Knowledge spillovers through RD cooperation

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1. Introduction

Despite the abundant, mostly game-theoretical, literature on the relation between spillovers and the optimal outcome of cooperation in R&D versus non-cooperation, and the well-established increasing occurrence of cooperative agreements, the fact that firms might manage spillovers within and through R&D cooperation has yet hardly been addressed empirically, as pointed out by Cassiman and Veugelers (1998).

Thus far the measurement of spillovers focused mainly on supplier-buyer linkages or on patent data.
In this paper, we will argue that the mapping of R&D collaboration allows for a rather straightforward measurement of knowledge spillovers which may complement or readjust some of the conclusions that have resulted from other methodologies.

We will also show how the mapping can be used to categorise sectors along the Pavitt taxonomy and to find out to which extent the pattern of R&D collaboration overlaps with the pattern of innovation and the economic linkages that ensue from it.

2. How embodied are knowledge spillovers ?

Technological or R&D spillovers are most often defined as externalities, whit 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)

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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)

Although most researchers, explicitly or implicitly, do not regard technology transfer as part of spillovers, as this does not represent an externality, it is not always clear how the strict definition is ensured in empirical research and more specific in the estimation of spillovers. For instance, Coe and Helpman (1995) estimate international R&D spillovers, defined as externalities, by estimating the effect of foreign R&D on domestic productivity growth. As they regard trade as the spillover mechanism, it is not very clear to which extent their spillover estimates measure only externalities or externalities as well as voluntary technology transfer.

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 flows or flows of international trade (Terleckyj 1974; Coe and Helpman 1995; Debresson and Hu 1999; OECD 1999; Roelandt and den Hertog 1999)
Although the importance of supplier-buyer linkages for innovation is well established (e.g. Debresson et al. 1997 ; Christensen, Rogaczewska and Vinding 1999) 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.

Geroski, Machin and Van Reenen (1993) argue that the fact that the spillover variables they used have very small positive effects can, apart from institutional differences, be explained by the limited spillovers of knowledge embodied in specific products as by the time that knowledge is embodied in new products it may be too use-specific to have any further relevance to spill over into other applications.

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 assumed to have become more tacit this might explain why hybrid forms like strategic alliances have become so popular. Cooperation may increase knowledge flows between partners and can allow partners to internalise 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 acknowledge that partners may voluntarily increase spillovers between them. As a consequence the magnitude of spillovers will depend on the decision to cooperate.

We will not pursue the matter of the possible advantages and disadvantages of collaborative agreements further, as these have already been reviewed extensively elsewhere (see e.g. Teece 1992, Mowery 1992 and Hagedoorn 1993).

Our main objection to the input-output based approach is that it does not account for disembodied *pure* knowledge spillovers and neglects other important (international) channels of technology diffusion.

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.

Although Goto and Suzuki (1989) found that supplying industries R&D efforts contributed to the productivity growth of user industries, they established that the impact of R&D efforts of Japanese electronics-related industries on the productivity growth of other Japanese manufacturing industries can be attributed to a greater extent to knowledge diffusion than to the transaction of intermediate and investment goods.

Unfortunately, computing disembodied spillovers is less straightforward and more tricky than computing embodied spillovers

Most methods consist in establishing, in an indirect way, the impact of disembodied knowledge flows rather than in quantifying knowledge 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.

Goto and Suzuki (1989) showed that the diffusion from electronics-related industries to other industries in Japan is greater the closer those industries are to the electronics-related industries in the technological space.

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

Row sums measure the R&D by industry of origin and column sums account for R&D by industry of use. Intrasectoral elements are regarded as process-related R&D.

Jaffe (1986, 1989) proposes a method to characterise 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.
Unlike Scherer Jaffe's measure has no direction which should not be surprising for a distance measure but poses some problems for calculating spillovers as it seems hard to believe that intersectoral spillovers are balanced.

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 absorption capacity of firms than it is for the spillover between firms. Especially what 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 are thrown on spillovers that result from unintended knowledge flows.

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, except for Belgium (Flanders), 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 inter-firm linkages and that it may also be useful to compare matrices of flows through R&D cooperation with matrices based on patent data.
If the matrix of intra- and intersectoral knowledge flows resulting from R&D collaboration is computed, correlations between these matrices and I-O and technology flow and distance matrices can be estimated, following Capron et al. (1996), Verspagen (1997b) and Veugelers and De Backer (1999).

3. Estimating knowledge spillovers through R&D cooperation

In what follows we describe the method that we used to calculate intra- and intersectoral knowledge flows, based on data on R&D cooperation between Belgian firms in EU FWP, in EUREKA projects and in technological strategic alliances up to 1997 (Dumont and Meeusen, 2000).
The basic hypothesis is that the number of cooperative links between firms is a proxy measure for the underlying knowledge flows.
We constructed an asymmetric matrix of intra- and intersectoral knowledge flows. The asymmetry was obtained by hypothesising that in R&D projects more knowledge flows from the main contractant - often the technologically more advanced partner - to other contractants than the other way round, whereas knowledge flows between 'normal' partners are assumed to be balanced. 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'. The hypothesis that in joint R&D projects as a rule more knowledge flows from the main contractor to another partner than the other way round is open for discussion.

The analysis was performed at the NACE 2-digit level, due to insufficient data for an analysis at a more disaggregated level. So, for example, if a firm belonging to NACE sector 32 is the main contractant in a project or agreement that involves 5 partners of which one is another firm belonging to NACE 72, we assume a knowledge flow of 0.4 (2/5) from NACE 32 to NACE 72 and a knowledge flow of 0.2 (1/5) from NACE 72 to NACE 32 whereas if none of the firms is the main contractant both knowledge flows equal 0.2.

The column sums account for the total amount of knowledge flowing towards a given sector and the row sums account for the knowledge flowing out of the given sector. The overall intersectoral spillover measure per sector is the amount of knowledge flowing from a given sector to the other sectors (Spill-Out), and from the other sectors to the given sector (Spill-In) . Apparently overall intersectoral spillovers are high for all sectors, with exception of NACE 17 (Textiles), which reveals that cooperation occurs more between sectors than within sectors, even at a rather high level of aggregation. This supports the finding by Verspagen (1997a) of the importance of intersectoral spillovers. It also reveals that cooperation between 'national' *competitors* in international R&D projects and technological agreements, which can be traced on the main diagonal of the matrix, is rather limited, although, as pointed out by Griliches (1992), data for this kind of analysis should ideally be collected at business-unit level rather than on firm level. In our analysis major R&D-active firms which are competitors for some of their activities span several sectors, even at the 2-digit level used.

As cooperation seems to occur more between than within industries, and firms within sectors can be expected to be more technologically related than firms from different 2-digit sectors, the relationship between spillovers and proximity is probably not a clear-cut, monotonically increasing one.

Table 1 : Matrix of intra- and intersectoral knowledge flows in R&D cooperation between Belgian firms

	15	17	24	25	26	27	28	29	31	32	33	34	36	45	64	70	72	73	74	**Total**	**Spill-Out**	**DIFF**	**INT**
NACE 15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.33	0	1.33	1.00	0.2	0.14
NACE 17	0	3.27	0.07	0	0	0	0	0.05	0	0.07	0	0	0.05	0	0	0	0	0	0.05	3.56	0.08	0	0.18
NACE 24	0	0.07	0	0	0	0	0	0	0	0.07	0	0	0	0	0	0	0.04	0.11	0	0.29	1.00	-0.14	0.05
NACE 25	0	0	0	0	0	0	0.12	0	0.5	0	0	0	0	0	0	0	0.2	0	0.06	0.88	1.00	0.03	0.22
NACE 26	0	0	0	0	0.55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.55	0.00	0	0.07
NACE 27	0	0	0	0	0	1.23	0.27	0.07	0	0.6	0.03	0	0	0	0	0	0	0	0.46	2.66	1.00	-0.06	0.15
NACE 28	0	0	0	0.12	0	0.27	0.92	0.27	0	0	0	0	0	0	0	0	0	0	0.65	2.23	0.59	-0.05	0.48
NACE 29	0	0.05	0	0	0	0.07	0.27	0	0.25	0.2	0	0	0.05	0	0	0.33	0	0	0.19	1.40	1.00	-0.03	0.29
NACE 31	0	0	0	0.25	0	0	0	0.25	0	0.24	0	0.06	0	0	0.14	0	0	0	0	0.94	1.00	-0.18	0.12
NACE 32	0	0.07	0.07	0	0	0.6	0	0.4	0.49	1.64	0.5	0	0.17	0.18	0.86	0	0.67	0	0.18	5.83	0.72	0.11	0.06
NACE 33	0	0	0	0	0	0.03	0	0	0	0.25	0	0	0	0	0	0	0	0	0	0.28	1.00	-0.28	0.11
NACE 34	0	0	0	0	0	0	0	0	0.06	0	0	0	0	0	0	0	0	0	0	0.06	1.00	0	0.04
NACE 36	0	0.05	0	0	0	0	0	0.05	0	0.17	0	0	0	0	0	0	0	0	0.05	0.32	1.00	0	0.08
NACE 45	0	0	0	0	0	0	0	0	0	0.18	0	0	0	0	0	0	0	0	0.05	0.24	1.00	0	0.33
NACE 64	0	0	0	0	0	0	0	0	0.14	0.45	0	0	0	0	0.13	0	0	0	0.13	0.85	0.85	-0.17	0.07
NACE 70	0	0	0	0	0	0	0	0.16	0	0	0	0	0	0	0	0	0.2	0	0	0.36	1.00	-0.17	1
NACE 72	0	0	0.04	0.4	0	0	0	0	0	0.47	0	0	0	0	0	0.2	1.32	0	0.17	2.59	0.49	-0.03	0.07
NACE 73	0.83	0	0.22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.05	1.00	-0.14	0.17
NACE 74	0	0.05	0	0.06	0	0.86	0.92	0.25	0	0.18	0	0	0.05	0.05	0.13	0	0.33	0	0.34	3.22	0.89	0.14	0.14
Total	0.83	3.56	0.4	0.83	0.55	3.05	2.49	1.49	1.44	4.53	0.53	0.06	0.32	0.24	1.25	0.53	2.76	1.44	2.33				
Spill-In	1	0.08	1	1	0	0.6	0.6	1	1	0.64	1	1	1	1	0.9	1	0.52	1	0.94				

Mowery, Oxley and Silverman (1996) find mixed evidence on the effect of alliances on the technological distance between partners. In a substantial part of the considered alliances collaboration seems to have increased specialisation (i.e. divergent development of capabilities of the collaborating partners). However, technological proximity can be essential for the absorption of transferred knowledge.

The advantage of the proposed matrix is that it does not depend on any distance measure, but reflects knowledge flows in a rather straightforward manner.

In Pavitt (1984) the characteristics of some 2000 innovations by British firms in the period 1945-79, that experts considered to be significant, were used to develop a taxonomy based on the sources and the nature of technological opportunities and innovations, on R&D intensity and the type of knowledge flows.

In table 2 the Pavitt taxonomy is given, as well as the results of a number of national NIS pilot studies in which the taxonomy has been explored. Supplier dominated and specialised suppliers rely on their suppliers respectively clients as a source of technology and innovation. Science based sectors highly invest in own R&D activities and often have strong links with universities and research institutes.

In the obtained matrix as given in table 1, diffusion can be measured for each sector as the logarithm of the row sum related to the column sum.

Science-based sectors can be expected to be characterised by ‘positive’ diffusion and supplier-dominated sectors by ‘negative’ diffusion. NACE 15 (*Food & Beverage*), NACE 74 (*Other services to firms*), NACE 32 (*Electronic Equipment*) and NACE 25 (*Rubber and Plastic Products*) have a positive diffusion index. When accounting for the number and magnitude of intersectoral flows NACE 32 in particular diffuses a lot of knowledge to other sectors. NACE 33 (*Instruments and Office Machines*), NACE 31 (*Electrical Machines*) and NACE 64 (*Telecommunications*) have the highest negative diffusion index. In the train of thought of our matrix, the three latter sectors absorb a lot of technological know-how through R&D cooperation from the *Electronic Equipment* sector. The number of links with universities and research institutes could easily be added to the matrix, revealing the research-industry linkages of the given sectors.

It would be interesting to compare the results on interindustry linkages and research-industry linkages that would follow from the mapping of collaboration in FWP with the results from studies that have explored the Pavit taxonomy, which are mostly input-output based.

Table 2 : Pavitt taxonomy in OECD NIS pilot studies

(PAVITT, 1984)	AUSTRIA (1996)	NETHERLANDS (1995)	DENMARK (1996)
SUPPLIER DOMINATED			
- Agriculture - Construction - Services - Traditional manufacturing - Textiles - Wood/ Paper	- Forest cluster (wood/ paper)	- Construction - Transport - Textiles	- Furniture
High dependency on external sources for technology / little own R&D	+	+	+
SPECIALISED SUPPLIERS			
- Machine-building - Instruments			- Supply of dairy factories - Electro-medical instruments
Design & development and clients are the main source of technology			+
SCIENCE BASED			
- Electronics - Chemistry (incl. pharmaceuticals)	- Pharmaceutical cluster - Telecommunications cluster	- Chemical cluster - Non-continuous production : - Machines - Instruments - Metal working - Electrotechnical products	- Pharmaceuticals
Own R&D is important, close contacts with universities and research institutes	+	+	+

The proposed procedure would result in a uniform outcome of comparable matrices for each country and would establish a connection with the work carried out in other Focus Groups, in particular the one on Clusters.

It would certainly add a relevant international dimension, refering to DeBresson (1999), to the analysis and would allow us to determine, and to compare between countries, the degree of overlap between supplier-buyer linkages, the technological proximity of firms and their pattern of R&D collaboration.

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