INTERNATIONAL R&D SPILLOVERS: A SURVEY

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Abstract

This paper presents a critical survey on macro and micro levels studies that evaluate the impact of foreign R&D on domestic productivity growth in industrialized countries. Although the available studies converge towards the conclusion that significant international spillovers take place, we identify several issues that underline the need for further research. These issues are related to the structural models that are estimated, to the weighting scheme that is used to compute a foreign stock of R&D, and to the knowledge transmission mechanisms that are considered. It also clearly appear that there is a lack of analysis at the micro level.

Résumé

Ce papier présente un survol critique de la littérature sur les études aux niveaux macro et micro qui ont évalué l'impact de la R&D étrangère sur la croissance de la productivité domestique des pays industrialisés. Alors que les études disponibles convergent vers la conclusion qu'il existe d'importantes externalités internationales, plusieurs problèmes méthodologiques sont identifiés mettant ainsi en avant la nécessité de davantage de recherche dans ce domaine. Ces problèmes concernent les modèles structurels, les méthodes de pondération utilisées pour calculer les stocks de R&D étrangères ainsi que les mécanismes de transmission des connaissances. Il apparaît également que trop peu d'études sont disponibles au niveau microéconomique.

1. Introduction

The theoretical and empirical economic literature provides evidence that the knowledge originating in a particular country or region increasingly transcends its national boundaries and contributes to the productivity growth of other geographic areas. However, little empirical evidence has been produced about the direction, the magnitude and the effectiveness of the various channels through which such spillover effect are transmitted. The purpose of the present paper is to survey the economic literature on international R&D spillovers[1]. Although robust findings appear in the available studies, it seems that further empirical investigations are still required so as to deepen our understanding of the international knowledge transmission mechanisms, both at the macro and the micro economic levels.

Regarding macro economic approaches, the focus is essentially on the contribution of foreign technology to domestic productivity growth. The same holds for the studies at the micro level, though the concept of foreign technology refers to technologies 'outside the walls of the firm'. We do not tackle the difference between applied and basic research, nor do we take into account the role of R&D generated in public research institutions. We further concentrate exclusively on R&D spillovers that take place between industrialised countries. Finally, we do not pretend to survey all existing papers along this line of research, but the most representative of specific issues.

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[1] For previous surveys on the similar topics, see Griliches (1992, 1995), Mohnen (1996), van Pottelsberghe (1997, 1998), Blomström and Kokko (1998) and Cincera (1998).

Section 2 begins with a broad definition of international R&D spillovers. Section 3 describes the main empirical frameworks that have been used so far to evaluate a stock of foreign R&D. The fourth and fifth sections survey the studies that have examined the relationship between spillovers and productivity growth at the macro and microeconomic level, respectively. The last section concludes with some suggestions for further research.

2. The concept of R&D spillovers

The pioneering paper of Griliches (1979) identifies two main sources of potential externalities generated by R&D activities, namely rent spillovers and knowledge spillovers. International rent spillovers depict the fact that the prices of imported intermediate input and capital goods do not embody completely the product innovation or the quality improvement that result from innovation activities. Therefore, the analysis of productivity growth has to take into account the indirect benefits that emanate from the technological improvement of goods and services produced by trade partners. Rent spillovers arise because the prices of intermediate inputs are not fully adjusted for quality improvements resulting from R&D investments in other countries or firms. This failure to correctly embody a higher quality into output prices is commonly regarded as a consequence of imperfectly monopolistic pricing arising from competitive pressures in the innovating industry. They originate exclusively from economic transactions and may be assimilated to 'errors' in the output deflators of the supplying industries. Quoting Mohnen (1996), these rent spillovers are also a fact of life; if the innovator could perfectly discriminate, no rent spillovers would occur. Griliches and Lichtenberg (1984) formalize this argument by considering the presence of errors in material deflators which has repercussions on the measured total factor productivity growth of an industry. It should be kept in mind that the major feature emanating from these formalizations is the recognition that rent spillovers are entirely due to measurement problems of economic transactions.

Knowledge spillovers arise because of the imperfect appropriability of the knowledge associated with innovations. Poor patent protection, the inability to keep innovations secret, and reverse engineering practices all contribute to the pervasiveness of R&D. International knowledge spillovers or the diffusion of knowledge across countries take place when the knowledge generated by a country contributes to the innovation process of other countries. They occur when ideas (or knowledge) are 'borrowed' by a research team of country *j* from a research team of country *i*. As opposed to rent spillovers, knowledge spillovers is not necessarily synonymous to economic transactions or measurement errors. It is generally characterized by the international transfer of technology which may occur via different routes: foreign direct investments, foreign technology payments, international R&D collaboration, publications in technical and scientific papers, and the migration of scientists and skilled labor forces.[2] Since these knowledge spillover channels are often associated with an economic transaction, the extent to which they also reflect some rent spillovers is not so clear-cut.

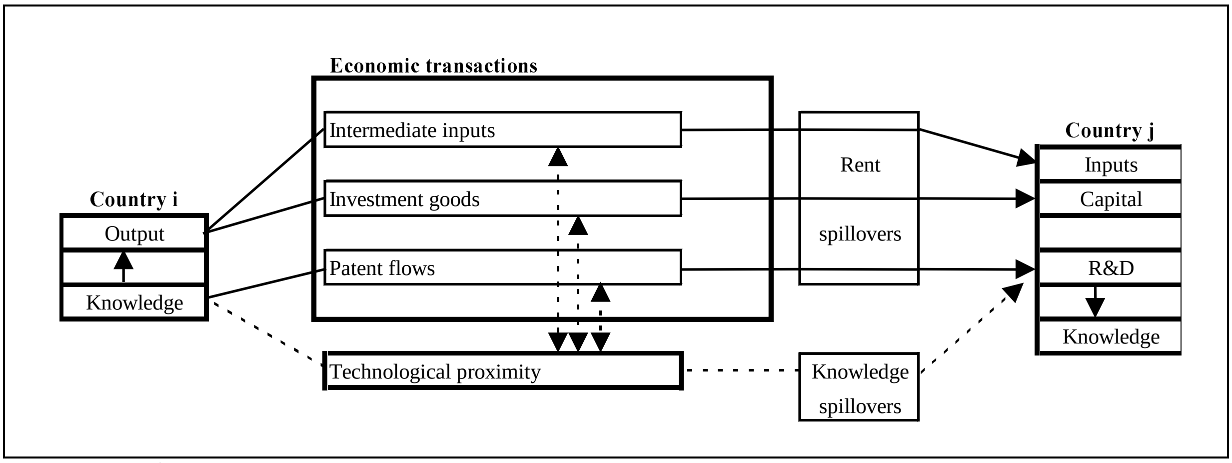
Indeed, if the distinction between the two spillover concepts appears to be clear-cut from the analytical point of view, it is likely to be more ambiguous conceptually, or once an empirical analysis is to be implemented. The ambiguity is due to the fact that it is a difficult task to dissociate empirically rent spillovers from knowledge spillovers. Two reasons lie behind this empirical barrier. First, rent spillovers are approximated through economic transactions which may also be associated with - or imply - some knowledge transfers. Second, the two types of R&D spillovers might not be combined but their respective profiles across countries might be

[2] Foreign technology payments include royalties, licensing fees and patents sales.

similar. Therefore, since each type of R&D spillover is estimated under a common econometric procedure, serious collinearity bias might emerge. This may explain, at least partly, why very few studies try to distinguish rent- from knowledge spillovers, preferring to rely on the broader concept of R&D spillovers.

Figure 1 recapitulates the different channels through which the innovative activity of the firm of country *i* may potentially benefit the firms of country *j*. Since the paper focuses on international spillovers, the users and producers refer to countries as a whole (macro level) and firms from different countries (micro level). As far as economic transactions are concerned, three kinds of rent spillovers (depicted by straight lines) may be distinguished. The first one, the input-related rent spillovers, is associated with country *j*'s imports of intermediate inputs from country *i* or technology goods purchased by firm j from firm i. The second one, the investment-related rent spillovers, corresponds to transactions of investments goods between the two countries. The third one, the patent-related rent spillovers, is characterized by the use by country *j* of patents granted to country *i*. In these three cases, rent spillovers may or may not take place, depending on the transaction price charged by the innovation-producing country or firm. The horizontal dotted line stands for potential knowledge spillovers which may follow various channels and are facilitated by the technological proximity between the firms of the two countries. Knowledge spillovers are not directly embodied in economic transactions but may either be combined to them or follow similar trajectories.

Figure 1.
Picturing potential rent-and knowledge spillovers from country (firm) *i* to country (firm) *j*



Source: adapted from van Pottelsberghe (1997).

An example of similarity is given by the drug industry which buys a substantial part of its intermediate inputs, and most likely borrows ideas, from firms in foreign countries. Yet, knowledge transfer might also occur without any economic transaction. The length of the vertical doted lines sketches our conjecture that from the first to the third concept of rent spillovers, one may get closer to the concept of knowledge spillovers. If country *j* buys patents or investment goods from country *i*, the two industries are likely to be technologically similar and to benefit from each other's innovations. Knowledge spillovers may be combined - or associated - with rent spillovers. A patent granted to country *i* might be used by a research team of country *j*, in order to generate incremental innovations. From this viewpoint, the economic transaction may partly control for knowledge transfers.

3. The measurement of foreign R&D capital stocks

Given their inherent complexity, international technological spillovers have no widely accepted measures. We consider that they surround any R&D externalities that emanate from one country and benefit other firms in other countries. The main technique used to estimate the impact of international R&D spillovers is founded on the hypothesis that R&D expenditures diffuse proportionately to the level of potential relationship between countries or firms from different countries. The degree of international economic transaction is often considered as being the main factor influencing the diffusion level of technological know-how across countries. With *n* countries (firms), the foreign R&D capital stock variable for country (firm) *j* is constructed as a weighted sum of the other countries' (firms') R&D capital stocks R_i :

$$S_j = \sum_{i=1}^{n} a_{ij} \cdot R_i \qquad i \neq j \qquad (1)$$

where a_{ij} pertains to a weighting matrix A and measures, for instance, the share of country *i*'s output accounted for by its sales to country *j* or similarly at the firm level. In the case of rent spillovers, the weights used to compute the stock of 'external' R&D are derived from economic transaction matrices (e.g., import matrices) while in the case of knowledge spillovers the weights can be characterized by an evaluation of the technological proximity between countries or firms. The aggregated R&D spillover variables, corresponding to the four concepts presented in Figure 1, would be computed as follows:

$$S_{m,j} = \sum_{i=1}^{n} \frac{M_{i,j}}{Q_i} \cdot R_i \qquad i \neq j \qquad (2)$$

$$S_{k,j} = \sum_{i=1}^{n} \frac{I_{i,j}}{Q_i} \cdot R_i \qquad i \neq j \qquad (3)$$

$$S_{p,j} = \sum_{i=1}^{n} \frac{P_{i,j}}{P_i} \cdot R_i \qquad i \neq j \qquad (4)$$

$$S_{w,j} = \sum_{i=1}^{n} w_{i,j} \cdot R_i \qquad i \neq j \qquad (5)$$

At the macro level, these four foreign R&D capital stocks aim at estimating international spillovers related to intermediate inputs ($S_{m,j}$), to investment goods ($S_{k,j}$), to patent flows ($S_{p,j}$), and knowledge spillovers ($S_{w,j}$). $M_{i,j}$ is country *j*'s imports from country *i*; $I_{i,j}$ is country *j*'s imports of investment good from country *i*; $P_{i,j} / P_i$ is the share of country *i*'s patents which is likely to be used by country *j*; $w_{i,j}$ is an indicator of country *j*'s technological proximity with country *i*; and Q_i and R_i are country *i*'s output and R&D capital, respectively. $S_{m,j}$ and $S_{k,j}$ may be interpreted as the sum of the R&D intensities which are embodied in the intermediate inputs and investment goods purchased by country *j*.

At the micro-level, several weights or technological proximities have been used. Mohnen (1996) distinguishes between two kinds of technological proximities. In the first set of proximities, the weights are measured on the basis of inter-firm or inter-country flows of good and services, capital goods, R&D personnel, patents, innovations, citations or R&D cooperation agreements. Quoting the author, these proximities follow the argument that the more i purchases intermediate inputs or capital goods from j, hires scientists from j, manufactures goods patented by j, uses innovations discovered by j, cites j's patents in his own patent applications, or cooperates with j on R&D, the more it is technologically close to j. The second set of technological proximities departs from the construction of vectors characterizing the firms' or industries' technological positions into different spaces. The closer firms are in such spaces, the more they can benefit from each other research activities. Various vectors or spaces can be used. Having the number of patent applications classified across technological classes, lines of business, categories of R&D activities or qualifications of R&D personnel allows one to construct firm' vectors and position firms into technological spaces. For instance in the approach developed by Jaffe (1986, 1988, 1989), the firm's position in the technological space is characterized by the distribution of its patents over patent classes. Goto and Suzuki (1989) consider industry sectors to be technologically close to each other if they perform the same kind of R&D. In Adams (1990), technological proximities between manufacturing industries are constructed on the basis of the number of scientists hired with the same type of qualification.

It should be noted that each of these technological proximities has its own drawbacks and it is not obvious how to make the relevant choice among them. As pointed out by Verspagen (1997), the first kind of technological proximities is based on a user-producer principle while the second set of proximities adopt more explicitly a technology perspective for measuring spillovers. In the author's opinion, both perspectives are aimed at measuring knowledge spillovers but they place different emphasis on different aspects of the complicated process of the diffusion of knowledge. The user-producer method tends to stress transaction based linkages while the second approach tends to stress technology-based linkages between firms and sectors. Hence, the two categories of proximities should be viewed more as complementary rather than as substitutes. Furthermore, the user-producer approach to modelling knowledge spillovers tends to under estimate the real magnitude of pure knowledge spillovers. As discussed in the previous section, one reason is that the user-producer approach is related to economic transactions rather than pure knowledge transfer between the two actors. Indeed, to the extent that a knowledge producer can appropriate the returns of his innovative activities, the price at which new products or processes are sold will be higher than the marginal costs involved to produce them. Hence, the potential technological spillovers existing between the producer and the user of an innovation are likely to embody important rent spillovers besides pure knowledge spillovers. On the other hand, while technological innovations may be useful to other R&D performers, they are not always subjected to user-producer relationships. Mohnen (1996) also finds it difficult, both theoretically and empirically, to distinguish between rent and pure knowledge spillovers. As pointed out by the author, proximity measures based on intermediate input flows are more likely to reflect rent spillovers while the weighting matrices based on patent and innovation flows should be viewed more as indicators of knowledge transmission. The proximities based on distances in technological spaces are most likely to represent knowledge spillovers of a tacit kind.

In a nutshell, it is clear that there is *a priori* some equivalence between the various concepts of R&D externalities with regard to what is really measured. It seems that if some knowledge spillovers are associated with a particular economic transaction, it would not be possible to dissociate the pure knowledge spillovers components to the estimated rent spillovers. Concerning the potential collinearity bias, they would appear if the weighting components corresponding to different concepts of R&D spillovers were similar.

Given the more disagregate information available at the micro level, additional methods have to be mentioned to measure R&D spillovers at this level. One of this method consists in adding industry dummies in the set of explanatory variables entering the production function Since these dummy variables take, in essence, the same value for all firms in a given industry and to the extent that R&D performed outside an industry has a similar effect on all firms of that industry, these dummy variables can be interpreted in terms of inter-industry spillovers. However, as pointed out by Mohnen (1996: p.50), these variables are also likely to pick up opportunity effects such as "the closeness to science, technical knowledge from upstream materials and equipments suppliers, downstream users, governments agencies and research labs". An alternative method for assessing the effect of R&D spillovers is based on the comparison between its estimated rate of returns at the industry level and the estimates at the firm level. Indeed, if significant spillovers exist within an industry, then the computed rate of returns should be higher at the meso- than at the micro level. Mairesse and Mohnen (1990) in their study of the impact of spillovers do not however report higher estimates at the industry level than at the firm level. The argument invoked by the authors for explaining this result rests in the fact that the assumed rate of obsolescence for computing the spillover stock should actually be much less than the corresponding one used for constructing the firm's own R&D capital. To the extent that the pool of R&D spillovers embody a large component of social returns, the rate at which this pool depreciates over time can be expected to be lesser than private R&D stocks. Hence the assumption of a same rate of obsolescence for both spillover and own R&D stocks may explain why the authors' estimates do not differ significantly at the aggregated and firm levels respectively. Another approach – the vector approach - for estimating the impact of R&D spillovers considers the R&D capitals of different industry sectors as separate regressors. But as noted by Griliches (1992), this approach is not really feasible because of multicollinearity issues among the regressors and because of lack of degree of freedom, e.g. there are in general more industry sectors or firms than available time periods for each sector or firm.

Regarding the assessment methods, there are two ways of estimating the magnitude and the direction of R&D spillovers reported in the literature. The first approach is based on case studies which "examine in detail all the costs and benefits, direct and indirect, present and future, related to a particular R&D project in a particular sector"[3]. Another approach – the one that is surveyed in this paper - is to estimate the impacts of R&D spillovers using econometric methods. The knowledge capital or spillover stock is entered as a separate regressor in addition to conventional inputs and own R&D stock into an extended Cobb-Douglas production function. Some of these studies have based their investigation by considering the dual approach which relates the impact of spillovers on production costs incurred by firms rather than on productivity gains (total factor productivity growth) as it is the case in the primal approach.

4. Macroeconomic evaluations

The existing quantitative analyses of the impact of foreign technology on domestic productivity growth consider that technology is either disembodied – i.e. pure knowledge spillovers - or embodied –i.e. rent-spillovers - in a particular channel of technology transfer. These studies yield sometimes unstable results, depending on the country and/or the transfer channel considered. Nevertheless, there is more evidence toward the recognition that international R&D spillovers contribute significantly to productivity growth. The main channels that have been used so far to measure the impact of international R&D spillovers on

[3] Mohnen (1996: p.41). The author cites four case studies in four different sectors: hybrid corn (Griliches, 1958), computers (Bresnahan, 1986), forest products (Seldon, 1987) and space programmes (Bach et al., 1992).

domestic productivity growth are presented in Table 1. These channels are international trade (at least 10 studies), foreign technology payments (5 studies) and disembodied R&D spillovers (the so-called vector approach, 5 studies).[4] In general, a majority of the two former types of studies tend to support the view that both international trade and technology payments are efficient channels of R&D spillovers whereas the five studies which do not take into account any particular channels provide evidence about significant spillovers between some pairs of countries. Among the three studies which construct an unweighted sum of foreign R&D and therefore implicitly assume that technology transfer are disembodied, two find significant spillover effects and one is inconclusive.

In the previous section we suggested that inward foreign direct investments are likely to be a substantial mode of international technology transfer. Yet, only two studies evaluate in some way the efficiency of this channel. Hanel (1994) approximates the foreign R&D pool of knowledge for 19 Canadian industries as being proportional to the share of sales accounted for by foreign subsidiaries, both in the intra- and extra-industry dimensions. Foreign R&D seems to contribute to Canadian productivity growth, but to a much lesser extent than domestic R&D. Again the significance of the estimates are fragile. Van Pottelsberghe and Lichtenberg (2001) provide the only study which formally takes into account foreign direct investments as a channel of international technological diffusion. With part of the data provided by Coe and Helpman (1995) the authors evaluate how foreign R&D capital stock contributes to the productivity growth of 13 other industrialized countries through imports, inward FDI and outward FDI. The econometric results support the view that significant R&D spillovers take place through both imports and outward FDI. The stock of foreign knowledge embodied into inward FDI has no significant effect in their study.

Patent data is also used in order to evaluate the extent to which technology leaks out of national boundaries, but is not considered as a particular channel. Rather, this kind of data allows either to compare the relative technological performance of countries (see Eaton and Kortum, 1995a, 1995b, 1999 in Table 1) or to evaluate bilateral technological proximities between firms or countries (see Branstetter, 2001, and Guellec and van Pottelsberghe, 2001a, 2001b). Sjöholm (1996), relying on Swedish patent citation data shows that international trade and geographical proximity intensify - or are strongly correlated with - the international diffusion of knowledge. Guellec and van Pottelsberghe (2001a) also obtain a significant contribution of foreign technology approximated through a patent proximity index. They further show that smaller countries benefit more from foreign R&D than larger ones. In addition, the countries with a higher domestic R&D intensity have a higher impact of foreign R&D, which shows that research activities allow to absorb foreign knowledge through an improved absorptive capability.

Mohnen (1996) suggests that the main reason why some studies often yield inconclusive or fragile results lies in the high collinearity between the various R&D intensity measures, combined with a low number of observations. This collinearity would arise because domestic and foreign R&D move in tandem; they are strategic complements or mutual inputs to each other. It is therefore difficult to dissociate their individual effects statistically. For instance, the studies by Coe and Helpman (1995) produce strongly significant output elasticities of foreign R&D thanks to the high numbers of observations and, consequently, to the large variations in the data.

[4] In this case, authors measure the impact of the R&D capital stock of country A on the productivity growth of country B. These studies rely on long time series and focus mainly on bilateral R&D spillovers between two or more countries, such as Japan and the US in Bernstein and Mohnen (1995).

Table 1.
The literature on international R&D spillovers[1]

Authors	Sample	Channels[2]			Disembodied		Disembodied - Patents			Geo
		Trade	FDI	FTP	Sum	Vect.	Data	Prox.	Citat.	Prox.
Soete and Patel (1985)	5 countries			(+)						
Deolalikar and Evenson (1988)	Indian sectors			+						
O'Sullivan and Röger (1991)	6 countries					+				
Mohnen and Lépine (1991)	Canada-sectors			+						
Mohnen (1992a)	Canada total manufacturing	+								
Mohnen and Gallant (1992)	5 countries			+						
Fecher (1992)	10 countries				(0)					
Mohnen (1992b)	5 countries				+					
Soete and Verspagen (1993)	Cross-country	0		0						
Park (1993)	10 countries				+					
Hanel (1994)	Canada, 19 sectors		(+)							
Eaton and Kortum (1995a)	19 OECD countries	+					+			+
Bernstein (1995)	11 sectors - US & Canada					+				
Bernstein and Yan (1995)	10 sectors -Canada-Japan					+				
Coe *et al.* (1995)	77 South countries	+								
Gittleman and Wolff (1995)	Cross-country	(0)								
Bernstein and Mohnen (1998)	US and Japan 11 industries					+				
Coe and Helpman (1995)	22 countries	+								
Badulescu (1996)	7 countries					+				
Sjöholm (1996)	Sweden, 261 references	+							+	+
Verspagen (1997)	22 sectors - 14 countries	+								
Vuory (1997)	Finnish sectors	(+)								
Sakurai *et al.* (1997)	33 sectors, 10 countries	(+)								
Lichtenberg and van Pottelsberghe (1998)	22 OECD countries	+								
Eaton and Kortum (1999)	5 countries						+			
Guellec and van Pottelsberghe (2001a)								+		
Van Pottelsberghe and Lichtenberg (2001)		+	+							

1. Adapted from van Pottelsberghe (1998, Chapter 6). FDI = foreign direct investments; FTP = foreign technology payments; the disembodied spillover studies either aggregate outside R&D (Sum) or use the vector approach (vect.), Prox. = proximity indicator; Geo-prox = distance between countries. Cf. Table A1 in the appendix for a more detailed summary of each study. 2. '+' indicates a positive impact of R&D spillovers on productivity growth; '0' indicates an insignificant impact, and '-' a negative impact; the parentheses indicate that the results are fragile, or unstable.

In short, the studies listed in Table 1 generally converge towards the recognition that foreign R&D contributes substantially to the productivity growth of industrialized economies. Table A1 in the appendix provides the main conclusions of each studies. Some frequent observations are that *(i)* the extent to which foreign R&D is propitious is higher in the smallest countries and in the countries with a high degree of openness regarding imports; *(ii)* the output elasticity of foreign R&D is often higher than the output elasticity of domestic R&D but the reverse is true when rates of return are computed; and *(iii)* the US is recognized as a substantial R&D spillover-generator but benefits only marginally from other countries' technological potentials. The R&D spillovers emanating from Japan seem to be weak, if not non-existant.

If these broad results are increasingly recognised as granted, some empirical issues still deserve to be tackled or at least deserve further empirical validation. Four of them are of particular importance: they are related to the weighting scheme, the absorptive capability, the size of the country, and to some specific channels.

- **The weighting scheme**

Coe and Helpman (CH)'s study (1995) has the advantage to deal with a large number of data which takes into account the sources and destination of R&D spillovers among 22 industrialized countries over the period 1971-1990. The authors evaluate the effects of trade-embodied R&D spillovers among industrialized countries. Their focus is therefore on the indirect benefits emanating from the import of goods and services that have been developed by trade partners. They compute the foreign R&D capital stock as the import-share-weighted average of the domestic R&D capital stocks of trade partners:

$$S_i^{fm-CH} = \sum_{j \neq i} \frac{M_{ij}}{M_{i\cdot}} \cdot R_j \quad , \tag{6}$$

where i *and* j = 1,.., 22 are country indexes; where M_{ij} is the flow of imports of goods and services of country i from country j; and $M_{i.}$ is the total imports of country i from its 21 trade partners: $M_{i.} = \Sigma_j \; M_{ij}$. This formulation implicitly assumes that a country will reap, *ceteris paribus*, more international R&D spillovers if it imports more from countries with a relatively high domestic R&D capital stock. However, as quoted by Coe and Helpman:

> " *The specification of (6) may not capture adequately the role of international trade. Although, the foreign stock of knowledge S^{fm-CH} consists of import weighted foreign R&D capital stocks, these weights are fractions that add up to one and therefore do not properly reflect the level of imports. It might be expected that whenever two countries have the same composition of imports and face the same composition of R&D capital stocks among trade partners, the country that imports more relative to its GDP may benefit more from foreign R&D.* ". [p. 863]

Lichtenberg and van Pottelsberghe (LP) (1998) have serious reservations about Coe and Helpman's weighting methodology. These reservations are driven by both the empirical results obtained by Keller (1996) and an intuitive deduction showing that the import-share weighting scheme is highly sensitive to a potential merger between countries. Keller (1996) shows that results qualitatively similar to Coe and Helpman (1995), and even quantitatively more important, are found in a systematic analyses where trade shares (or trade partners) are matched at random.[5] LP (1998) suggest that what really matters is the real R&D intensity embodied in the import flows of country *i*. In this case, the foreign R&D capital stock should be computed as in (2), the imports of country *i* from country *j* being naturally embodied with the R&D intensity of country *j*. This formulation reflects both the direction and the intensity of international R&D spillovers.

LP (1998) present the actual values of the foreign R&D capital stocks of the US and Japan in 1990, computed from Coe and Helpman data, with the two alternative methods, before and after a merger of eleven EC countries. The US (Japanese) foreign R&D capital stock computed with CH's method increases by more than 100% (25%) after the merger, whereas the LP variable decreases only marginally by 4% (2%). This confirms that the alternative methodology proposed by LP is much less sensitive to a potential merger between countries than the weighting scheme proposed by Coe and Helpman. Finally, LP find through non linear estimates that the GDP (y_{jt}) outperforms total imports ($m_{i.}$) as a denominator in the trade-related weighting scheme.

- **Absorptive capability**

The higher the knowledge-absorptive capability of a country, the more it should benefit from foreign R&D. It is clear that any firm intending to adopt or improve the knowledge generated by other firms or public institutions (be they domestic or foreign) will have to invest in 'imitative' or 'adaptive' research activities. This argument is forcefully stated by Geroski (1995) and has some empirical validation. For instance, the econometric studies of Cohen and Levinthal (1989) illustrate that a firm's own R&D activity enhances its absorptive capacity of R&D results generated by other firms. Furthermore, the survey results of Mansfield (1981) show that imitation costs on average are about 65 percent of the original innovation costs. Guellec and van Pottelsberghe (2001a) tested this hypothesis by interacting foreign R&D with business R&D intensity for each country. Their results show that the impact of domestic R&D intensity on the elasticity of foreign R&D is positive and significant: a country with business R&D intensity higher by 0.1% will have an elasticity higher by about 0.002. If firms from a country want to take fully advantage from international spillovers, they have to spend on R&D. It is clear that the absorptive capability of a country could be proxied by other indicators than the R&D intensity, such as the proportion of researchers, highly skilled professionals, or vocational training.

- **Size of countries**

Coe and Helpman (1995) provided evidence that larger countries (the G7) are associated with a larger output elasticity of domestic R&D. One might wonder whether this kind of distinction also occurs with respect to the impact of foreign R&D. The number of researchers is lower the smaller a country is. Hence the probability that the colleagues with whom you interact are located abroad is higher when you are from a small country. Guellec and van Pottelsberghe (2001a) test this "size effect" hypothesis by interacting foreign R&D with an indicator of size for each country and confirm that smaller countries do benefit more from foreign R&D than larger ones, although the effect is quite small. The results of Lichtenberg and van Pottelsberghe (2001) suggest that the effect of the size of a country on the impact of foreign

[5] Keller (1996) compares the estimation of Coe and Helpman with his own estimates obtained from assigning bilateral trade partners randomly. That is, rather than constructing the foreign knowledge stock variable using the observed bilateral trade share matrix, the author uses random trade shares matrices and re-does Coe and Helpman regressions. Within a Monte-Carlo analytical framework, Keller conducts 1000 similar experiments.

capital stock depends on the transmission mechanism considered. Contrary to the R&D embodied into imports, they find that the R&D embodied into outward FDI has a higher impact in larger countries.

- **Other channels of technology transfer**

Most of the weighting schemes that have been used so far concern trade flows and, to a lower extent, technology payments and foreign direct investment. Although other transmition mechanisms do exist (with substantial theoretical support), trade flows has been extensively used, probably thanks to data availability. The effectiveness of other channels of technology transfer still needs further empirical validation. For instance, how can we measure the impact of technology sourcing practices (e.g., through outward FDI, foreign R&D investments, international R&D joint ventures, international M&A). The role of people, and especially the analysis of international migrations of skilled technicians and scientists would certainly improve our understanding of international R&D spillovers. Finally, Guellec and van Pottelsberghe (2001b) illustrate the growing share of international co-inventions (patents invented by inventors from two different countries) and cross-border ownership (the applicant of a patent invented in a foreign country). Such type of patent data could be used to improve our understanding of how knowledge diffuses internationally and contributes to productivity growth.

Most of these transfer modes are inter-related and are generally closely associated with MNC's activities. This is obvious for inward FDI, R&D joint ventures, foreign R&D investments, and technology sourcing. Foreign technology payments and international trade are also two channels of technology transfer which are mostly governed by MNC's.

5. Microeconomic evaluations

Table 2 summarizes the findings of selected studies on the assessment of the impact of knowledge and rent spillovers on firms' productivity performance. It should be noted that as compared to the macro level, there are less studies reported in the literature that have estimated the impact of international spillovers at the firm level, in particular rent spillovers. The main reason rests in the difficulty of gathering harmonised and comparable information from different countries at the firm level[6]. Moreover, as explained in Section 3, the methods for the formalization of rent spillovers are based on intermediate inputs, investment goods or patent flows matrices, which typically are not available at the firm level. Then, the comparison of the findings reported in these studies has to be done cautiously since they largely differ as regards the composition of the sample of firms, the period investigated, the country or the econometric model estimated, in addition to the type of R&D spillovers examined.

Another important point that differentiates these studies is the proximity measure considered to measure the knowledge spillover pool. Among the studies reported in Table 2, two main approaches for modelling these proximities have to be distinguished. The first one attaches the same weight to the R&D of all other firms (Antonelli, 1994; Raut, 1995; Bernstein and Mohnen, 1998; Cincera, 1998 and Los and Verspagen, 2000), and the second one locates firms into a patent space (Jaffe, 1986, 1988, 1989; Branstetter, 2001 and Capron and Cincera

[6] Among others, differences in accounting practises, definition of variables or data availability can be mentioned.

1998, 2001) or a R&D space (Harhoff, 2000)[7]. The studies of Klette (1994) and Adams and Jaffe (1996) estimate the effects of knowledge spillovers at a sub-level which allow them to examine the issue of geographic localization. They measure the impact of parent firm R&D on plant-level productivity by decomposing the available pool of spillovers into a share that is close to the recipient firm (geographic local component) and a share that is far away (geographic external component). On this basis the relative contribution of each share on productivity growth is estimated. Bernstein and Mohnen (1998), Capron and Cincera (1998, 2001) and Brandstetter (2001) operate a similar distinction by decomposing the spillover pool into a national component and an international one. The international spillover stock is constructed by computing the weighted sum of R&D stocks on the basis of all firms located outside the country of the recipient firm[8].

As far as rent spillovers are concerned, Imbriani and Reganati (197) and the studies surveyed by Blomström and Kokko (1998) estimate the influence of inward FDI on productivity growth of firms in the host country. Among the other channels of technology diffusion at the micro level, Veugelers and Cassiman (2000) consider in addition to own R&D, the productivity impact of technology acquisition and R&D collaboration while Ke and Luger (1996) take into account the educational attainment as well as the working experience of the labor force as additional inputs. In Fecher (1990), the firm's spillover stock is constructed as a weighted sum of R&D performed by all industry sectors in the economy less the firm's own R&D. The weights are proportional to the input-output flows across industry sectors.

On the whole, the estimates associated with R&D spillovers are significant, positive and exceed the ones obtained for the own R&D stock. This is not astonishing since as emphasised by Mohnen (1996: p.51), "In a world of certainty and free disposal, R&D spillovers are expected to have beneficial effects, since it is reasonable to assume that firms do not adopt new ideas which reduce their profits. However, one can raise a number of arguments claiming that R&D can have detrimental effects on profit, productivity growth or welfare. For strategic reasons, firms may feel obliged to enter an R&D race without necessarily benefiting from it. R&D spillovers can increase or decrease the price that a producer can charge for his product, depending on whether the new product from outside R&D is substituable or complementary to the firm's own product. New products can displace old ones. This process of creative destruction can be harmful if innovators do not have time to recover their R&D investments. Firms may have to incur heavy adjustment costs to learn the new technologies. Finally, R&D can reduce welfare when firms use R&D as a strategic tool to raise entry barriers, or when firms are obliged to duplicate R&D to stay in the race."[9]

In Jaffe's opinion (1986: p. 984) too, "from a purely technological point of view, R&D spillovers constitute an unambiguous positive externality. Unfortunately, we can only observe various economic manifestations of the firm's R&D success. For this reason, the positive

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[7] Los and Verspagen (2000) also consider this kind of proximities in addition to the one which attaches no weights. However, the authors do not make use of technological distances between each pair of firms but instead between each pair of industries. They use a concordance table (Verspagen et al., 1994) which maps the 4 patent digit IPC codes into one or more of the 22 ISIC manufacturing industries into which they classified the firms in their sample.

[8] Besides separating the domestic and foreign components of the R&D spillovers stock, some studies have also made a distinction between the local and the external components of the spillover pool. For instance Jaffe (1986) explores the effect of spillovers generated by firms which carry out R&D activities within the same field of technological specialization than the recipient firm (technological local component).

[9] See Capron and Cincera (2001) for an attempt to estimate separately the knowledge positive and the rivalry negative impact of R&D spillovers.

technologically externality is potentially confounded with a negative effect of other's research due to competition". The author continues by stating that it is not possible with available data, to distinguish between these two effects but in his study, he finds evidence that both are present.

Regarding the international dimension of knowledge externalities, most studies are based on samples of firms operating in a single country, except in Bernstein and Mohnen (1998) and Brandstetter (2001) who analyze R&D spillovers between Japan and the USA, and Capron and Cincera (1998, 2001) who extent the analysis to the three pillars of the Triad. The results reported by these authors indicate that the impact of R&D spillovers on productivity growth differs according to the geographic area considered. In the United-States for instance, the national stock affects significantly the output but not the foreign stock. An opposite observation emerges for Japan, which appears to benefit from the foreign stock. Japan seems to depend to a large extent on technologies developed outside while American firms are mainly turned to their domestic technologies. Interestingly, Bernstein and Mohnen (1998) have also found that international spillovers exist from the USA to Japan, but not in the opposite direction. Branstetter (2001) too, reports some evidence that Japanese firms benefit positively from R&D undertaken by US firms while no effect of Japanese R&D on US firms' output growth is estimated[10]. As far as Europe is concerned, no consistent effect is obtained for this continent. Consequently, the receptivity of European firms to new technologies can be questioned. These empirical observations are, to a large extent, in accordance with the positioning often emphasized for the three geographical areas. As a technological leader, the United-States is principally concerned by its own technological development. On its side, Japan has demonstrated that it was highly successful in implementing technologies developed outside, particularly in the United-States. The weakness of European countries in fast growing technological fields, their higher specialization in slow growing or declining activities and a more defensive and/or passive behavior regarding R&D intensive activities induce a lesser sensitiveness to spillovers. Consequently, the lesser R&D intensity of European countries combined to a weaker propensity to internalize technological spillovers might jeopardize its long-term competitiveness. In spatial terms the studies of Klette (1994) and Adams and Jaffe (1996) suggest that the impact of the R&D performed in parent company's labs on its plants' productivity diminishes with both the geographic and technological distances.

Finally, regarding rent spillovers, the main results of micro studies that have analyzed the impact on productivity performance of embodied technology transfer give clue that, inward FDI, purchase of capital goods that embody new technologies, educational attainment of the work force, as well as R&D collaborations, enhance the productivity performance of firms.

[10] In this respect, the macro economic estimates of Lichtenberg and van Pottelsberghe suggest that Japanese R&D benefit other countries essentially through its export, but not through FDI from European or American countries.

Table 2.
Econometric studies assessing the impact of technological spillovers on firms' productivity performance

Authors	Weight / channels	Sample			Own R&D stock	R&D Spillover Stock		
		period	# of firms	geogr. area		nationl.	total	internatl.
Disembodied technology transfer (knowledge spillovers)								
Antonelli (1994)	*no weights*	84-85	92	Italy	0	0		
Raut (1995)	*no weights*	75-86	192	India	+	++		
Bernstein & Mohnen (1998)	*no weights*	62-86	11[a]	USA	++	+		0
	no weights			Japan	++	+		+
Cincera (1998)	*no weights*	87-94	625	World	+		++	
Los & Verspagen (2000)	*no weights*	74-93	485	USA	+	++		
Los & Verspagen (2000)	*time trends*	74-93	485	USA	+	+		
Cincera (1998)	*time trends*	87-94	625	World	+		+	
Jaffe (1986)	*techn. prox.*	72-77	434	USA	++	+		
Harhoff (2000)	*techn. prox.*		443	Germany	++	+		
Brandstetter (2001)	*techn. prox.*	83-89	209	USA		++		0
	techn. prox.		205	Japan		0		0
Capron & Cincera (2001)	*techn. prox.*	87-94	101	Europe	+	0		0
	techn. prox.		378	USA	+	++		0
	techn. prox.		133	Japan	+	0		++
Klette (1994)	*geogr. prox.*	89-90	804	Norway		0		+
Adams & Jaffe (1996)	*geogr. prox.*	74-88	19561	USA		++		+
B. Embodied technology transfer (rent spillovers)								
Fecher (1990)	*I/O matrice*	81-83	292	Belgium	+	++		0
Veugelers & Cassiman (2000)	*own r&d*	1992	494	Belgium	0			
	tech. Acquis.						0	
	tech. Acquis.				+		+	
	R&D collab.				0		0	
	Both				+		+	
Ke & Luger (1996)	*tech. Acquis.*	85-90	210	USA	+		++	
	educ. attain.				+		++	
	work exper.				+		0	
Imbriani & Reganati (1997)	*inward FDI*	1992	35[a]	Italy	+		++	
Blomström & Kokko (1998)	*inward FDI*					++		?

Source: Adapted and extended from Cincera (1998).
Notes : a) R&D intensive industries ; b) '+' indicates a positive impact of own R&D and R&D spillovers variables on productivity growth; '0' indicates an insignificant impact, and '-' a negative impact; '++' indicates a larger impact of the variable.

6. Open fields for further research

This survey of international R&D spillovers shows that the R&D implemented in any given country do contribute to the worldwide productivity growth, either through knowledge spillovers or through rent-spillovers. There is clearly a need for more empirical analyses at the microeconomic level and at the industry level. In addition, the very few existing micro or mesoeconomic studies do not tackle the services sector, which account for at least 70 percent of industrialised economies' GDP. More studies at these sub levels would allow to compare them with macroeconomic ones.

As regards the formalisation of R&D spillovers, several issues should be adressed in order to improve the measure of these effects. For instance, the assumed rate of obsolescence for computing the spillover stock should actually be much less than the corresponding one used for constructing the firm's own R&D capital to the extent that the public R&D stock, given its public nature, can be expected to depreciate less rapidly. The timing of spillover effect should also be considered. How much time does it take to foreign knowledge to contribute to generate new products or processes and translate into domestic productivity growth? Because of substantial lags in the diffusion of knowledge international spillover are not immediate. Yet, no study, to the best of our knowledge tries to evaluate this time lag[11]. This issue is further puzzling in the sense that it is closely related, from an empirical point of view, to the problem of disentangling competitive effects from rent and knowledge spillover effects. There has been no attempt so far to approximate the direct competitive effect of foreign R&D on domestic productivity growth[12]. In order to gauge the importance of international spillover effects, it may also be worth it to examine the factors improving the absorptive capabilities of foreign R&D such as education, training, mobility of the human capital or R&D collaborations

[11] In Cincera (1997), R&D spillovers take two years on average to affect firms' patenting while own R&D expenditures have a more immediate effect.
[12] See Capron and Cincera (2001) this issue.

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Table A1.
The literature on international R&D spillovers, main findings at the macro level[1]

Authors	Sample	Main results
1. Trade		
Mohnen (1992a)	Canada total manufacturing	Output elasticity of Foreign R&D is more important than for domestic R&D, but the rate of return to foreign R&D is 10 times lower than to domestic R&D.
Soete and Verspagen (1993)	Cross-country	No significant effect of foreign R&D or fragile estimates.
Coe and Helpman (1995)	22 countries	Output elasticity of Foreign R&D is more important than for domestic R&D in all countries but the G7. R&D spillovers in each country increase with the propensity to import.
Gittleman and Wolff (1995)	Cross-country	No significant effect of foreign R&D or fragile estimates.
Verspagen (1997)	22 sectors - 14 countries	The results underline the importance of international and domestic R&D spillovers for productivity growth.
Vuory (1997)	Finnish sectors	Foreign R&D through the import of capital goods more efficient during 1981-93. Then comes the domestic indirect R&D.
Sakurai *et al.* (1997)	33 sectors, 10 countries	Embodied R&D is an important source of TFP growth in services.
Lichtenberg and van Pottelsberghe (1998)	22 OECD countries	Significant R&D spillovers from 22 North countries, increasing with the level of trade. Weighting scheme different from Coe and Helpman (1995)
Van Pottelsberghe and Lichtenberg (2001)	13 OECD countries	Significant R&D spillovers embodied into trade flows. The impact of foreign R&D embodied into trade was smaller in the 80's than in the 70's.
2. Foreign direct investment		
Hanel (1994)	Canada, 19 sectors	Estimates are fragile, the significance increases with gestation lags. The return to Foreign R&D is much less important than the return on the industry's own R&D.
Van Pottelsberghe and Lichtenberg (2001)	13 OECD countries	Significant spillover effect on growth through outward FDI, especially in the 80's as compared to the 70's.
3. Foreign technology payments		
Soete and Patel (1985)	5 countries	Do not dissociate the separate effects of foreign technology payments and domestic R&D. They consider implicitely the two technology sources to be substitute.
Mohnen and Lépine (1991)	Canada-sectors	Complementarity relationship between own R&D and foreign technology payments.
Mohnen and Gallant (1992)	5 countries	Foreign technology payments capture part of the foreign R&D spillovers but have a weak impact on productivity growth as compared with foreign R&D.
Soete and Verspagen (1993)	Cross-country	No effects of foreign R&D or foreign technology payments on productivity growth.
4. Foreign patents		
Eaton and Kortum (1999)	5 countries	Calibration of a general equilibrium model; European countries derive most of their growth from foreign R&D whereas the US and Japan rely slightly more on their own research.
Eaton and Kortum (1995a)	19 OECD countries	The spillovers declines with the geographical distance, trade helps but not a lot, and a country's level of education plays a significant role in the ability to absorb foreign ideas.
5. Unweighted sum of foreign R&D		
Fecher (1992)	10 countries	No significant effect of foreign R&D or fragile estimates.
Mohnen (1992b)	5 countries	Own and foreign R&D are complementary, and foreign R&D is a big contributor to productivity growth, even in the US.
Park (1993)	10 countries	Foreign R&D is more important than domestic R&D and its effect is larger for the smaller countries and the more open economies. Foreign R&D less important if the US is excluded.
6. Vector approach		
O'Sullivan and Röger (1991)	6 countries	No spillovers to US; no spillover between Europe and Japan; Foreign R&D has a stronger effect than own R&D in Europe.
Bernstein and Mohnen (1998)	US and Japan 11 industries	Strong spillovers from US to Japan but no spillovers from Japan to US.
Bernstein (1995)	11 sectors - US & Canada	The productivity growth effects of foreign R&D are more important from the US to Canada than the other way round. (the results vary across industries)
Bernstein and Yan (1995)	10 sectors - Canada- Japan	Little international spillovers from Japan to Canada, but quite substantial ones in the other direction. (the results vary across industries)
Badulescu (1996)	7 countries	All countries benefit from outside R&D; only Japan and Norway are no significant R&D spillovers sources for the other countries.
7. Patent citations		
Sjöholm (1996)	Sweden, 261 references	Geographic proximity and international trade affect positively the inflow of knowledge to Sweden. Knowledge flows are approximated through patent references.
8. Patent proximity		
Guellec and van Pottelsberghe (2001)	16 OECD countries	Significant 'disembodied' international R&D spillovers. The impact of foreign R&D increases with domestic R&D intensity and with the size of countries.

1. Adapted from van Pottelsberghe (1998, Appendix to Chapter 6).

Table A2.
The literature on international R&D spillovers, main findings at the micro level[1]

Authors	Sample	Main results
Disembodied technology transfer (knowledge spillovers)		
No weights		
Antonelli (1994)	84-85, 92, IT	Technological spillover effects stemming from firms located in the same technological district strongly benefit to the recipient total factor productivity growth.
Raut (1995)	75-86, 192, IN	The aggregate industry level spillover R&D capital has a positive impact on firms' productivity growth.
Bernstein & Mohnen (1998)	62-86, 11[a], US+ JP	Evidence for important R&D spillover effects from the US to Japan is found but not in the opposite direction.
Cincera (1998)	87-94, 625, World	The sum of the firms' R&D expenditures has a positive impact on firms' productivity performance.
Los & Verspagen (2000)	74-93, 485, US	R&D spillovers have a positive and significant impact on productivity. This result does not significantly differ according to whether the total R&D spillovers stock is weighted or not.
Technological proximity		
Jaffe (1986)	72-77, 434, US	There is a positive relationship between own R&D, R&D spillovers and productivity. High-tech firms benefit more from the spillover effects.
Harhoff (2000)	443, DE	R&D spillovers affect positively R&D investment and enhance the productivity of firms in R&D intensive sectors, the higher the stcok of own R&D (absorptive capacity).
Brandstetter (2001)	83-89, 414, US+JP	Spillover effects apear to be more national than international in scope. Japanese firms do however to some extent benefit from the R&D of US firms.
Capron & Cincera (2001)	87-94, 625, World	The productivity growth of US firms is only affected by the R&D of US firms. Japanese firms seem to benefit from international spillovers while EU firms show some difficulties to internalize US and Japanese R&D spillovers.
Geographic proximity		
Klette (1994)	89-90, 804, NO	The productivity performance of a plant depends positively from the R&D of the other plants that belong to the same group and operate in the same or across different business lines. No effect is detected for the plants that are part of the same firm and operate in different business lines.
Adams & Jaffe (1996)	74-88, 19561, US	The effects of parent firm R&D on plant-level productivity are diminished by both the geographic and technological distance between the research lab and the plants and spillovers transmitted by technologically similar firms are significant but depend on R&D intensity more than total industry R&D.
B. Embodied technology transfer (Rent spillovers)		
Fecher (1990)	81-83, 292, BE	No significant effect of foreign R&D or fragile estimates.
Veugelers & Cassiman (2000)	1992, 494, BE	Important complementarities between several innovation activities, i.e. own R&D, R&D cooperation, external technology acquisition, are observed. The so-called "make and buy" strategy in combination (or not) with R&D cooperation appears to have the highest impact on productivity peformance.
Ke & Luger (1996)	85-90, 210, US	Increasing R&D investment and technology embodied in labor (educational attainment) and in capital stock (by replacing old equipment often) affect positively the production growth of firms in the computer-electronics sector while an opposite effect is observed for agglomeration economies.
Imbriani & Reganati (1997)	1992, 35[a], IT	Industry sectors whith a high share of MNC's are charaterized by higher firms' productivity levels.
Blomström & Kokko (1998)	Survey	Spillovers generated by MNC's increase with the level of local capability and competition in the host country. Diffrences are observed across countries and industry sectors. The impact on the home country is less obvious.

Notes : a) R&D intensive industries.