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Abstract:

This paper surveys what we know about international R&D spillovers, with a particular attention devoted to the business literature that link the R&D internationalization to economic performance. Despite the fact that there is a large literature on the internationalization of R&D at the country level, there are only few studies that examine the implications of international innovation and research activities at different levels of disaggregation. The few studies that exist emphasize the significance of international R&D and R&D offshoring in promoting economic performance. However, the existing literature comes finally with different conclusion as regards the relative importance of international spillovers and, the evidences presented so far with respect to R&D offshoring are still far from being conclusive.

Keywords: international R&D spillovers, R&D offshoring, economic performance

JEL classification: F01; O31; O32; O40

Introduction

The research of international R&D spillovers has witnessed an increasing attention at the beginning of the 90's with the development of new endogenous growth models. This new wave of macroeconomic growth models, known as R&D-based or innovation-driven growth models, have emphasize the determinant role of innovation as a major engine of technological advance and long-run productivity growth (Romer 1990, Grossman and Helpman 1991, Aghion and Howitt 1998). Particularly, these theories have emphasized the important role of commercially oriented innovation, technological differences and R&D spillovers in explaining country's productivity. In fact, in the modern economy, national economies become more and more integrated in the global system; there are interactions and interdependence across countries through international trade in the upstream and downstream markets, capital openness, foreign direct investment and the worldwide technology transfer and certainly, these aspects and relations have significant effects on the economic performance and growth of national economies. Accordingly, country's productivity depends not only on its R&D capital or accumulated knowledge stocks by also on external R&D effort in others economies. Indeed, own R&D effort guarantees more optimal exploitation of existing resources as well, strong R&D base enhances the ability to benefit from advanced technologies which increases the productivity level. On the other side, foreign or international R&D creates direct benefits that come from learning about technological novelty because of the international knowledge flows coming from different diffusion channels. Hence, international R&D spillovers play a crucial role in the explanation of productivity growth and mainly productivity convergence across countries (Coe and Helpman 1995, Coe et al. 1997, Lichtenberg and van Pottelsberghe de la Potterie 1998, Lopez-Pueyo et al.2008, …).

Despite the fact that the globalization of R&D and innovation is not entirely a recent phenomenon, there is still a continuous debate on the economic implications of the internationalization of innovation activities and the offshoring of R&D, particularly that the remarkable increasing trend of international R&D still raises several policy concerns and many questioning about the management of geographically dispread R&D activities. In fact, although international R&D spillovers allows the access to external knowledge and technology and generates growth opportunities, it could be also a source of the local core knowledge dissemination, so that it may threaten the competiveness and performance of the home country at the long-run.

In the literature of international spillovers, only few studies have been focusing on the impact of international R&D on productivity. Their particular area of interest is the interaction between economies with respect to international R&D spillovers and despite the considerable effort made in this setting to define a proper measurement of such spillovers, there still until now a need to a more adequate international R&D measure especially at a more disaggregate level. As a matter of fact, to our knowledge the majority of these studies are aggregate in their nature and usually they relate the economic productivity to both domestic and foreign R&D capital, considering in general international trade as a major channel of technological transfer. Therefore, in spite of the recent increase in the empirical work on the relationship between economic performance and international spillovers, our knowledge of the scope of these spillovers, its magnitude, its efficiency and the nature of the channels of transmission is still quite not enough.

The remainder of this paper looks at the measurement of international R&D spillovers. Then, we review the business literature with respect to R&D internationalization beginning with the theoretical studies on the geography of innovation and R&D offshoring. This is followed by a review of empirical studies that examine the relationship between international R&D and economic performance at different level of aggregation. The main findings are discussed in the concluding section.

I. International spillovers and R&D offshoring

In the past two decades, macroeconomic growth models have emphasize the determinant role of knowledge spillovers as they enhance innovation and productivity (Romer 1990, Grossman and Helpman 1991) and until the 90's, our knowledge as regards R&D and technological spillovers was limited to the theoretic models of endogenous growth and even the significance of international technology spillovers were rarely examined in the endogenous growth literature. Conceptually, Griliches (1979, 1992) define two types of R&D spillovers: rent and pure knowledge spillovers. The so-called rent spillovers take place when the price of input does not reflect the gain in productivity related to the derived innovative activities and it arise for example from the trade in intermediate goods while the pure knowledge spillovers is not incorporated into tradable goods. It is transferred without any previous intentions, which means that the owner is not able to control the use of such knowledge or to benefit from a direct payment following the exploitation of this knowledge by the recipient. The pure knowledge spillovers may result from informal know-how sharing, the departure of key scientists and researchers, products imitations or reverse engineering. From a theoretical point of view the distinction between the two types of knowledge spillovers seems quite apparent. However, coming to the empirical practices; it is not so evident to differentiate between these two dimensions of knowledge spillovers.

Several studies examine the empirical relevance of R&D spillovers in the context of open economies by introducing a measure of external R&D to a standard knowledge, cost, or production function framework (Hall, 2010). International R&D spillovers measure is defined as a weighted sum of the R&D stocks from external sources.

$$S_i = \sum_{j \neq i} w_j \; RD_j \qquad (1)$$

Where the w_j weights are used to capture some knowledge flows or technical proximity between the receivers of R&D spillover either it is a country, industry, firm and the source of R&D spillover. These weights reflect in some way the transmission channels of these spillovers. In this framework, Coe and Helpman (1995) was among the pioneering studies that has advance an explicit indicator of international R&D spillovers. They use cumulative R&D expenditure as a proxy of the stock of knowledge. International spillover is the sum of domestic capital stocks of the countries that are the source of spillovers or country's trading partners weighted by the import share of the partner in total country's imports. Thus, according to Coe and Helpman (1995) foreign R&D is presented as follow:

$$S(CH)^f{}_i = \sum_{j \neq i} \frac{m_{ij}}{m_{i.}} \; S_j^d \qquad (2)$$

With m_{ij} is the flow of imports goods and services from country i to country j, and $m_{i.} = \sum_j m_{ij}$, is the total imports of country i from its trade partners. According to this definition, the country takes more advantage from international R&D spillovers if it imports more from countries with a relatively high domestic R&D stock. Lichtenberg and Van Pottelsberghe de la Potterie (1998) argued that the weighting scheme proposed by Coe and Helpman is subject of "aggregate bias" since it is invariant to the degree of data aggregation thus, they define an alternative "less biased" weighting scheme of foreign R&D capital, in which the weighting factor is equal to the share of the home country's GDP that is imported from the partner country. Hence, the formulation of foreign R&D capital stocks as defined by Lichtenberg and Van Pottelsberghe de la Potterie (1998) is:

$$S(LP)_{it}^{f} = \sum_j \frac{m_{ijt} S_{jt}^{d}}{y_{jt}} \qquad (3)$$

Where y_{jt} is the country's j GDP, so that the stock of R&D that country i receive from country j is country j' s R&D stock times the fraction of country j' s output that is exported to country i.
The CH and LP weighting scheme were largely used in the literature international R&D spillovers to examine the significance of such spillovers at different level of aggregation.

Most of studies on international knowledge spillovers focus on trade-related spillovers, however there is another important knowledge diffusion channels as foreign direct investment (FDI) and inward FDI (Braconier and Sjöholm 1998, Hejazi and Safarian 1999, Xu and Wang 2000, Van Pottelsberghe de la Potterie and Lichtenberg 2001). The literature on FDI-related spillovers point out that inward FDI-related spillovers and especially R&D offshoring represent an important source of knowledge spillovers. R&D offshoring is defined as the location or transfer of R&D activities abroad. It can be done internally by moving services from a parent company to its foreign affiliates sometimes referred to as 'captive' or 'in-house' offshoring (UNCTAD, 2006). As a matter of fact, Multinationals enterprises (MNEs) and foreign affiliates have become the most important driver in the modern economy as they are able to exploit and transfer knowledge and technology across borders. In fact, since early 9o's, there was an increasing trend in foreign R&D and multinationals enterprises (MNEs) has began to locate R&D facilities aboard outside their home countries to tap into knowledge and technology sources in centres of scientific excellence in order to benefit from cost reducing and more technological spillovers (Dunning and Narula 1995, Kuemmerle 1999). According to the UNCTAD, MNEs account of the most R&D investment either in their home countries or in the host countries and referring to OECD statistics, MNE's expenditures in R&D are increasing especially outside the home country. Research activities have become more broadly located; while most R&D activities have been usually carried out at home, firms have begun to change their innovation and research strategies, through R&D offshoring and building global R&D and innovation networks.

II. Impact of R&D internationalization on Economic performance

1. Theoretical Models of international spillovers and R&D offshoring

The strategic decision of R&D location, the trade-off between centralized versus decentralized R&D and their implications for home country and host country have been quietly examined in the theoretical literature. Several theoretical studies have examined the effect of internal and external knowledge spillovers on R&D offshoring and the geography of innovation. Conceptually, they distinguish between internal and external spillovers; internal knowledge spillovers represent the intra-spillovers that may occur for example between firm's plants located in the home and host countries. Internal knowledge transfers are usually imperfect because of the cost of transfer and also the need to adopt the transferred know-how to local market condition and requirement and when the dissimilarities between the home and host counties are important, the cost of adaptation is larger and the efficiency of internal transfer is less important.

As regards external spillovers, according to agglomeration literature (Audretsch and Feldman 1996), knowledge dissemination requires geographical proximity thus external spillovers occur only with the presence of R&D activities in the same location. So, in case of R&D decentralization, there are two-way external spillovers: Incoming external spillovers with the possibility to source local know-how and outgoing external spillovers. The extent to which external spillovers are integrated in the own knowledge base depends on the absorption capacity of the receiver, which depend in its turn on the own R&D resources: Indeed, the stronger is the R&D base of the host country, the more important is the cost of outgoing external spillover (Gersbach and Schmutzler 1999, Sanna-Randaccio and Veugelers 2007).

Gersbach and Schmutzler (1999) argued that agglomeration and R&D delocalization is worthwhile under sufficient level of internal and external spillovers efficiency in such way it is possible to sense external know-how and adopt the knowledge acquired outside internally inside the home country. As a matter of fact, R&D offshoring is an important channel to source out locally available know-how however it requires at the same time an optimal organization of the knowledge flows to avoid the spelling of core know-how outside the home country (Sanna-Randaccio and Veugelers, 2007).

Although R&D offshoring generates several benefits, it has also potential costs especially via the outgoing external spillovers. In fact, as there are incoming external spillovers due the geographical proximity between the subsidiary and the local firm there is also outgoing external spillovers. Such dissemination of know-how has a negative impact and this negative effect sort via the market competition. The importance of this negative effect depends on the intensity of competition in the host market as well as the local know-how base. Therefore, Sanna-Randaccio and Veugelers (2007) and Belderbos et al. (2008) highlight the importance of the management and organization of the internal knowledge transfer to limit the costs of decentralized R&D and benefit from an optimal location-specific knowledge and to avoid the spilling of core innovation. Therefore, there are complementarities between an efficient management of internal and external knowledge and the competition in the host market (Belderbos et al. 2008).

Gersbach and Schmutzler (2011) examine also the relation between foreign direct investment (FDI) and R&D offshoring and found that FDI liberalization could lead to R&D relocation under certain conditions. R&D offshoring may occur only with the presence of well developed internal communication, fairly significant external spillovers and with sufficiently weak market competition. According to the authors, R&D relocation becomes an important motivation of FDI. In fact, FDI has a dual role, besides the easier access to foreign market; technology sourcing is as well a major incentive of the offshoring of R&D and innovation activities. These findings emphasize once again the importance of the efficiency of internal and external knowledge transfer in order to optimize the benefits of technology sourcing.

Qu et al. (2013) are among the few studies that analyze the implications of R&D offshoring in the context of emerging markets, and from the host country perspective. They study the strategic interaction in the decision of R&D between foreign affiliates and domestics firms. Qu et al. (2013) develop a game- theoretic model that study foreign and domestic R&D investment in a two-stage non-cooperative game. They found a kind of a trade-offs between cost reduction due to its own R&D effort and the cost reduction due to external spillovers. This trade-off depends on the degree of the ease learning from foreign affiliate; when the learning capacity is important, it is more interesting to exploit external spillovers rather than investing on its own R&D. However, when the ease of learning is not sufficiently important, the optimal strategy become to rely on its own R&D resources since R&D external spillovers does not generate satisfactory productivity gains. R&D offshoring has a positive impact on own R&D investment in the host country only in the presence of sufficiently important learning capacity. However, with difficult learning process, the effect of R&D offshoring becomes negative.

Theoretical studies of the impact of R&D-related FDI and R&D offshoring reaches ambiguous conclusion on the implications of international R&D in the home and host countries.

2. Empirical studies on the implications of R&D internationalization

A number of empirical studies have been carried out in order to analyze the relationship between economic performance and the internationalization of R&D activities using different methods and databases. These studies may fall into two major categories according to the scope of analysis: The first grouping assesses this relation at a macroeconomic level (country / region) and usually the TFP of a country is a function of domestic and foreign R&D capital. The second group examines the productivity effect of international R&D at a more disaggregate level (sector / technological field). Each of these categories provides different insight on the impacts of R&D internationalization at different level of aggregation.

a. Aggregates Studies

Empirical studies on the relationship between international R&D spillovers and economic performance have begun with in the mid 90's with the seminal work of Coe and Helpman (1995). Within the context of innovation-driven growth models and international R&D spillovers, several researchers have carried out studies at country level to test empirically the significance of international spillovers. In this strand of literature, international spillovers affect country's productivity through three principal channels: international trade, inward FDI and outward FDI.

The first wave of studies at the country level propose an empirical framework to test the effect of international R&D spillovers considering trade, particularly imports of intermediate goods, as a major channel of technology transfer in line with the then-new endogenous growth models. In fact, according to this strand of literature the extent and importance of international spillovers may depends on the economic relations between countries, such as the volume of their bilateral trade (Coe and Helpman 1995, Coe et al. 1997, Engelbrecht 1997, Lichtenberg and Van Pottelsberghe de la Potterie 1998, Bayoumi et al.1999, Crespo et al. 2004, Coe et al. 2009). Generally, two alternative weighting schemes that were originally proposed to measure trade-related spillovers (Coe and Helpman 1995, Lichtenberg and Van Pottelsberghe de la Potterie 1998).

Starting from a standard production function, the studies mentioned above examine to what extent the total factor productivity level of a country depend on its own R&D and also on foreign R&D effort. They extend the basic relation between total factor productivity and R&D capital by introducing the foreign R&D capital stocks in the production function. Foreign R&D capital stock is introduced to capture the influence of trade-related international R&D spillovers. As we discussed above, international R&D spillovers is defined as a weighted sum of the R&D capital stocks of the other countries, by applying the bilateral imports weights share as a weighting scheme to measure the technological proximity between the sender and the receiver.

Using data on 22 OECD countries during the period between 197 and 1990, Coe and Helpman (1995) found interesting results confirming the fact that not only domestic R&D affects country's total factor productivity, but also foreign R&D capital has a positive effect on domestic productivity and this effect become stronger the more the economy is open to international trade. In addition, the results show that the effect of foreign R&D varies across countries and over time: On the one hand, the elasticity of TFP with respect to foreign R&D capital stocks had witnessed further increase during the 80's for the majority of OECD countries. On the other hand, the effect of domestic R&D capital is more important than the foreign capital R&D effect on TFP for large countries while in most small countries, the elasticity with respect to international R&D spillovers is larger always compared to domestic R&D stocks. Using previous estimations of international R&D spillovers (Coe and Helpman 1995, Coe et al. 1997), Bayoumi et al. (1999) found that even countries with limited domestic R&D stock can enhance their productivity via international trade with others countries partners that have large stock of cumulative R&D and important knowledge bases. Hence, the authors suggest that the gains of outputs spillovers depend on trade linkages between countries and the openness of the economy. Lichtenberg and Van Pottelsberghe de la Potterie (1998) and Coe et al. (2009) confirm as well these findings and suggest that countries that are more open to international trade take more advantages form the productivity effect of international R&D spillovers using alternative measure of international spillovers[1].

Despite the significant of international R&D, Engelbrecht (1997) found that human capital resources decreases the estimate coefficient of international R&D spillovers which emphasizes the dual role of human capital for domestic innovation and TFP catch-up process. In fact, the idea behind the introduction of human resources variable along with R&D variable in an extending version of Coe and Helpman (1995) model is to capture the effect of others type of innovation like "learning by doing" and aside with the effect of innovation through formal R&D. Crespo et al. (2004) examine also the significance of international R&D considering both dimension of knowledge "rival" and "nonrival"[2]. Crespo et al. (2004) present a model[3] in which the productivity growth is explained by a proxy of technical knowledge (R&D and human capital), international R&D spillovers measured used Lichtenberg and Pottelsberghe (1998) weighting scheme as well as the traditional production factor the stock of physical capital and employment. The estimation results emphasize the significant role of the stock of knowledge along with international spillovers in boosting up economic growth in the OECD countries. However, the effect of international spillovers or foreign R&D is much less important than the effect of own technological knowledge stock[4]. Furthermore, the authors found high correlation between the import shares and the effect of international spillovers on growth which means that the influence of international spillovers increases with the R&D potential of trading partners. Still, the capacity of the country to benefit of the foreign spillovers depends on both its human and R&D capital endowments.

Most of aggregate studies on international R&D have been influenced by the seminal work of Coe and Helpman (1995) that consider trade as a main channel of knowledge transfer between countries. Hence, these studies focus always on trade-related R&D spillovers and there is a less extensive literature that examines others potential channels of international spillovers as foreign direct investment and R&D offshoring. Castellani and Pieri (2013) is among the recent studies in this strand of literature that focuses on the relationship between R&D offshoring and productivity. This paper investigates to what extent R&D offshoring activities of domestic multinational affect the home

[1] Coe et al. (2009) use three alternative measure of international R&D spillovers: The first one is based on Coe and Helpman (1995) definition of foreign R&D capital, the second referring to the weighting scheme proposed by Lichtenberg and van Pottelsberghe de la Potterie (1998) and a simple average of trading partners' domestic R&D capital.

[2] Crespo et al. (2004) gather human capital and R&D stock in a single variable (T), according to a linear combination, to represent the stock of technological knowledge. This combination is determined using the procedure of principal components.

[3] Crespo et al. (2004) study concerns 28 OECD countries between 1988 and 1998 and they the instrumental variables approach to cope with the problem of simultaneity between the growth of output and R&D investment.

[4] Crespo et al. (2004) found that the elasticity of stock of technological knowledge with respect to the output level is 3.46% while the international spillovers have an elasticity of only 0.33%.

regions performance. It examines both inward and outward international activity referring to the fDi Markets[5] database that covers Greenfield investment in all sectors and countries worldwide. The offshoring activity is approximate using the number of outward investment projects from each region referring to the NUTS2 level[6] of European region classification. The authors focus on R&D international projects and consider manufacturing activity as a benchmark for comparison purpose.

Castellani et al. (2013) argued that offshoring activities of domestic multinational contribute to higher productivity growth in the home region, yet this positive effect "fades" with the level of investment project carried outside the home country. However, these decreasing returns of offshoring business activities do not seem to occur in case of R&D offshoring; there is no an inverted-U relation between outward R&D investment and productivity growth. In fact, the results shows that R&D offshoring affects positively the home region productivity growth and this is independently from the destination of the R&D investment, whether the host country is an advanced country within Europe or if it is an emerging country outside the European region. Besides that, the authors put forward that the positive effect of outward R&D investment is stronger when the multinational chooses South East Asian countries as a host destination for Greenfield projects of R&D.

The main differences between these different studies as regards the measurement of R&D spillovers, methodologies and results are highlighted in the ***Table 1*** below.

Table1: Overview of empirical studies on the impact of international R&D spillovers on economic productivity: Aggregate-level analysis

Authors	***Sample***	***Model***	***International R&D***	***Main Results***
Coe et Helpman (1995)	21 OECD countries plus Israel (1971-1990) International sources (OECD's main science and technology indicators , OECD Analytical Data Base, For bilateral imports share IMFs *Direction of trade*	Production function in which total factor productivity (TFP) of a country is a function of domestic and foreign R&D capital stocks. **Cointegration equation method**	***CH weighting scheme*** $S^{f-CH}{}_i = \sum_{j \neq i} \frac{m_{ij}}{m_{i.}} S^d_j$	A positive effect of foreign R&D on domestic productivity. The positive effect of international spillovers becomes stronger the more the economy is open to international trade. For small countries, the effect of foreign R&D capital is more important than the effect of domestic R&D.
Lichtenberg and van Pottelsberghe de la Potterie (1998)	21 OECD countries plus Israel (1971-1990) Bilateral imports flows United Nations *International* trade *Statistics* yearbooks	Total factor productivity is explained according to domestic R&D stock and international spillovers	***LP weighting scheme*** $S^{f-LP}_{it} = \sum_j \frac{m_{ijt} S^d_{jt}}{y_{jt}}$	Countries that are more open to international trade take more advantages form the productivity effect of foreign R&D

[5] The fDi Markets database is provided fDi intelligence which is a specialist division of The Financial Times Ltd. From the fDi Markets, the authors had access to 60,301 Greenfield investment in the period between 2003 and 2006. However, fDi Markets database do not collect only realized projects but also planned future Greenfield. Therefore, the authors choose to drop the last two years of data since some future projects could be realized differently.

[6] The authors refer to the Nomenclature of Units for Territorial Statistics (NUTS) that indicates hierarchical classification of administrative areas of the European statistical office (Eurostat). NUTS levels are from 1 to 3 and indicate different degrees of aggregation.

Engelbrecht (1997)	21 OECD countries (1971-1985)	TFP is explained with respect to domestic R&D capital, , the interactive between foreign R&D capital stock and the import share in GDP and the domestic stock of human capital	**CH weighting scheme**	The introduction of human capital factor decreases the effect of the international R&D spillovers. The author emphasizes the double role of human capital for domestic innovation and TFP catch-TFP catch-up process.
Bayoumi et al. (1999)	Individual model of each G-7country ,Aggregate model of others industrial countries , Regional models for developing countries	TFP is a function of the stock of R&D capital, international R&D spillovers, and trade.	**CH weighting scheme**	The productivity effect of international spillovers depends on trade linkages between countries and the openness of the economy.
Crespo et al.(2004)	28 OECD countries 1988-1998 International data sources (OECD, Eurostat)	Productivity growth is explained by a proxy of technical knowledge (R&D and human capital), international technology spillovers **Instrumental variable approach**	**LP weighting scheme**	Significant role of the stock of knowledge along with international spillovers countries. The effect of international spillovers is much less important than the effect of own technological knowledge stock. High correlation between the import shares and the effect of international spillovers on growth.
Coe et al.(2009)	24 OECD countries (1971-2004) International sources (OECD's main science and technology indicators , OECD Analytical Data Base, For bilateral imports share IMFs *Direction of trade*	Extended model of Coe and Helpman (1995) with the introduction of institutional variables	**CH weighting scheme** **LP weighting scheme** **Simple average of trading partner's domestic R&D capital**	Significant effect of international R&D spillovers even with the introduction of alterative weighting scheme
Castellani and Pieri (2013)	262 European region (NUTS 2), 2003-2006 *fDi Markets* database	OLS estimation using the pooled cross-section data on cross section data on one-year growth	**The number of outward R&D project (Outward Greenfield investment in R&D)**	R&D offshoring leads significantly to higher productivity growth rates. This positive effect of R&D offshoring is independently from the destination of the R&D investment.

b. Disaggregate-level Studies

Empirical literature on the productivity impact of international R&D spillovers at the sectoral level is still in its infancy and despite there are several studies that examined the impact of R&D offshoring at the aggregate or national level, evidence at the sectoral level is still scare and inconclusive. As a matter of fact, despite that the importance of international R&D spillovers has been long recognized, the large part of empirical studies on the productivity effect of international spillovers are mainly aggregate in nature and to our knowledge, only few studies had examine their empirical significance at a more disaggregate level. Even so, most of these studies refer to the empirical framework that was originally initiated to scrutinize the existence of international R&D spillovers, in other words R&D and knowledge flows originating from one country and benefiting other countries through international trade (Coe and Helpman 1995, Coe et al. 1997). However, the main contribution of this strand of literature is the analyses of data at a more disaggregate level rather country-level data which allow considering the sector technical specificity especially that R&D investment are not uniformly distributed across all sectors. The studies examining the significance of international spillovers at the sectoral level consider the sector-country as a unit of observations (Verspagen 1997, Frantzen 2002, Jacobs et al. 2002, Keller 2002, etc) and their approach consist on introducing foreign R&D as an additional input to the usual production factors. In such a manner, the productivity of the domestic sector depend on its sector's own R&D effort but also on knowledge spillovers either from others domestics sectors or R&D carried aboard in foreign countries.

Different weighting scheme was used to measure international knowledge spillovers between sectors. Verspagen (1997) introduces the two-type of the so-called technology flow matrices. The first one is the "Yale matrix" that was originally developed by Putnam an Evenson (1994) and it is used in this paper to capture "rent-spillovers" associated with the trade of improved intermediate goods and improved products. As regard the pure knowledge spillovers, Verspagen (1997) refer to the EPO data. The technology flow matrices represent the patent flows from the industries that generate the knowledge and the spillover-receiving sector. The introduction of these two knowledge flows matrices along with the imports share weights is applied to provide a more complete insight on knowledge flows between sectors. In fact, the imports shares are introduced to capture the international distribution of trade-related spillovers while the knowledge flow matrix aim to capture the inter-sectoral spillovers. Frantzen (2002) adopt practically the same weighting scheme to measure the technological proximity by referring to the share of domestic outputs over the sectoral domestic markets, the share of imports over the sectoral domestic markets, bilateral sectoral imports as well as the share of patented inventions spilling over between sectors[7]. Keller (2002) suggests two alternative assumptions regarding the knowledge flows between industries; the first based on the input-output structure of the industry and the technology flow matrix based on information from patents and represents the flows of patented knowledge from an industry to another. Technology flow matrix reflects the importance of the industry's different source of knowledge. Along with bilateral trade, Jacobs et al. (2002) [8] and Lopez-Pueyo et al. (2008) combine the input-output tables with the share of sectoral bilateral trade to create foreign R&D stocks. On the one hand, Lopez-Pueyo et al. (2008) adopt this weighting scheme to measure international inter-sectoral spillovers and they refer to the imported intermediate goods flows sub-matrix of the input–output tables[9]. On the other hand, they refer to the two alternative weighting scheme initially proposed by Lichtenberg and van Pottelsberghe de la Potterie (1998) and Coe and Helpman (1995) to measure international intra-sectoral spillovers. In such manner, international intra-sectoral spillovers that a given domestic sector receive from the foreign same sector is the foreign country's R&D stock in the sector times the fraction of the country's sector's output exported to the home country of the domestic sector[10].

[7] Frantzen (2002) introduce the share of patented inventions made in a specific sector spilling over to another sector referring to the patent-based technology flow matrix. The weights are the same for all countries and they are provided by the Merit Centre of the University of Maastricht.

[8] The input-output tables were derived from the CPB Netherlands Bureau for Economic Policy Analysis and the share of bilateral trade refer to the STAN Bilateral trade database of the OECD.

[9] The international inter-sectoral spillovers as measured as follow $R_{ijt}^{of} = \sum_{k \neq i} \overline{(M_j / Y_j)} \gamma_{ki} R_{kjt}^{sf}$, the weighting γ_{ki} represent the imports of country *j* of inputs from sector *k* and directed to sector *i*.

[10] Lopez-Pueyo et al. (2008) present two alterative measure of intra-sectoral spillovers , the first is presented as follow $R_{ijt}^{sfLP} = \sum_{h \neq j} M_{iht} R_{iht}^{sd} \frac{1}{Y_{iht}}$ the index LP refer to the earlier paper of Lichtenberg and van Pottelsberghe de la Potterie (1998). The second measure is $\left(\frac{\overline{M}_j}{Y_j}\right) R_{ijt}^{sfCH} = \left(\frac{\overline{M}_j}{Y_j}\right) \sum_{h \neq j} m_{iht} R_{iht}^{sd}$ which represent the interaction between the foreign R&D stock presented by Coe and Helpman (1995) and the average rates of the economy openness.

Overall, the results presented in these studies come in line with the aggregate literature on international spillovers and confirm the significance of international R&D in enhancing sectoral productivity despite the dominance of domestic knowledge sources. Furthermore, Jacobs et al. (2002) shows that foreign R&D may affect indirectly the sector performance by improving the absorptive capacity and ensuring a better exploitation of foreign R&D effort. However, empirical evidence suggests that the impact of foreign R&D is not very straightforward since it varies considerably between countries and sectors. Furthermore, the significance of international spillovers depends on the dimension of knowledge spillovers that is used as well on transmission channels in question. As a matter of fact, based on a distinction between rent and pure knowledge spillovers, Verspagen (1997) found that domestic rent spillovers are more important than foreign spillovers in high-tech industries while foreign pure knowledge spillovers are more significant than domestic one in low-tech sectors. For medium-tech sectors, the elasticities associated to domestic and foreign spillovers are almost equal regardless the type of spillovers. In addition, the contribution of outside-industry and foreign R&D depends on the technological intensity of the sector. While Frantzen (2002) suggest that the effect of foreign R&D is greater for R&D-intensive sectors since such industries are more capable to benefit from international knowledge spillovers compared to less R&D-intensive industries, Keller (2002) argued that sectors that do not conduct much R&D benefit more from international R&D spillovers.

Both international intra-sectoral and inter-sectoral spillovers seem to contribute to sectoral productivity. However, Frantzen (2002) highlight that the effects of inter-sectoral spillovers exceeds those of intra-sectoral spillovers. Lopez-Pueyo et al. (2008) found that the combined intra-sectoral and inter-sectoral international R&D spillovers, associated with the trade pattern effect and the level of the openness of the sector have a greater effect on sector's performance. Indeed, the magnitude of these both effects is heterogeneous among industries depending on the technological sophistication and the openness to trade of the sector. In others words, sectors that are more open to imports and trade with advanced technologically sectors receive more international knowledge spillovers and benefit from more important productivity effect.

As we mentioned above, only few studies on international spillovers that concentrate on knowledge transfer between sectors and take into account the sectoral heterogeneity of these spillovers, and in spite of the new evidence on the relationship between sector's productivity and international R&D these findings are far from being conclusive and there is still no clear pattern that explain the relative significance of international spillovers among sectors. In this framework, Malerba et al. (2013) present a unified framework to compare four types of R&D spillovers: national versus international and intrasectoral versus intersectoral knowledge spillovers. This time, the authors refer to a multi-country data of 135 technological fields or products grouping in three different manufacturing sectors (chemicals, electronics and machinery) to measure and differentiate the effects related to different types of R&D spillovers referring to a set of assumption derived the existing literature on international R&D spillovers. Malerba et al.(2013) suppose that the ranking of different types of spillovers (intra-national vs. international and intrasectoral vs. intersectoral) vary considerably across industries depending on the own knowledge base and the level of sector's internationalization: sectors having a more globalized dimension may benefit from more international spillovers while sectors that have more important vertical linkages with local downstream industries intersectoral take more advantage from intersectoral knowledge flows nationally rather internationally.

To trace knowledge flows within the technological field, Malerba et al. (2013) define international spillovers as the R&D stocks of foreign technological fields weighted by the relative number of patent citations[11], over the whole sample period, from patents held by domestic firms and classified into the given technological fields to patents held by firms in the foreign country and classified into foreign technological field, with a distinction between intrasectoral and intersectoral international spillovers.

The results show that along with national spillovers, international spillovers are important drivers of innovation[12]. In addition, Malerba et al. (2013) found a positive and significant elasticity of the stocks of created knowledge with respect the international intrasectoral spillovers as well its effect is also more important than the elasticity of the stocks of knowledge to own R&D capital. In contrast with previous results underlined previous in a similar setting, Malerba et al. (2013) highlight a much larger effect of international intrasectoral knowledge spillovers compared to national intrasectoral sources of knowledge. These divergent results could be explained by the use of different level of aggregation. On the other hand, the estimations results reveal that the effect of national intersectoral spillovers is larger than the effect of the intersectoral component of international spillovers. Malerba et al. (2013) argued that there a kind of complementarity between the proximity in the technological distance and the proximity in the geographical distance. Indeed, according to the authors spillovers within the same technological fields are managed to reach an international scope while intersectoral spillovers are mainly enhanced by geographical proximity. In fact, being in the same technological field facilitate the absorption of external spillovers if it is from a foreign sources while the absorption of knowledge generated by others technological field require at least a geographical proximity to overcome difference in technical and scientific specificity.

In summary, the main findings of these studies are presented in ***Table 2***, with a review of the different weighting scheme presented in these studies.

Table 2: Overview of empirical studies on the impact of international R&D spillovers on economic productivity: Sectoral level studies

Authors	***Sample***	***Methodology***	***International R&D***	***Main Results***
Verspagen (1997)	Unbalanced panel of 22 sectors in 14 OECD countries (1974-1992) *Data sources:* OECD STAN ANBERD databases BITRA databases	Ordinary least square (OLS) WITHIN / BETWEEN estimators	Foreign R&D stocks (R&D expenditure of foreign sectors) *Weighting scheme:* Bilateral import share Knowledge flows matrix: “Yale matrix” and EPO data (patent flow)	The significance of international R&D in enhancing sectoral productivity in OECD countries. The impact of foreign indirect R&D varies considerably between sectors and depends on the dimension of knowledge spillovers (rent /pure spillovers).

[11] Patents application data are derived from the European Patent Office (EPO) from six OECD countries (France, Germany, Italy, Japan, the UK and the US) during the period between 1980 and 2000. For R&D data, the authors refer to the OECD-ANBERD R&D data of manufacturing ISIC classes.

[12] Malerba et al. (2013) examine the long-run relationship between the stocks of cumulated knowledge, R&D resources, national and international spillovers, Malerba et al. (2013) adopt the cointegration approach and estimate the model using dynamic ordinary least square technique.

Frantzen (2002)	Panel of 22 manufacturing sectors in 14 OECD countries (1972-1994) *Data sources:* OECD STAN Databases OECD Business Sector Database OECD Science and Technology Database OECD ANBERD Database	Cointegration approach Ordinary least square (OLS) Dynamic ordinary least square (DOLS)	Foreign R&D stocks: intra-sectoral spillovers + inter-sectoral spillovers *Weighting scheme:* Patent-based technology flow matrix (the Merit Center from EPO) Bilateral sector imports Share of domestic output and of imports over the sectoral domestic markets.	The importance of both inter-sectoral and intra-sectoral spillovers with the presence of an economy scale effect. The effect of inter sectoral spillovers exceeds the impact of intra-sectoral spillovers. The effect of foreign R&D capital is greater in R&D-intensive sectors.
Jacobs et al.(2002)	Panel of 11 business sector (manufacturing and services) (1973-1992) *Data sources*: Statistics Netherlands CBS OECD ANBERD Database STAN Bilateral Trade Database	Cointegration approach Two-way fixed effects estimations	Foreign sector's R&D stocks *Weighting scheme:* Input-output tables Bilateral trade share	The Dutch business sectors are taking advantage from R&D conducted at home and aboard. Foreign R&D affects indirectly sectoral productivity by improving the absorptive capacity of domestic sectors.
Keller (2002)	Panel of two- to three-digit manufacturing industries in 8 OECD countries (1970-1991) *Data sources:* OECD business enterprises R&D Database	OLS methods	Foreign R&D stocks (foreign same sectors and others sectors) *Weighting scheme*: Input -output specification Technology flows matrix	Foreign R&D spillovers remain significant despite the dominance of domestic knowledge sources. The contribution of outside-industry R&D and foreign R&D depends on the technological intensity of the sector.
Lopez-Pueyo et al.(2008)	Panel of 10 manufacturing sectors in 6 OECD countries (1979-2000) *Data sources:* OECD ANBERD Database Input-Output Tables	Cointegration approach Ordinary least square (OLS) Dynamic ordinary least square (DOLS)	International spillovers *Weighting scheme:* LP and CH weighting scheme (Intra-sectoral spillovers) Imports share / Input-output tables (Inter-sectoral spillovers)	Significant effect of international intra-sectoral and inter-sectoral R&D spillovers. Sectors that are more open to trade receive more international knowledge spillovers and benefit from more important productivity effect. The magnitude of the productivity effect is heterogeneous among industries, depending on the technological sophistication and the level of openness to trade of the sector.

Malerba et al. (2013)	Multi-country panel of 135 technological fields (in chemicals, electronics and machinery) in 6OECD countries (1980 and 2000). *Data sources:* the European Patent Office (EPO) OECD-ANBERD R&D data	Cointegration approach Dynamic ordinary least square methods	Intra-sectoral and inter-sectoral international spillovers (R&D stocks of foreign technological fields) *Weighting scheme*: Number of patent citations.	International spillovers are important drivers of innovation. The effect of international intra-sectoral knowledge spillovers is larger than the effect of national intra-sectoral sources of knowledge since intra-sectoral spillovers are less affected by geographical proximity. The effect of national inter-sectoral spillovers is larger than the effect of the inter-sectoral component of international spillovers. The relative importance of national versus international spillovers varies considerably across sectors.

Conclusion:

Through this paper, we shed the light on the different approach adopted in the literature to address the thematic of international R&D spillovers in order to build a unified framework and to move one step forward in this direction. Although there is a large literature on the internationalization of R&D and innovation activities, there are relatively few studies that examine the relationship between economic performance and international R&D spillovers. These studies has adopted in general a common practice by constructing a stock measure of international R&D spillovers using foreign R&D expenditure to capture the cumulative notion of knowledge, and then relating this measure to productivity performance of the country, sector or technological field. Different measure of international spillovers, weighting scheme and approaches have been proposed to capture the effect of national vs. international R&D as well as intrasectoral and intersectoral knowledge spillovers. The weighting scheme proposed in the aggregate studies has known a great prevalence even in the disaggregate studies. However, the weighting scheme was mainly designed to capture mainly trade-related R&D spillovers, so it disregards other potential channels of international knowledge diffusion.

As we discussed in the preceding sections, the existing literature come finally with different conclusion and the evidences on the productivity effect of international spillovers still so far from being conclusive. On the one hand, empirical evidence shows that national spillovers are stronger than international knowledge spillovers. As a matter of fact, knowledge diffusion is constrained by geographical distance and culture barriers across countries in such way knowledge transfer is always associated with communication and learning costs especially the tacit nature of the transferred knowledge. On the other hand, several papers highlight the presence of different transmission channels such as international trade, FDI or even labour mobility that may reduce communication and transport costs and favor international spillovers diffusion especially with the presence of know-how proximity or complementarity between the source and the destination. Therefore, the relative importance of international knowledge spillovers over national spillovers depend upon to what extent the knowledge is tacit and difficult to absorb, the technological distance as well as the effectiveness of the transmission channels. Furthermore, the relative importance of international intersectoral and intrasectoral spillovers is heterogeneous among industries depending on the technological sophistication and the level of openness of the sector.

A few reflections on these findings highlight that there is difficult to consistently present a clear pattern as regards the relative importance of international spillovers at different level of aggregation. These results call for new in depth-research on the causes of the differences in the global reach of the international spillovers.

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