmes of the EU, covering the shared-cost type of collaborative research, have made an important contribution to the development of scientific and technological cooperation in Europe. Although designed essentially to catch up with the US and Japan they have become the main instrument of the European S&T Policy. They enhance the competitiveness of Europe by promoting transnational cooperation in precompetitive or pre-normative research, and encouraging the dissemination of information. (Lucchini, 1998)

The EU involvement in R&D cooperation can be traced as far back as the Treaty of Rome – establishing the European Atomic Energy Community, and other multi-annual research programmes to be carried out either through the Joint Research Centres (JRC) or through research funding to organizations in member countries (Caloghirou, 2000).

However, at the beginning of the 1980s concerns arised that European firms were falling behind their American and Japanese counterparts in terms of innovation and world market share, especially in the IT industry. Therefore, the Community launched a first Programme (ESPRIT 1) in 1984 to strengthen the scientific and technological basis of European Industry. ESPRIT 1 served as a model for the creation of a more general ‘‘umbrella typed’’ programme, which was named the 1<sup>st</sup> Framework Programme on R&D. The Framework included various other Programmes in many technological areas, promoting cooperative R&D. They aimed to link up the diverse and complementary technical capabilities of companies, universities and research laboratories from different European countries in pursuit of common technological goals (European Commission, 1997, Peterson and Sharp 1998, Mollina 1996).

The rationale for cooperative R&D stems basically from competitiveness and market failure issues. However in Europe political and economic changes transformed the scene. New members have already been included in the EU -and many more might be included soon-, and new countries have emerged. Although the basic policy rationales have not altered, they have been joined with the cohesion and employment rationales for supporting collaborative R&D. It has been argued that ‘‘there may be a trade-off between competitiveness and cohesion which may decrease the effectiveness of the Framework Programmes for RTD’’ As empirical evidence has shown, it is time to take stock of this widespread cooperative R&D in Europe (Caloghirou et al., 2000).

The main RTD policy instrument of the Framework Programmes has been the ‘‘shared cost’’ contract research projects, referring to the support by the Commission of 50% of the total costs of joint research for companies, whereas universities and research institutes may receive up to 100% of the marginal or additional costs of the projects.

Each one of these projects involves at least two partners and usually one of them is responsible for the overall management of the projects and therefore undertakes a more coordinating role. He is thus referred to as the prime contractor, whereas the other participants as partners.

Four Framework Programmes have already been completed (1984-1987, 1984-1991, 1990-1994 and 1994-1998) and the fifth is currently running (1998-2002).

The results of the FWP have been mixed. On the one hand they have not yet shown a substantial impact on European competitiveness and trade performance in the world markets. This is due to the fact that collaborative research has been undertaken under the ‘precompetitive’ label. Therefore too often successful projects did not produce marketable results, either because ‘they have been isolated from market and social considerations despite their technical excellence, or because the means by which they were to be exploited was not specified or even thought about at the earliest stages of work’ (PREST, 2000)<sup>4</sup>. On the other hand they have helped to keep Europe in the technological race. But the most important effect is that the FWP have gradually become the driving force behind the formation of dynamic networks beyond the formal collaboration, since they bring together researchers from the best laboratories in European firms and giving the opportunity for private firms to benefit from a larger pool of resources than is available in a single nation. They have unquestionably fostered the emergence of closer linkages and the creation of a critical mass through networking. In addition, they provide stable financial support; they lead to a reduction of competition among researchers and between researchers and industry and of course provide access to complementary skills, means and tools. (Vavakova, 1995, Lucchini 1998).

The lack of stability of cooperative agreements is often taken as an indication of failure. However, Bureth, Wolff and Zanfei rightly argue, that the prolongation of networks can not be considered a value per se. They refer to alliances that, despite poor results, are maintained because of high sunk costs (Bureth, Wolff and Zanfei, 1999: p.204). On the other hand, collaborative projects may very well, even when the project as such is not considered by all partners to have been successful, have improved the performance and the networking capabilities of individual partners, when the cooperation ends after the completion of the project or even when partners break up before it had been anticipated.

## **5. Data**

The Laboratory of Industrial and Energy Economics (LIEE) at the National Technical University of Athens (NTUA) has developed a new, extensive database called STEP TO

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<sup>4</sup> That is why in the Fifth Framework Programme one of the changes that are implemented is the recognition of the need for economic and social acceptance of the technologies and other results that have been produced through funded research.

RJVs Databank<sup>5</sup>, which includes several databases with detailed information on collaborative R&D in Europe. The paper draws information from one of the core databases: The EU-RJV database, which contains information on cross-national R&D collaboration that has been established in Europe through the FWP. The basic source of information was Cordis, an official EU database, disseminating information about European Research and Development and related matters. We have used two criteria for creating this database. At the Programme level, we have selected Programmes focusing mainly on industrial research. Thus, we have excluded Programmes that simply provide support, or are related to human capital and mobility, socio-economic research, forecasting, economic aspects and other EU actions. The implementation of the above criterion resulted to a final inclusion of 64 programmes from all 4 Frameworks. Many of these are big, well-known programmes such as ESPRIT, AIM, BRITE/EURAM, RACE, in some of the major technological areas promoted by the European Commission. But some other less well-known programmes have been included, since R&D cooperation is also performed through these research initiatives as well<sup>6</sup>.

The second criterion was implemented at the project level. We have selected projects that had at least one firm participating. Therefore projects involving collaboration solely between universities or research institutes or projects for which it was impossible to identify whether a specific organization was actually a firm, were excluded.

After the implementation of the above criteria the final number of research consortia included in our database is 9,335, covering an extensive period of 16 years, from the start in September 1983 till the end of 1998. About 20499 organizations (entities) from 52 countries are responsible for 64476 participations in these research collaborations.

However, the real value adding part of this database is the conjunction of the information regarding the EU research consortia with financial data of the firm' participants. The source of information in this case was "Amadeus", a commercially available database that contains longitudinal financial information for approximately 200,000 European Firms. Almost 40% of the firms participating in these consortia were identified and data for a total of 2722 European firms were retrieved. The sectoral data are the ones that will be used in our analysis, since the primary activity of the identified firms is available (NACE 1 classification).

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<sup>5</sup> The database was constructed in the context of an EU funded TSER project entitled "Science and Technology Policies Towards Research Joint Ventures" (Record Control Number 39084)

<sup>6</sup> A complete list of the Programmes included in the database is shown in the Appendix I.

## 6. Estimating knowledge spillovers through R&D cooperation

The basic hypothesis, that was used to compute intra- and intersectoral knowledge flows, is that the number of cooperative links between firms is a proxy measure for the underlying knowledge flows.

We constructed an asymmetric matrix. The asymmetry was obtained by hypothesising that in R&D projects more knowledge flows from the partners to the prime contractant than the other way round, whereas knowledge flows between ‘normal’ partners are assumed to be balanced. In Dumont and Meeusen (2000) the opposite hypothesis was used, as it was believed that the prime contractor, which most often is the technologically more advanced partner, had more knowledge to transfer to the partners than the latter could transfer to the prime contractant.

The results of a survey on the impact of the fourth FWP in Finland, however, shows that the project coordinator more often found the project successful than other participants (Luukkonen and Hälikkä, 2000: p.52). As a coordinator they have a central position in the project which, amplified by greater research capacities, probably allows them to gather and absorb more knowledge from the other participants than the vice versa.

Therefore we turned round the hypothesis.

Furthermore, we assumed knowledge flows to be inversely related to the total number of participants in each project or agreement. In this way we account for the importance of ‘intimacy’ and coordination costs.

To restrict the analysis to the most significant sectors, we computed the matrix for the 25 most active sectors in terms of participation. This results in a matrices with 625 cell values.

The analysis was performed at the NACE 2-digit level. So, for example, if a firm belonging to NACE sector 32 is the main contractant in a project involves 5 partners of which one is another firm belonging to NACE 72, we assume a knowledge flow of 0.2 (1/5) from NACE 32 to NACE 72 and a knowledge flow of 0.4 (2/5) from NACE 72 to NACE 32 whereas if none of the firms is the main contractant the knowledge flow equals 0.2 (1/5).

The sector at the left hand side of the matrix gives the ‘supplier’ sector (aggregated over all countries) and the sector at the top of the matrix gives the ‘user’ sector of the given country. The matrix therefore focuses only on the knowledge flowing from all countries to the given country and not on the knowledge from the given country to the other countries.

**Table 1: Matrix of intra- and intersectoral knowledge spillovers within the FWP (France)**

<b>FR</b>	<b>15</b>	<b>17</b>	<b>23</b>	<b>24</b>	<b>26</b>	<b>27</b>	<b>28</b>	<b>29</b>	<b>30</b>	<b>31</b>	<b>32</b>	<b>33</b>	<b>34</b>	<b>35</b>	<b>40</b>	<b>45</b>	<b>50</b>	<b>51</b>	<b>60</b>	<b>63</b>	<b>64</b>	<b>72</b>	<b>73</b>	<b>74</b>	<b>92</b>
<b>15</b>	2,60	0,00	0,00	0,38	0,00	0,00	0,00	0,00	0,00	0,10	0,00	0,00	0,00	0,08	0,00	0,00	0,00	0,13	0,00	0,00	0,00	0,00	0,00	0,48	0,00
<b>17</b>	0,00	0,43	0,00	0,14	0,00	0,00	0,03	0,00	0,00	0,03	0,40	0,00	0,14	0,79	0,00	0,00	0,34	0,24	0,00	0,00	0,06	0,00	0,00	0,17	0,00
<b>23</b>	0,00	0,00	0,00	0,26	0,00	0,00	0,08	0,38	0,00	0,06	0,02	0,17	0,00	0,00	0,36	0,04	0,00	0,00	0,00	0,00	0,00	0,00	0,13	1,44	0,00
<b>24</b>	0,41	0,33	0,27	2,12	0,47	0,46	0,37	0,29	0,58	2,00	3,93	0,51	0,45	1,19	1,00	0,29	0,00	0,64	0,36	0,00	0,00	0,23	2,60	7,23	0,00
<b>26</b>	0,00	0,00	0,11	0,13	0,71	0,00	0,00	0,00	0,29	0,00	0,99	0,21	0,00	0,86	0,13	0,38	0,00	0,40	0,02	0,00	0,00	0,10	0,69	1,21	0,00
<b>27</b>	0,00	0,00	0,00	0,13	0,00	1,34	1,24	1,19	0,18	0,25	1,97	0,17	1,71	2,99	0,93	0,13	1,26	0,25	0,00	0,00	0,00	0,11	0,94	2,51	0,00
<b>28</b>	0,00	0,00	0,11	0,47	0,09	0,59	1,15	0,66	0,15	0,11	0,90	0,23	0,08	1,43	0,97	0,58	0,69	0,04	0,22	0,00	0,00	0,25	0,63	2,47	0,00
<b>29</b>	0,00	0,14	0,10	1,29	0,11	0,81	2,31	5,10	0,86	0,99	2,35	1,35	2,14	3,62	1,76	0,47	1,80	0,13	0,34	0,00	0,00	0,71	0,60	4,38	0,02
<b>30</b>	0,00	0,00	0,00	0,00	0,00	0,00	0,48	0,24	17,53	0,17	8,53	0,21	0,55	2,02	0,46	0,17	0,25	0,35	0,00	0,00	0,04	7,37	2,46	4,98	0,30
<b>31</b>	0,00	0,00	0,00	0,10	0,00	0,29	0,14	0,21	1,40	1,81	6,27	1,48	1,27	0,57	1,03	0,47	2,57	0,56	0,26	0,00	0,08	1,79	1,87	2,44	0,56
<b>32</b>	0,00	0,10	0,00	0,57	0,00	0,20	0,77	0,57	9,63	4,25	63,02	7,16	1,55	3,99	0,92	0,00	1,68	3,76	1,33	0,11	0,22	8,22	5,20	10,54	1,84
<b>33</b>	0,00	0,00	0,00	0,39	0,17	0,29	0,04	0,47	2,34	1,53	9,85	2,62	0,62	5,84	0,75	0,00	0,17	1,26	0,48	0,00	0,00	2,60	1,30	3,68	0,44
<b>34</b>	0,00	0,00	0,13	0,32	0,22	0,59	0,58	1,71	2,24	3,32	5,75	0,56	8,68	13,60	0,41	0,37	13,85	1,78	0,27	0,00	0,31	3,88	0,59	4,05	0,53
<b>35</b>	0,00	1,43	0,00	0,19	0,50	0,58	0,41	7,09	1,25	0,39	7,55	3,85	1,70	43,74	0,82	0,00	1,39	0,70	0,29	0,00	0,10	4,15	0,22	5,48	0,00
<b>40</b>	0,00	0,00	0,14	0,09	0,17	0,31	0,82	0,89	0,78	2,10	1,63	0,38	0,17	0,80	5,35	0,09	0,35	0,74	0,12	0,00	0,04	1,03	0,71	4,75	0,21
<b>45</b>	0,00	0,00	0,00	0,45	0,10	0,13	0,15	0,33	0,21	0,00	1,16	0,31	0,42	0,43	0,28	1,65	0,13	0,00	0,08	0,00	0,00	0,80	0,47	1,11	0,05
<b>50</b>	0,00	0,00	0,11	0,17	0,00	0,38	0,23	0,31	0,13	0,69	0,67	0,04	1,85	1,08	0,22	0,00	0,87	0,34	0,12	0,00	0,00	0,64	0,53	0,83	0,06
<b>51</b>	0,38	0,21	0,21	0,59	0,18	0,22	0,24	0,13	0,98	0,57	4,84	0,94	0,65	0,83	0,85	0,36	0,56	0,61	0,31	0,00	0,08	2,63	1,22	1,85	0,07
<b>60</b>	0,00	0,00	0,00	0,00	0,00	0,00	0,03	0,46	0,00	0,75	0,40	0,29	0,08	0,00	0,25	0,02	0,12	0,00	3,49	0,00	0,00	0,00	0,00	1,18	0,24
<b>63</b>	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,15	0,09	0,07	0,32	1,05	0,00	5,21	0,02	0,00	0,10	0,00	0,33	0,14	0,00	0,31	0,00	0,23	0,00
<b>64</b>	0,00	0,00	0,00	0,00	0,00	0,00	0,06	0,00	2,21	0,48	9,30	1,13	0,24	0,32	0,38	0,00	0,00	2,40	0,00	0,00	0,18	4,12	1,79	2,87	0,76
<b>72</b>	0,00	0,06	0,00	0,07	0,00	0,00	0,23	0,33	13,02	0,63	14,16	1,76	0,95	4,81	0,96	0,33	1,67	3,73	0,29	0,11	0,58	12,50	3,41	10,14	0,28
<b>73</b>	0,48	0,00	1,07	0,60	0,00	0,13	0,20	0,26	1,66	2,08	4,60	2,13	0,66	1,21	1,18	0,06	1,31	0,82	0,00	0,00	0,39	3,72	0,60	4,57	0,00
<b>74</b>	0,14	0,49	0,48	0,60	0,45	0,14	0,67	1,17	3,73	1,44	8,77	2,20	0,82	6,40	5,11	1,06	1,17	1,18	0,88	0,14	0,14	6,82	1,63	8,74	0,60
<b>92</b>	0,00	0,00	0,00	0,00	0,00	0,00	0,04	0,00	0,30	0,15	3,59	0,31	0,32	0,00	0,20	0,00	0,00	0,13	0,10	0,00	0,00	0,24	0,00	1,11	2,32
<b>REC</b>	5,98	8,18	4,58	28,33	9,78	7,93	12,88	43,82	30,76	21,10	112,75	24,97	10,79	82,56	21,79	7,21	11,01	14,99	7,07	0,54	3,37	62,41	31,69	86,94	3,12
<b>HEI</b>	5,70	6,59	3,51	41,59	6,63	10,06	14,31	41,87	44,01	31,17	139,23	28,77	16,94	69,42	21,74	8,78	15,55	16,25	5,88	0,22	4,61	79,68	44,44	89,24	1,68

To elucidate matters we show the matrix of unweighed spillovers for France as an example in table 1.

From these matrices we computed other matrices in which we weighed the spillover values. First, following Cohen and Levinthal (1989), we considered that own R&D activities are important to absorb R&D that spills over. We therefore constructed national sectoral R&D stocks<sup>7</sup> from the OECD ANBERD database and we used the average over the period 1985-95 as a measure of the absorptive capacity of a given sector.

The spillover measures that were computed are summarized in Box 1.

### Box 1: Mathematical definition of spillovers

Spillover from sector J (all countries) to sector I in country C:

$$SP_{cij} = \sum_n \sum_k \sum_l (D_{pc}) / NP_n [(P_{nk} \in C \text{ AND } P_{nk} \in I \text{ AND } P_{nl} \in J) \rightarrow 1; 0]$$

C: country I, J: sector

n: project number

k, l = 1... NP<sub>n</sub>

NP<sub>n</sub>: Number of participants in project n

D<sub>pc</sub> = 2 if P<sub>nk</sub> is prime contractor and 1 if not

P<sub>nk</sub>: k-th participant in project n

Spillover weighed by domestic sector I's R&D stock and all countries sector J's R&D stock:

$$SPRD_{cij} = SP_{cij} * (RD_{ci} * \sum_m (RCP_{cm} * RD_{mj}))$$

RD<sub>ci</sub>: R&D stock of sector i in country c

m = 1 ... number of countries

RCP<sub>cm</sub>: Revealed Comparative Advantage (country c-country m)

<sup>7</sup> R&D stocks were computed following the formula given in Coe and Helpman (1995).

The second weight concerns the spillover pool.

For this we used the national sectoral R&D stocks to construct international sectoral R&D pools.

We have used the bilateral measures of Revealed Comparative Preference (RCP) as defined in Dumont and Meeusen (2000) and used in OECD (1999), as weights for constructing this international R&D pool.

The RCP gives an indication of the preference of organizations of a given country to cooperate with partners from a given other country.

On the basis of the matrices with weighed spillovers we derived clusters using cut-off criteria, similar to those Hauknes (1999) used to derive I/O-based clusters for Norway. A first cut-off (link strength) restricts the linkages on the basis of the fraction of the spillover from a sector to a given sector in the total spillover a given sector receives. The second cut-off (significant sectors) restricts the linkages on the basis of the fraction of spillover from a sector to a given sector in the total spillover for all sectors (Hauknes, 1999:p.63-64).

The clusters that result from these procedure are given in figure 1.

We represent three degrees of linkages. The strongest linkages represent intersectoral spillovers that are higher than 30 % of the total spillover flowing to the given (encircled sector in figure 1) sector and higher than 2 % of the total spillover for the given country and these are depicted by the thick arrows. The weaker linkages represent respectively fractions of 20 %-1% (normal arrow) and 10 %-0.5% (dashed line).

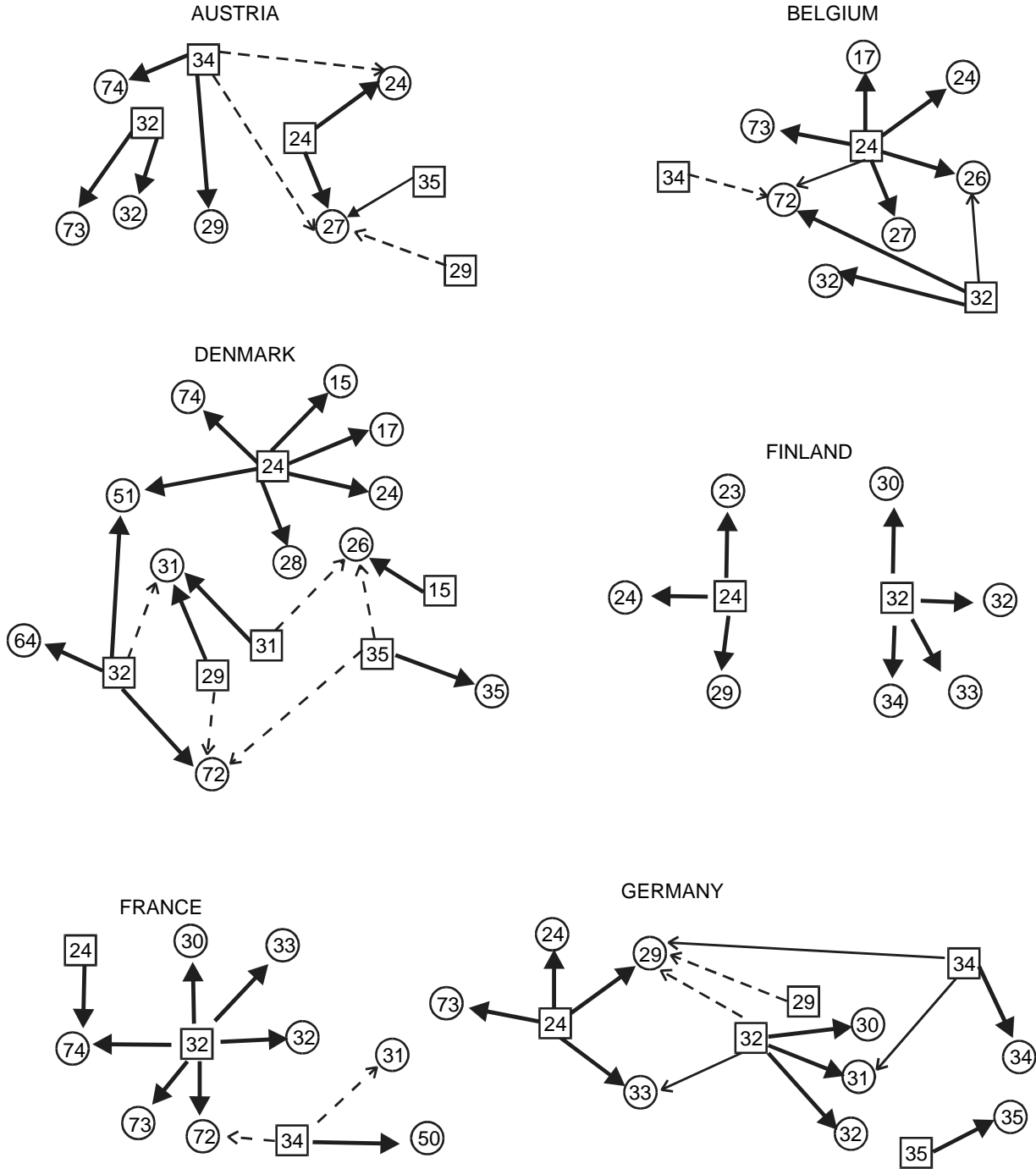
There are two types of biases.

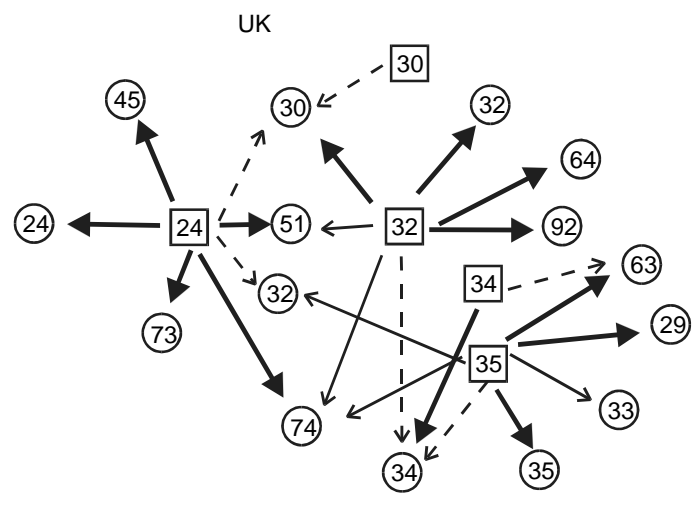
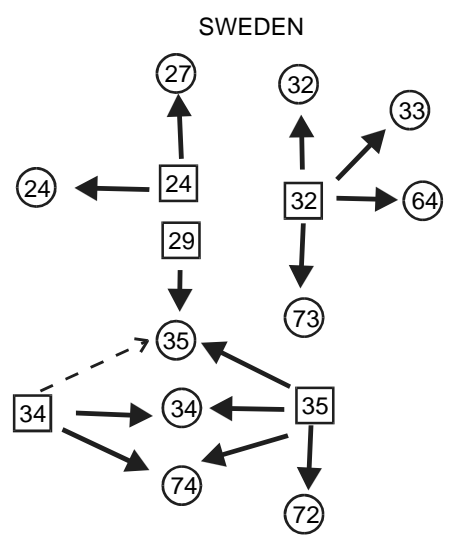
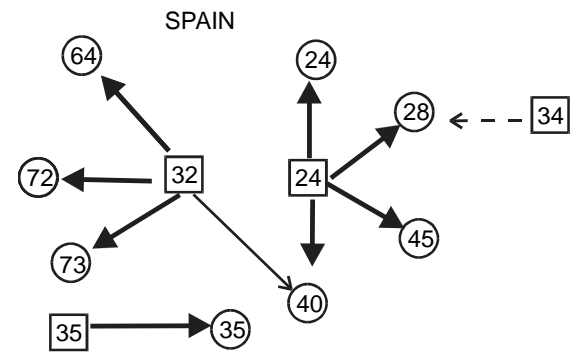
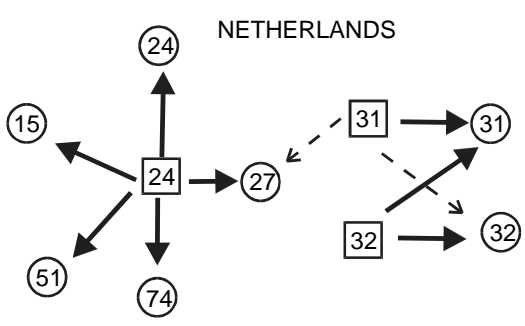
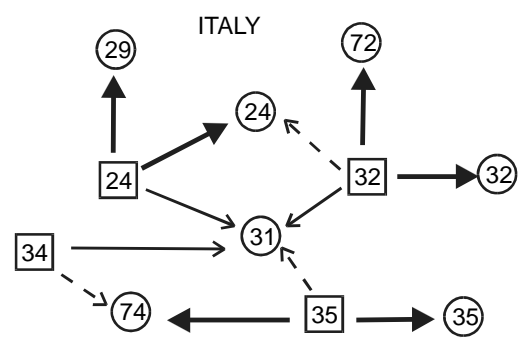
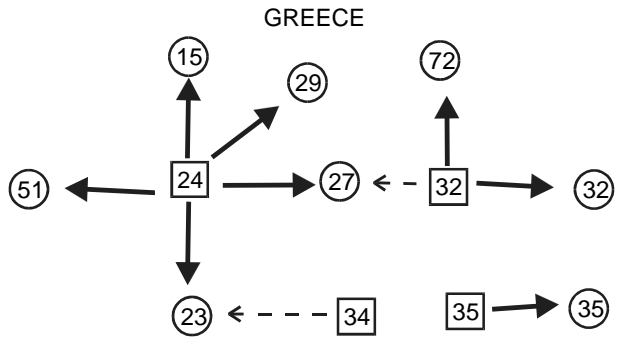
The first one follows from the FWP policy bias. The technological domains that the EC promotes through its FWP obviously influence the pattern of intra- and intersectoral cooperation. The mapping of more near-market collaboration (e.g. EUREKA) or of private alliances could preclude this bias<sup>8</sup>. The policy bias should however not be overstated, as the EC only fixes broad technological areas and is not concerned with specific sectoral patterns. Figure 1 clearly shows that the sectoral patterns are country specific, especially what user industries are concerned.

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<sup>8</sup> Data on EUREKA collaboration are also available from the EU-RJV database and could be used in future research. There are also some datasources on private R&D alliances available.

Figure 1: FWP clusters on the basis of weighed spillovers





□ Supplier sector (all countries)  
 ○ User sector (country)

→  $SP_{ij} \geq 30\%$  of  $SP_i$  AND  $SP_{ij} \geq 0.02 * \sum_j SP_j$

→  $SP_{ij} \geq 20\%$  of  $SP_i$  AND  $SP_{ij} \geq 0.01 * \sum_j SP_j$

- - - →  $SP_{ij} \geq 10\%$  of  $SP_i$  AND  $SP_{ij} \geq 0.005 * \sum_j SP_j$

The second bias follows from our weighing procedure. By multiplying two R&D stocks we may overestimate knowledge spillovers to R&D intensive sectors, and underestimate spillovers to low-tech industries. Some way of normalizing the R&D stocks could be considered.

R&D intensive sectors that are active in EC-popular technological areas are present in all clusters (i.e. *chemicals* (NACE 24) and *electronic equipment and components* (NACE 32)). The clusters are probably not very revealing from this perspective.

Figure 1 reveals that the clusters are more country specific with regard to user sectors than with regard to supplier industries. Moreover, some low-tech industries like *food and beverages* (NACE 15), *textiles* (NACE 17) and *iron, steel and non-ferrous metals* (NACE 27) appear in a number of clusters.

Both the weighed and unweighed spillover measures clearly show that in the FWP cooperation within the same sector is important, although the two-digit level is too aggregated to conclude from this that there is a high degree of cooperation between direct competitors. However, the matter should be analysed further, as it could reveal that the FWP may be fostering some collusive networking in important technological fields, if it is found that pre-competitive cooperation is followed by more near-market alliances, especially between large competitors.

Even at the two-digit level it can be seen that the clusters obviously show some connection to I/O linkages but that they can not simply be reduced to an I/O pattern.

The clusters reveal where, within the policy framework put forward by the EC, pre-competitive cooperation, can be assumed to have resulted in knowledge spillovers from foreign towards domestic firms.

There are important differences between countries as to the sectors that benefit from knowledge spillovers.

The spillover pattern could reveal that firms from small countries rely on cooperation with firms from other countries, by lack of eligible domestic partners. The spillover matrix and the cluster of Belgium show that this applies to some extent if they are compared to the matrix

which was computed for spillovers between domestic firms partnering in FWP (see Dumont and Meeusen 2000).

In FWP the share of collaborative links between partners of the same country is significantly smaller for small countries than for large countries (OECD, 1999:b).

International spillovers are probably more important to small countries than to large countries (see also Coe and Helpman 1995) and networking can help small countries overcome the problem of insufficient scale.

From this point of view the proposed method seems interesting for small open economies, the more so because as Debresson and Hu (1999) pointed out, I/O-based analyses are not very reliable for this kind of countries. Even for large countries the patterns reveal important international linkages that I/O-tables fail to grasp.

We would like to conclude this section by rounding up the strength and drawbacks of the proposed method.

The main advantage of the method is that it allows for a straightforward way to estimate knowledge spillovers for a large number of countries, starting from common databases, which ensures comparability.

The policy bias that follows from the use of data on cooperation within EU FWP could be precluded by using data on more near-market cooperation or private alliances. From a dynamic perspective it would, for that matter, be interesting to compare the pattern that results from publicly subsidized cooperation to the pattern of more spontaneous networking.

As to the limitations of the method, missing data can bias the spillover estimation and cluster detection procedure.

Computing the spillovers and detecting the clusters is furthermore rather sensitive to the hypotheses and criteria that are used. Using other criteria to weigh the spillovers or to cut-off linkages for the clusters could result in a different outcome.

We assume that cooperation results in knowledge spillovers in a rather mechanical way, without controlling for variables that could be important determinants. The spillovers should be tested econometrically as to their significance.

Finally, R&D networks entail far less than innovative networks. By only focusing on R&D we neglect other important (e.g. non-technical ) aspects of the innovation process.

## **7. Science-industry linkages**

The FWP of the EU not only envisaged to promote transnational interfirm collaboration, but also to encourage the cooperation between firms, higher education institutes (HEIs) and public and private research institutes (RECs).

The EC found indications of a 'European paradox' in a number of EU member states. This paradox consists in the poor link between strong scientific performance and below-average innovative performance (EC, 1997: p.180).

The cooperation between firms on the one side and HEIs and RECs on the other side is often hindered by diverging expectations, needs and a different spirit of enterprise.

HEIs and RECs represented 61.3 % of all participations in the third FWP and 54.4 % in the fourth FWP. This high degree of participation can be explained by the pre-competitive nature of the projects and the fact that these institutes can receive financing for up to 100 % of their project costs.

These institutes took up the role of prime contractor in over 28 % of all projects that have been contracted between 1994 and 1996, especially in projects related to agriculture and agro-food and less so in more industrially oriented areas like IT and materials technology (EC, 1997: p. 540).

HEIs and RECs have a preference to cooperate with each other rather than with firms. Over 60 % of their FWP linkages are with other HEIs or RECs.

This high percentage slightly decreased during the fourth FWP in favour of science-SME linkages. The EC considers that the diversity of members increases complementarity and potential synergies of research networks, and therefore encourages science-industry cooperation in the fifth FWP (EC, 1997: p.540).

Luukkonen and Hälikkä (2000) refute the suggestion by Peterson and Sharp (1998) that the FWP have fostered few science-industry linkages.

We computed science-industry linkages for the top-25 sectors relative to their total interfirm linkages.

Spillovers from HEIs and RECs were computed in the same way as interfirm spillovers.

**Table 2 : Science-industry linkages in FWP as a fraction of industry linkages**

	15	17	23	24	26	27	28	29	30	31	32	33	34	35	40	45	50	51	60	63	64	72	73	74	92		
<b>AT</b>																											
REC	NA	0,5	NA	0,6	0,0	0,8	NA	0,3	NA	0,6	0,5	0,4	0,8	NA	0,6	0,3	1,0	0,3	NA	NA	NA	NA	1,3	0,2	0,2		
HEI	NA	0,1	NA	1,4	1,3	0,5	NA	0,8	NA	0,3	0,7	0,0	0,7	NA	1,1	0,0	0,0	0,0	NA	NA	NA	NA	1,9	0,3	0,0		
<b>BE</b>																											
REC	4,1	0,4	NA	1,2	1,0	0,5	0,3	1,0	NA	0,8	0,3	0,8	0,2	0,3	0,3	NA	NA	0,7	1,1	NA	0,5	0,3	5,0	1,7	0,3		
HEI	2,4	0,2	NA	1,2	0,5	0,3	0,8	1,1	NA	0,4	0,4	1,1	1,1	0,8	0,5	NA	NA	0,9	0,7	NA	0,4	1,0	5,8	0,9	0,2		
<b>DK</b>																											
REC	8,4	0,1	NA	3,7	1,6	0,5	0,3	0,8	NA	1,3	0,5	1,2	0,0	0,7	0,8	3,0	0,0	0,5	NA	0,0	0,4	0,7	NA	1,6	NA		
HEI	7,8	0,2	NA	6,4	1,2	1,0	0,7	0,7	NA	0,6	1,0	1,5	0,3	0,6	0,4	1,4	0,0	0,4	NA	0,0	0,4	1,2	NA	2,4	NA		
<b>FI</b>																											
REC	2,7	NA	1,5	1,6	NA	1,0	3,3	1,5	0,3	1,1	0,2	0,4	0,0	0,9	1,2	NA	0,0	1,0	NA	NA	0,6	NA	NA	1,2	NA		
HEI	3,3	NA	1,3	1,4	NA	0,3	1,6	1,1	0,0	0,7	0,5	0,6	0,3	0,8	1,2	NA	0,0	0,5	NA	NA	0,6	NA	NA	0,8	NA		
<b>FR</b>																											
REC	1,5	2,6	1,7	3,1	3,1	1,2	1,3	2,0	0,5	0,9	0,7	0,9	0,4	0,8	0,9	1,1	0,4	0,7	0,8	1,1	1,5	1,0	1,1	1,0	0,4		
HEI	1,4	2,1	1,3	4,6	2,1	1,6	1,4	1,9	0,7	1,3	0,9	1,0	0,7	0,7	0,9	1,4	0,5	0,8	0,6	0,4	2,1	1,3	1,6	1,0	0,2		
<b>DE</b>																											
REC	3,0	0,3	1,4	1,1	0,7	0,7	0,9	0,8	0,3	0,4	0,4	1,0	0,4	0,7	0,6	1,3	0,2	0,9	0,8	0,4	0,6	0,5	2,5	1,1	0,2		
HEI	3,9	0,2	1,3	1,3	0,6	0,8	1,2	0,7	0,5	0,5	0,5	1,1	0,6	0,5	0,6	0,9	0,2	1,1	0,7	0,3	0,6	0,7	2,7	0,8	0,2		
<b>GR</b>																											
REC	1,2	0,9	1,4	NA	1,8	0,5	2,3	1,0	NA	NA	0,5	0,8	NA	0,9	NA	2,2	NA	1,9	1,0	NA	0,2	1,1	NA	NA	0,3		
HEI	1,4	0,5	3,3	NA	2,2	1,9	1,0	0,9	NA	NA	0,8	0,8	NA	0,8	NA	2,4	NA	2,8	0,0	NA	0,4	1,1	NA	NA	0,7		
<b>IT</b>																											
REC	1,5	0,8	0,2	1,1	1,8	0,6	0,3	0,9	0,4	0,4	0,5	0,4	0,5	0,7	0,9	0,4	0,0	0,5	0,3	0,0	0,7	0,4	0,9	0,9	NA		
HEI	1,9	0,6	0,5	1,4	1,0	0,8	0,5	0,9	0,6	0,8	0,6	1,0	0,8	0,7	0,2	0,7	0,5	1,3	0,3	0,0	0,7	0,5	0,9	1,0	NA		
<b>NL</b>																											
REC	1,7	0,1	NA	1,2	1,1	0,9	0,2	0,6	NA	1,0	0,1	2,0	0,2	NA	0,7	0,6	NA	2,9	0,6	0,7	NA	0,3	NA	1,4	0,5		
HEI	1,5	0,1	NA	0,9	0,4	0,8	0,3	1,0	NA	0,3	0,2	0,5	0,6	NA	0,3	0,5	NA	3,5	0,8	0,6	NA	1,1	NA	1,3	1,4		
<b>ES</b>																											
REC	2,8	1,6	3,6	0,8	0,9	1,5	0,6	1,2	0,0	2,6	0,6	0,2	0,9	0,5	0,8	0,8	0,3	1,2	0,6	1,3	0,3	0,5	0,7	0,9	0,3		
HEI	3,6	0,3	1,3	1,4	0,4	1,2	0,4	0,6	0,0	2,5	0,7	1,0	1,2	0,5	0,7	1,0	0,6	1,4	0,1	0,4	0,4	1,0	0,6	0,7	0,1		
<b>SE</b>																											
REC	1,3	NA	NA	0,7	4,4	1,3	0,4	0,7	1,6	1,2	0,5	0,5	0,7	0,8	0,6	NA	NA	NA	NA	NA	0,4	0,5	0,3	0,8	0,2		
HEI	5,2	NA	NA	1,6	2,2	0,6	0,7	0,5	0,8	2,1	0,4	0,5	0,4	1,1	1,0	NA	NA	NA	NA	NA	0,3	0,4	0,2	0,6	0,1		
<b>UK</b>																											
REC	2,9	1,0	1,2	1,2	1,1	0,8	0,8	0,9	0,3	0,6	0,5	0,6	0,5	0,6	1,2	0,8	0,4	1,3	0,3	0,7	0,4	0,8	2,0	1,0	0,3		
HEI	2,6	0,7	1,8	1,5	1,4	0,8	2,0	0,8	0,7	0,5	0,5	0,7	0,5	0,5	0,9	0,5	0,5	1,7	0,1	0,5	0,3	0,9	1,9	1,0	0,3		

In table 2 we give the ratio of science-industry spillovers to industry spillovers for 12 countries.

A small ratio reveals that firms from the sector in the top of the table do not cooperate often with science institutes compared to their cooperation with firms.

There are some remarkable results.

The low R&D-intensive sector *food and beverages* (Nace 15), has a high ratio for all countries and another low-tech industry *textiles* (NACE 17) has a high ratio for France and for Spain w.r.t. RECs.

On the other hand, high-tech sectors that are often considered to be science-based like electronic equipment (NACE 32) and instruments and office machines (NACE 33) on average have low ratios.

Although the fact that projects in the field of IT and materials technology are more industrially oriented may bias these results, they suggest that science-industry linkages within the pre-competitive FWP do not support the traditional view of science-basedness, following Pavitt (1984).

Especially the high degree of collaboration with HEIs and RECs of some low-tech industries seems to support this view.

## 8. Conclusions

In this paper we used available data on subsidized R&D collaboration to compute interfirm spillovers and science-industry linkages.

The underlying motive is twofold.

From a methodological perspective, we argued that data on R&D collaboration may comprise better knowledge spillovers than methods based on Input-Output tables, as the latter focus on embodied or rent spillovers.

From a policy perspective, we indicated that the rationale of a public policy oriented towards promoting interfirm collaboration, irrespective of which theoretical perspective is endorsed, depends on the magnitude and specificities of spillovers, and that this matter is still open to empirical scrutiny.

The EU launched ambitious Framework Programmes (FWP), essentially to foster the catch up of EU firms with the US and Japan. The FWP consisted in financial support for transnational collaboration between firms, higher education institutes (HEIs) and research institutes (RECs) in what was labelled as pre-competitive R&D projects, for which exemptions were issued on the strict EU competition rules.

Data on the FWP, which are available from an official EU datasource, amplified with firm level data, were used to compute interfirm knowledge spillovers, assuming that the number of cooperative interfirm links is a proxy for the underlying knowledge flows.

For 12 countries we constructed matrices for the 25 most cooperating sectors.

We also constructed matrices of weighed spillovers, in which we considered the absorptive capacity and the spillover pool to be function of sectoral R&D stocks.

Using the matrices with weighed spillovers we derived clusters of the sectors with the highest spillover linkages.

These clusters were found to be country specific w.r.t. to user sectors, but less so w.r.t. supplier sectors. Remarkably enough, despite the rather strict cluster criteria, low-tech sectors like *food and beverages; textiles; and iron, steel and non-ferrous metals* were present in a number of country clusters.

Intrasectoral spillovers are found to be important, although the two-digit level is probably too aggregated to conclude from this that there is a high degree of cooperation between direct competitors.

The matter should be analysed further, as it could reveal that the FWP may be fostering some collusive networking in important technological fields, if it is found that pre-competitive cooperation is followed by more near-market alliances, especially between large competitors.

If the matrices and clusters show some obvious connection with I/O-tables it is also clear that the FWP linkages do not simply fit in the value added chain.

We have also computed science-industry linkages and again found some remarkable results. *Textiles* and especially *food and beverages* were found to have a high degree of linkages with HEIs and RECs, which again shows that the classification of low-tech versus high-tech industries (e.g. on the basis of R&D intensity) is not very distinctive in the issue of networking. This is even more revealing as it concerns R&D networking and not innovative networking for which non-technical factors are known to be even more considerable.

We think that the proposed method can complement other procedures of measuring spillovers and that this is interesting both for the empirical issue of measuring or estimating spillovers, as for the issue of the policy rationale for promoting cooperation, which to a great extent depends on the magnitude and nature of spillovers.

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## APPENDIX 1

Programmes included in the RJV database.

<b>Programme Acronym</b>	<b>FWP</b>	<b>Number of Projects</b>	<b>Budget (million ECUs)</b>	<b>Average funding per project</b>	<b>Criteria</b>
ACTS	4th FWP	154	671	4,36	152
AERO 0C	2nd FWP	28	35	1,25	28
AERO 1C	3rd FWP	34	53	1,56	29
AGRIRES 3C	1st FWP	113	50	0,44	1
AIM 1	2nd FWP	43	20	0,47	36
AIM 2	3rd FWP	44	97	2,20	35
AIR	3rd FWP	436	377	0,86	184
BAP	1st FWP	366	75	0,20	69
BCR 4	2nd FWP	265	59,2	0,22	160
BIOMED 1	3rd FWP	274	151	0,55	3
BIOMED 2	4th FWP	674	374	0,55	146
BIOTECH 1	3rd FWP	156	186	1,19	33
BIOTECH 2	4th FWP	492	595,5	1,21	274
BRIDGE	2nd FWP	97	100	1,03	49
BRITE	1st FWP	219	185	0,84	206
BRITE/EURAM 1	2nd FWP	378	499,5	1,32	303
BRITE/EURAM 2	3rd FWP	472	770	1,63	388
BRITE/EURAM 3	4th FWP	2058	1833	0,89	1453
CAMAR	2nd FWP	80	55	0,69	21
CLIMAT 3C	1st FWP	108	17	0,16	0
CRAFT	3rd FWP	539	57	0,11	216
DECOM 2C	1st FWP	74	12,1	0,16	6
DECOM 3C	2nd FWP	73	31,5	0,43	31
DRIVE 1	2nd FWP	69	60	0,87	67
DRIVE 2	3rd FWP	66	124,4	1,88	59
ECLAIR	2nd FWP	42	80	1,90	41
ENNONUC 3C	1st FWP	789	175	0,22	136
ENS	3rd FWP	14	41,3	2,95	13
ENV 1C	3rd FWP	560	319	0,57	125
ENV 2C	4th FWP	715	914	1,28	222
EPOCH	2nd FWP	34	40	1,18	10
ESPRIT 1	1st FWP	241	750	3,11	234
ESPRIT 2	2nd FWP	435	1600	3,68	380

ESPRIT 3	3rd FWP	605	1532	2,53	483
ESPRIT 4	4th FWP	1599	2084	1,30	834
EURAM	1st FWP	87	30	0,34	62
EURET	2nd FWP	9	25	2,78	9
FAIR	4th FWP	632	739,5	1,17	240
FAR	2nd FWP	127	30	0,24	16
FLAIR	2nd FWP	34	25	0,74	17
FOREST	2nd FWP	38	12	0,32	14
HYMGEN C	2nd FWP	29	15	0,52	4
JOULE 1	2nd FWP	267	122	0,46	143
JOULE 2	3rd FWP	401	217	0,54	286
LIBRARIES	3rd FWP	51	22,5	0,44	35
LRE	3rd FWP	25	22,5	0,90	18
MAST 1	2nd FWP	48	50	1,04	48
MAST 2	3rd FWP	93	118	1,27	34
MAST 3	4th FWP	157	243	1,55	85
MAT	3rd FWP	178	67	0,38	57
MATREC C	2nd FWP	71	45	0,63	67
MHR 4C	2nd FWP	211	65	0,31	0
NNE-JOULE C	4th FWP	577			475
ORA	3rd FWP	19	14	0,74	16
RACE 1	2nd FWP	94	550	5,85	83
RACE 2	3rd FWP	123	554	4,50	118
RADWASTOM 3C	1st FWP	217	62	0,29	30
RADWASTOM 4C	2nd FWP	121	79,6	0,66	40
RAWMAT 3C	1st FWP	236	70	0,30	84
REWARD	2nd FWP	13	6	0,46	11
SMT	4th FWP	394	307	0,78	242
TELEMAN	2nd FWP	21	19	0,90	20
TELEMATICS 2C	4th FWP	641	913	1,42	431
TRANSPORT	4th FWP	336	263	0,78	223
<b>Totals</b>		<b>17596</b>	<b>18709,6</b>		<b>9335</b>

Source: Adapted from CORDIS, CD-ROM (1999 III).