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**The Impact of R&D Spillovers on Export  
Value: Does the Transmission Channel  
matter?**

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# The Impact of R&D Spillovers on Export Value: Does the Transmission Channel matter?

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## Abstract

There is overwhelming evidence in the literature that open economies benefit from spillover effects from foreign R&D efforts. These effects increase in particular total factor productivity. Several transmission channels have been detected and studied intensively. Most of them are related to foreign direct investments or international trade. These real economic phenomena are themselves affected by spillovers, either indirectly through their effect on total factor productivity or directly through, for example, increased business contacts between investors, traders and producers.

In this empirical paper we study the effects of R&D spillovers on exports within the OECD. Previous evidence pointed to the crucial role of the transmission channel for such spillovers. Therefore we distinguish between trade-related and foreign-direct-investment related channels and indicators. By doing so we are able to determine the relevance and importance of each of the suggested channels and measures. We control for alternative determinants of export value by extending the well-accepted gravity model for international trade by incorporating R&D spillovers in the standard gravity specification.

Our results indicate that – at least at the macro-level – the choice of the transmission channel matters. In particular we find clear evidence that imports are an important transmission channel for technological spillovers, whereas there is only weak evidence in favour of any role for foreign direct investments. Hence these findings imply that openness to trade is a better policy in order to benefit from foreign knowledge than openness to investments.

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## 1. Introduction

It is widely held that technological knowledge is spread internationally (for overviews see Griliches (1992), Nadiri (1993)). Such spillovers happen thanks to improved communication tools, economic integration or economic contacts through trade or investments (see Saggi (2002) for a general survey). Theories of endogenous technical change developed in the 1990s stress two important characteristics of knowledge (Aghion and Howitt (1992), Grossman and Helpman (1991), Romer (1990), Segerstrom et al. (1990)). First, knowledge is non-rival. Hence contrary to the traditional factors of production more economic agents can use it with only negligible marginal costs. Secondly, knowledge is partly public. Hence others may benefit from the inventor's findings. Within these growth models technological spillovers affect economic growth through increased domestic total factor productivity.

However, not all countries are affected in the same way and to the same extent by international technological spillovers. Several reasons are put forward why the international knowledge diffusion is often imperfect. First, according to the *inefficiency view*, there may be barriers to the adoption of new technology. In particular distance between countries may hamper the spread of technology. Distance can be either interpreted as geographic distance (Keller (2002a)<sup>1</sup>), cultural diversity or institutional heterogeneity. These elements may explain the technological gap between the leading and following countries. Secondly, countries require the complementary human and physical capital to adopt the technology (Mankiw (1995)). In reality, the *absorptive capacity* differs across countries. According to Falvey et al. (2007), the absorptive capacity depends mainly on the level of education of the receiving economy. Moreover the benefits are largest for countries neither too far nor too close to the technological frontier. This view is also known as the *appropriate technology paradigm*<sup>2</sup> in the growth and productivity literature. Jerzmanowski (2007) argues that, in case this paradigm holds, the technological frontier is no longer uniform, but countries have to choose the best technology available to them. He

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1 Keller (2002) finds that technology spillovers are mostly local instead of global. Spillovers are declining with distance. They are halved at about 1200 kilometers. Technological spillovers have however become more global over time and are stimulated by language skills.

2 For example Basu and Weil (1998) and Acemoglu and Zilibotti (2001) use this framework to explain income differences and the lack of income convergence.

empirically confirms that an inadequate mix of inputs hampers the introduction of the best technology. Finally, the spread of knowledge and its impact also depend on the existence and extent of *transmission channels*. Several transmission channels of international technological spillovers have been suggested and applied in the literature.

In this paper we focus on the latter issue. We study the impact of the choice of transmission channel on the effects of international knowledge spillovers. In order to evaluate various transmission channels, we distinguish between several potential transmission channels. Hence this paper contributes to the literature by comparing alternative (measures of) transmission channels for technological spillovers. Following the literature we mainly focus on international trade and foreign direct investments. Further, we define knowledge in a specific way, namely by looking at foreign research and development (R&D) business expenditures. R&D data are not only widely available (at least within the OECD), but they are also most often used to compute knowledge spillovers.

Although the study of the size of international knowledge spillovers might be interesting as well, we look in this paper into the effects of international knowledge spillovers. This paper makes an original contribution to this literature. Contrary to the extensive evidence regarding the impact of technological spillovers on productivity, their effect on exports has not yet been studied intensively. Nevertheless there are clear theoretical justifications why technological spillovers matter for trade. Therefore we are interested in the effects on export value, and how these effects depend on the choice of the transmission channel.

For that purpose we extend the well-known gravity model by incorporating alternative measures of technological spillovers. By doing so, we control for the main determinants of exports (country size, income, geographical effects). Hence we use technological spillovers in an attempt to explain more of the variation in total export flows between OECD countries.

This paper is structured as follows. Section 2 provides an extensive overview of the measures and empirical evidence of international technological spillovers. In Section

3 we formulate some theoretical insights into the relationship regarding the impact of knowledge spillovers on exports. Section 4 presents the empirical methodology, based on a selection of measures discussed in the previous section. In Section 5 we discuss the results. Finally, in Section 6 we draw some conclusions.

## **2. Measurement and Empirical Evidence of International Technological Spillovers**

Technological spillovers have been measured in many ways. In all approaches some measure is constructed based on one (or occasionally more than one) basic indicator of innovation from foreign countries. Most studies use R&D expenditures for the calculation of a foreign technological knowledge stock<sup>3</sup>. Inspired by the new growth theory, the constructed foreign knowledge stocks are added to a regression in order to explain either economic growth directly, or particular growth components or factors affecting economic growth. The estimated coefficient for the foreign knowledge stock is interpreted as (non-)evidence for international technological spillovers. In particular they have been used for explaining productivity and productivity differences. Occasionally, however, they have also been used for explaining the number of patents (e.g., Branstetter (2001), Peri (2005)). Alternatively, patents themselves can be used instead of R&D spillovers for the calculation of technological spillovers. However, R&D expenditures may be preferred to patents as innovation or knowledge indicator. It is indeed often hard to interpret patents as innovation or knowledge indicators for several reasons. First, not all innovation is protected by patents. On the one hand some knowledge is simply legally not patentable. On the other hand patenting might be too costly for some inventors (e.g., individuals, small firms). Secondly, although patents are legally protective, they may be commercially worthless for individual firms. Firms often seek protection before knowing the commercial applications that can be derived from it<sup>4</sup>. Thirdly, a specific patent may cover both small and major

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3 Mostly the foreign cumulative stock of knowledge is computed, e.g. based on the perpetual invention method.

4 A good example is the pharmaceutical sector. Pharmaceutical companies often apply for patents for new substances before they start the actual testing phase of each substance. If the latter turns out to be unsuccessful, the company may fail to launch new or improved medicines. Hence the patent loses its commercial value. For some discussion on innovation in the pharmaceutical sector, see Grabowski (2004). Stoneman's (1983) argument is even stronger: patents should be looked upon as an input in the R&D process since firms apply for patent protection before actually conducting research. This extreme situation is however unlikely given the scientific requirements that should be met before one is granted

scientific breakthroughs<sup>5</sup>. Harhoff et al. (1999) show that the technical and economic value of patents is highly skewed. Hence just counting patent grants may provide misleading information on total innovation output. Several methods have been suggested in the literature to overcome this problem, but currently these adjusted patent statistics are not yet available on an internationally comparative basis<sup>6</sup>. Fourthly, even if patents have the same commercial value and scientific quality, the propensity to patent varies across countries and sectors. Differences in intellectual property legislation are hardly responsible for the country heterogeneity, but more flexible legislation appears to facilitate foreign knowledge attraction (Branstetter (2004)). Jensen et al. (2008) show that there are substantial differences in the application outcomes and pendency periods across the main patenting offices, which might at least partly explain some of the differences in patenting behaviour across countries. Moreover there is clear evidence regarding sectoral variation in the propensity to patent (e.g., Blind et al. (2006) for German firms). Hence some caution is required when using patents as innovation indicator in international comparative studies.

For a correct measurement of technological spillovers one does not only need good domestic and foreign basic innovation indicators. One also needs to know what the international transmission channels of technological innovation are. Several channels have been put forward by recent theories of economic growth (see e.g., Coe et al. (1997)). In empirical innovation studies two channels are intensively studied, namely international trade – usually imports – and foreign direct investments (Keller (2004)). We discuss both channels in more details in the next two subsections.

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a patent. Hence at least a substantial part of the research has to be conducted before the patent is applied for.

<sup>5</sup> For a detailed discussion on the quality of patents from the United States Patent and Trademark Office (USPTO) see King (2003). For a recent discussion on the reliability of the enforceable property rights at the European Patent Office (EPO) see Burke and Reitzig (2007).

<sup>6</sup> These correction methods are based on renewal data (Schankerman and Pakes (1986), van Pottelsberghe de la Potterie and van Zeebroeck (2007)), the number of patent citations (Trajtenberg (1990), Hall et al. (2001, 2005), Jaffe and Trajtenberg (2002), Hagedoorn and Cloudt (2003), Marco (2007)), the patent family size, i.e. the number of countries in which protection is sought (Putnam (1996), van Pottelsberghe de la Potterie and van Zeebroeck (2007)) and the number of claims in the patent application (Tong and Frame (1994)). Lanjouw and Schankerman (2004) discuss the impact of varying patent quality on research productivity.

## 2.1. International Technological Spillovers through Trade

The new growth theory regards international trade as the main transmission channel for international technological diffusion (for an overview see Grossman and Helpman (1991, 1994)). Several explanations support this view. First, access to imported intermediate and capital goods enhance productivity of a country's own resources, regardless of whether they are complementary to domestic goods or horizontally or vertically differentiated (Rivera-Batiz and Romer (1991), Grossman and Helpman (1991), Eaton and Kortum (2002)). Secondly, international trade stimulates international communication about cross-border learning, product design, organisational methods etc. Thirdly, imported goods enable a country to imitate foreign technology. Although this may lead to international discussions (e.g., within the World Trade Organisation – see Falvey et al. (2006)), it remains an important source of knowledge for many developing countries (see e.g., Connolly (2003)). Finally, trade raises a country's productivity in the development of technologies and imitation of foreign technology.

Often cited is the work by Coe and Helpman (1995) who study the impact of domestic and foreign innovation on total factor productivity in OECD countries. In order to measure international technological spillovers they weigh foreign R&D expenditures by bilateral imports between the foreign and domestic country. This trade-related knowledge spillovers channel is selected for two reasons. First, imported goods are regarded as an important vehicle to transfer knowledge since they contain the final result of any newly developed technology. Secondly, imports reflect the intensity of the economic contacts between countries. The trade-related knowledge spillovers (TRKS) for domestic country  $i$  at time  $t$  in the Coe and Helpman (1995) specification are hence defined as<sup>7</sup>

$$(1) \quad TRKS_{it}^{CH1} = \sum_{d \neq i}^I \omega_{dit} S_{dt}$$

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<sup>7</sup> Since we provide an overview of alternative technological spillovers indicators in this chapter, we try to harmonize the notation wherever this is possible. We add a time subscript to all indicators although not all original sources include a time dimension.

where  $S_{dt}$  is the R&D capital stock of foreign country  $d$  (there are  $I=22$  countries<sup>8</sup> in the sample),  $\omega_{dit}$  is the share of domestic imports from foreign country  $d$ 's in the total domestic imports from all countries in the sample. Hence in this specification the foreign R&D capital stocks are weighted by the relative importance of each foreign country in the total domestic imports. The foreign-R&D elasticity of total factor productivity may however depend on the size of the domestic country's imports from a particular trading partner. Therefore Coe and Helpman alternatively estimate the impact of technological spillovers by interacting the weighted foreign-R&D stock with the share of domestic imports in domestic GDP:

$$(2) \quad TRKS_{it}^{CH2} = \frac{M_{it}}{GDP_{it}} \sum_{d \neq i}^I \omega_{dit} S_{dt}$$

where  $GDP_{it}$  is the level of GDP in the recipient (domestic) country and  $M_{it}$  the recipient's total imports from the other countries in the sample. Both technological spillover indicators point to a large impact of international technological diffusion on total factor productivity, in particular spillovers from larger to smaller (more open) OECD countries.

Coe et al. (1997) extend the analysis by Coe and Helpman (1995) examining North-South spillovers between OECD countries and 77 developing countries. Once more the focus is on imports as transmission channel for international technological spillovers. Coe et al. (1997) estimate the same empirical model as Coe and Helpman (1995), but without the domestic R&D capital stock when estimating based on the entire set of 77 developing countries. Moreover they make two adaptations to the empirical specification. First, Coe et al. (1997) use imports of machinery and equipment rather than total imports. This is consistent with the theory that these products embody foreign technology most. Hence their specification for the measurement of international technological spillovers becomes:

$$(3) \quad TRKS_{it}^{CHH} = \sum_{d \neq i}^I \theta_{di} S_{dt}$$

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8 21 OECD countries plus Israel.

where  $\theta_{di}$  is the share of country  $i$ 's bilateral machinery and equipment imports from foreign country  $d$ 's in country  $i$ 's total machinery and equipment imports (averaged over time). Secondly, they add a proxy for human capital. They also take interactions between the foreign R&D capital stock and respectively human capital and the share of machinery and equipment imports from industrial countries in GDP. Both interactions turn out to be relevant.

Also Falvey et al. (2007) confirm that trade-related knowledge spillovers, more precisely through imports, are an important source of economic growth for developing countries<sup>9</sup>. But the domestic economy's absorptive capacity and relative position to the technological frontier (so-called '*relative backwardness*') should be taken into account as well. Therefore they alternatively define the trade-related knowledge spillovers as

$$(4) \quad TRKS_{it}^{FFG} = \frac{MM_{it}}{GDP_{it}} \sum_{d=1}^5 \theta_{dit} \frac{S_{dt}}{GDP_{dt}}$$

Where  $GDP_{it}$  ( $GDP_{dt}$ ) is the level of GDP in the recipient (donor) country,  $MM_{it}$  the recipient's imports of machinery and transport equipment from the 5 selected donor countries,  $\theta_{dit}$  the share of donor  $d$  in  $MM_{it}$ , and  $S_{dt}$  the donor's R&D capital stock. In order to capture the effect of absorptive capacity and relative backwardness on international technological spillovers,  $TRKS^{FFG}$  is interacted with measures for both phenomena. On the one hand, absorptive capacity ( $AC^{FFG}$ ) is measured by the average years of secondary schooling in the population over 25 (see Abramowitz (1986) and Benhabib and Spiegel (1994)). Relative backwardness, on the other hand, is measured by

$$(5) \quad RB_{it}^{FFG} = \frac{INITGDPL_{it} - INITGDPL_{USi}}{INITGDPL_{USi}}$$

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9 The size of the impact of trade-related knowledge (R&D) spillovers in Coe et al. (1997) and Falvey et al. (2007) is similar. A 1% increase in foreign R&D expenditures increases economic growth by respectively 0.06 % and 0.07 %.

where  $INITGDPL_{it}$  ( $INITGDPL_{USi}$ ) is the initial GDP per worker in the domestic country (USA). Hence relative backwardness is measured proportional to the US, which is a common approach in the literature.

Neither absorptive capacity nor relative backwardness play an important role in enhancing the benefits of trade-related knowledge spillovers, based on a standard simple regression. Alternatively Falvey et al. (2007) apply Hansen's (1999) threshold regression method for panel data. For  $AC^{FFG}$  a single significant threshold is obtained. This implies that countries with a higher absorptive capacity gain more from trade-related knowledge spillovers. For  $RB^{FFG}$  two significant thresholds are found, indicating that countries far away from, as well as countries very close to the technological frontier benefit least of all from trade-related knowledge spillovers.

A related theoretical literature deals with patent races. Halmenschlager (2006) shows that the pace of innovation is stimulated in case spillovers take place and absorptive capacity matters simultaneously. Recent studies moreover point to the importance of absorptive capacity at the sector level and even at the firm level. Griffith et al. (2004) conclude that the absorptive capacity is important at the sectoral level across thirteen OECD countries. A seminal paper by Cohen and Levinthal (1989) shows that firms need to invest in their absorptive capacity, i.e. they have to perform R&D activities themselves, in order to benefit from R&D spillovers. This is confirmed by more recent studies (e.g., Grima (2005), Cockburn and Henderson (1998) for the pharmaceutical sector<sup>10</sup>).

Although the empirical evidence in favour of trade-related knowledge spillovers seems overwhelming, Keller (1998) casts doubt on this transmission channel. Based on a Monte-Carlo robustness test, using randomly created trade patterns as weights in the foreign knowledge stock calculation appears to explain variation in productivity better than using the real trade patterns. Hence at least some trade-unrelated knowledge spillovers have to be taken into account. In a response to Keller (1998), Coe and Hoffmaister (1999) argue that Keller's so-called random trade patterns are not random since they concentrate tightly around the inverse of the number of trading

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<sup>10</sup> For a theoretical contribution and overview, see Leahy and Neary (2007)

partners. They suggest three alternative sets of truly random weights that turn out to underperform in comparison with the true bilateral import shares. Hence their results reconfirm the role of trade as transmission channel.

Keller (2002b) makes two new contributions regarding international technological spillovers. First, he distinguishes between different industries, whereas earlier studies only focused on cross-country productivity differences. Secondly, he allows for both domestic<sup>11</sup> and foreign transmission of technology. In order to achieve this distinction Keller uses both input-output data and imports. On the one hand, for the domestic knowledge spillovers, the R&D capital stock from other domestic industries is weighted by a particular sector's share in the total intermediate inputs that are used from the other domestic industries. Therefore domestic spillovers are defined as

$$(6) \quad DS_{ist}^K = \sum_{k \neq i}^I \eta_{ks} S_{ikt}$$

where  $\eta_{ks}$  denotes, for each industry  $s$ , the share of its total intermediate inputs used from industry  $k$  ( $\sum_{k \neq i}^I \eta_{ks} = 1, \quad \forall i$ ) which are obtained from the input-output tables.  $S_{ikt}$  is the domestic R&D capital stock in sector  $k$ .

On the other hand, for the trade-related international knowledge spillovers, the foreign R&D capital stock is weighted by each foreign country's share in the bilateral imports by the domestic country, similar to Coe and Helpman (1995). However a further distinction is made between imports within the same industry and imports from other industries. Hence the intra-sectoral trade-related international knowledge spillovers become

$$(7) \quad TRKS_{ist}^{K-int\ ra} = \sum_{d \neq i}^D \mu_{dist} S_{dst}$$

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11 Several papers specifically focus on domestic technological transfers: see e.g., Griliches (1979), Wolff and Nadiri (1993), Nadiri (1993), Griliches (1995) and Mohnen (2001).

where  $\mu_{dist}$  is the bilateral import share of country  $i$  from country  $d$  ( $D$  is the total number of countries) for industry  $s$  at time  $t$ .  $S_{dst}$  denotes the R&D capital stock from country  $d$  in sector  $s$  at time  $t$ . Let  $\gamma_{kst}$  be the share country  $i$ 's imports of the  $k$  intermediate ( $k=1, \dots, S; k \neq s$ ) that are used in sector  $s$ . Then the inter-sectoral trade-related international knowledge spillovers are measured by

$$(8) \quad TRKS_{ist}^{K-int er} = \sum_{k \neq s}^S \gamma_{kst} TRKS_{ikt}^{K-int ra}$$

Keller's results imply that about half of the effect on productivity comes from domestic own-industry R&D. Domestic inter-industry spillovers account for 30 percent, while international technological (intra- and inter-sectoral) spillovers are responsible for 20 percent of the effect on productivity. Similar results are obtained by Unel (2008) for the OECD, although the impact of international R&D spillovers is less robust. Unel's findings are based on an empirical approach similar to Coe-Helpman's (1995) and Keller's (2002a) methodology. However an alternative weighting is applied. This alternative weighting originates from Lichtenberg and van Pottelsberghe de la Potterie (1998)<sup>12</sup>. These authors modify the Coe-Helpman specification as follows:

$$(9) \quad TRKS_{it}^{LP} = \sum_{d \neq i}^I \frac{M_{idt}}{GDP_{dt}} S_{dt}$$

where  $M_{idt}$  are the bilateral imports by country  $i$  from country  $d$  (or the exports from  $d$  to  $i$ ). This formulation reflects not only the intensity of international R&D spillovers, like in the Coe-Helpman-Keller specification, but additionally also the direction of international R&D spillovers.

Finally, some authors have paid special attention to the impact of geographical distance on international technological spillovers. Keller (2002a), Xu and Wang (1999) and Papageorgiou et al. (2007) use a specification that weighs the R&D stock

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<sup>12</sup> Also applied by Xu and Wang (1999).

of trading partners by the geographical distance between the home and foreign country. Let  $D_{id}$  be the distance between country  $i$  and  $d$ , then we get

$$(10) \quad TRKS_{it}^{K-XW-PSZ} = \sum_{d \neq i}^I \left[ \frac{1 - \ln(D_{id})}{\sum_{d \neq i}^I (1 - \ln(D_{id}))} \right] S_{dt}$$

Note that strictly speaking this indicator is not trade-related anymore, although one typically assumes that trade is inversely related to geographical distance (e.g., Leamer and Levinsohn (1995)).

Finally note that there is some evidence that exports can be a transmission channel for technological spillovers too. Falvey et al. (2004) obtain results that support the existence of spillovers through both imports and exports, but the evidence for exports is less convincing. A related literature deals with exporting-by-learning. Firms learn from interaction with foreign customers, foreign quality standards etc. There is hardly any evidence that learning-by-exporting matters for developed countries (Keller (2004), p. 767-769)<sup>13</sup>. Only for particular developing countries the effect seems to play a role (Kraay (1999), Aw et al. (2000) Bigsten et al. (2004), Van Biesebroeck (2005)).

Many empirical studies look into the existence, size, channels and impact of international technological spillovers. In particular in the context of North-South relations these findings bring about important policy conclusions. Overall, these studies point to the existence of international technological spillovers, both between developed and developing countries and among developed countries. For recent overviews see for example Saggi (2002), Keller (2004), Ciruelos and Wang (2005), Xu and Chiang (2005) and Schiff and Wang (2006).

Generally speaking, although there is convincing evidence that technological spillovers matter through several transmission channels, these empirical studies only contain evidence for the impact of technological spillovers on economic growth or

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13 Recently, some more detailed analysis has been performed. Greenaway and Kneller (2007) indicate that it depends on each particular sector whether learning-by-exporting boosts productivity. Crespi et al. (2006) find some support for the learning-by-doing hypothesis among UK firms based on more detailed information about the sources of learning.

productivity. Hence the question whether they also matter for international trade and trade patterns has not been studied yet. In this paper we will try to close this gap.

## **2.2. International Technological Spillovers through Foreign Direct Investments**

Next to trade-related knowledge spillovers, foreign direct investments are regarded as an important transmission channel for international technological spillovers. Nevertheless, in comparison with the international trade channel, the theoretical foundations are limited. Furthermore the empirical evidence is often inconclusive about inward foreign direct investment spillovers (for a recent survey see Görg and Greenaway (2004) and Smeets (2008)). Not only methodological and measurement issues are responsible for this inconclusiveness (Görg and Strobl (2001)), but also more fundamental causes are put forward, including issues about worker mobility, absorptive capacity, spatial proximity, demonstration effects, vertical linkages etc. (Smeets (2008)).

Two methodological approaches are popular. The first one looks into the impact of the number of patents (or mostly patent citations) on productivity. The findings are mixed (Saggi (2002)). The second, more recent approach is more promising for the foreign direct investment channel. Similar to the trade channel, in this approach most attention is paid to knowledge spillover effects through foreign direct investments on productivity. Also the econometric approach is usually similar. Foreign direct investment data are directly linked to productivity growth, either at aggregate levels (e.g., Xu (2000)), or at the firm level (e.g., Griffith et al. (2002), Keller and Yeaple (2003), Javorcik (2004), Görg and Strobl (2005), Kugler (2006), Branstetter (2004), Javorcik and Spatareanu (2008)). Based on this approach there is significant evidence that foreign direct investments cause international knowledge spillovers<sup>14</sup>. In spite of the recent promising findings, Keller and Yeaple (2003) show however that foreign direct investment spillovers are different across sectors. In particular they appear to be stronger in the high-tech sector.

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<sup>14</sup> Nevertheless, van Pottelsberghe de la Potterie and Lichtenberg (1998) argue that only outward, and not inward, foreign direct investment is a source of technological spillovers.

Firm-level data also point to an important role for the presence of multinational companies in creating international knowledge spillovers. Within the own international network of multinational firms technology is transferred both from the headquarters to the subsidiaries and the way around (Birkinshaw and Hood (1998), Håkanson and Nobel (2000), Veugelers and Cassiman (2004), De Backer and Sleuwaegen (2005)). Crespi et al. (2008) confirm based on firm-level data about innovation and productivity that multinationals contribute to technological spillovers. However, also suppliers and in particular competitors appear to be sources of total factor productivity growth through knowledge spillovers.

Also the impact of spillovers on own innovation is studied. d'Aspremont and Jacquemin (1988) theoretically show that spillovers give an incentive to conduct R&D as well as to form R&D joint ventures. Own R&D efforts are needed to benefit from spillovers, for example by increased profitability. Without own R&D efforts rivals may benefit from spillovers, causing lower profitability. Empirical evidence points to a positive effect of technological spillovers on firms' innovation and research cooperation. Recent examples are Veugelers and Cassiman (2002), Belderbos et al. (2004), Veugelers and Cassiman (2005) and Vencatachellum and Versaevel (2006).

Despite the recent promising findings, generally speaking however, the foreign direct investment channel appears to be much more sensitive to the data, country or sector chosen. Moreover, since statistical data on foreign direct investment is less widely available than trade data, one often has to rely on more case evidence (e.g., country studies) to get a better insight into the role of foreign direct investments.

In this paper we will measure – in line with the empirical literature – knowledge spillovers through foreign direct investments in a macro-economic and broad way, since we wish to take into account spillovers between a relatively large set of countries. Hence similar to the trade-related knowledge spillovers measured by equation (2), we will calculate foreign direct investment related knowledge spillovers (FDIKS) by

$$(11) \quad FDIKS_{it} = \frac{FDI_{it}}{GDP_{it}} \ln \left( \sum_{d \neq i}^I \omega_{dit}^{FDI} S_{dt} \right)$$

where  $GDP_{it}$  is the level of GDP in the recipient (domestic) country and  $FDI_{it}$  the recipient's total inward foreign direct investments (stock).  $S_{dt}$  is the R&D capital stock of foreign country  $d$ ,  $\omega_{dit}^{FDI}$  is the share of foreign direct investments from foreign country  $d$  in country  $i$  in the total inward foreign direct investments in the home country. Foreign countries can be either defined as all countries of the world (or the sample) or, alternatively, one can focus on the most important foreign investors (mostly top-5 is taken). In our calculations we will follow both approaches: first, we use all countries in the sample (call it measure (11-A)); Secondly, we focus only on the top-5 largest foreign investors for each country. Although these foreign-direct-investment-related knowledge spillovers are popular in the literature, some caveats should be formulated. First, foreign direct investment statistics are not systematically reported by geographical breakdown. For that reason, a calculation based on the top-5 investors is more realistic, although using the full sample is not impossible if one is willing to look up data from national statistical agencies. Secondly, bilateral foreign direct investment flows are relatively unstable over time. Thirdly, it is hard to compute stocks for bilateral foreign direct investment statistics, because of their limited availability, but also because the depreciation rate may depend on the source of the investment<sup>15</sup>. Therefore, in our empirical section; we opt for using the most recent data on foreign direct investment flows for the computation of the bilateral weights ( $\omega_{dit}^{FDI}$ ) despite the shortcomings. Fortunately, however, the share of a particular foreign country in the annual foreign direct investment inflow is more stable over time. Hence flows can be used in order to capture the relative importance of countries within the foreign-direct-investment-related knowledge spillovers indicator.

### 3. Trade and Knowledge Spillovers: Some Theoretical Insights

In the next section we will calculate the size of knowledge spillovers, followed by an analysis of their effect on the export value. We focus on total bilateral exports

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<sup>15</sup> Actually only a few national statistical agencies attempt to compute these stocks (e.g., Finland).

between OECD countries (see also data description below). The theoretical support for the impact of technology on trade consists of two strands of research. On the one hand, the '*product cycle*' trade models regard innovation as exogenous (Vernon (1966), Krugman (1979), Dollar (1986)). In a typical North-South setting, developed countries export innovative goods. Developing countries imitate these goods and will eventually start exporting them. In order to remain internationally competitive, firms in the developed countries cannot cease conducting research. More innovation leads to more exports. On the other hand, innovation can be endogenous within a growth model (Grossman and Helpman (1991), Segerstrom et al. (1990), Young (1991), Aghion and Howitt (1998)). International trade has dynamic effects on both growth and innovation, causing a simultaneous relation between trade and innovation. Although – a priori and theoretically – there might be endogeneity concerns regarding the relationship between trade and innovation, the empirical evidence is mostly in favour of a positive impact of innovation on international trade.

A popular tool to study the determinants of export flows empirically is the gravity equation. The standard gravity equation explains the variation in bilateral export flows by the exporter's and importer's GDP (country size) and the geographical distance between (the capital cities of) both countries. Mostly the exporter's and importer's GDP per capita (income) are added as well as dummy variables indicating border effects, common language, colonial ties etc. (see Anderson and van Wincoop (2004)). The basic version of the gravity equation has substantial theoretical underpinnings (Anderson (1979), Krugman and Helpman (1985), Bergstrand (1985, 1989, 1990), Deardorff (1998)). However, the basic version has regularly been extended to incorporate alternative explanations of trade. One of these explanations is the role of technological innovation. In an augmented gravity framework, Martinez-Zarzoso and Marquez-Ramos (2005) look into the effect of technology on international trade. A composite indicator of technology, reflecting many aspects of the innovation process, is included in the gravity model. They show that technology has a positive and significant impact on countries' exports. Hence more technological countries export more, controlling for income, size and several geographical and transportation effects. The effect is however larger for developing countries than for developed countries. In a similar gravity approach, Filippini and Molini (2003) add a composite indicator of technological distance in order to assess the role of the technological gap between

countries as determinant of trade flows between East Asian countries. They confirm the hypothesis that a wider technological gap decreases exports.

In contrast with the evidence about the impact of domestic innovation on trade, the direct effect of R&D spillovers on exports has not been studied yet. Given the clear evidence that such spillovers matter for productivity, in combination with the evidence that domestic innovation affects exports positively in a direct way, we are convinced that this is an important gap in the empirical trade literature, which we try to close in this paper.

#### **4. Empirical Methodology**

Many transmission channels for R&D spillovers are studied in the literature. In the empirical part of this paper, we take into account several of these, namely a selection of the indicators discussed in Section 2. In each case we use R&D expenditures as knowledge indicator. More precisely, we will calculate, on the one hand, spillovers based on equations (1), (2), (3), (4) and (9), which are all measuring trade-related technological spillovers. This selection implies that we do not take into account domestic or sectoral spillovers (as taken into account in equations (6)-(7)-(8)). Neither do we pay attention to interaction effects, like in equation (5). We leave these issues for further research. Although equation (10) would be an interesting alternative for measuring trade-related technological spillovers, we do not use it in this paper, since this distance-based indicator would interact with the geographical variables already present in our empirical specification, i.e. an extended gravity model. By using several measures of trade-related R&D spillovers, we are able to evaluate the impact of the selected indicators. On the other hand, we will also compute investment-based R&D spillovers based on equation (11). Comparing the size and the effect of R&D spillovers based on the trade, respectively the foreign direct investment, channel allows us to answer the question which transmission channel matters (most), and whether the measurement of the transmission mechanism has any impact on the evidence regarding knowledge spillovers.

We estimate the following extended gravity equation:

$$(12) \quad EX_{di} = \alpha + \beta_1 GDP_d + \beta_2 GDP_i + \beta_3 GDPCAP_d + \beta_4 GDPCAP_i \\ + \beta_5 DIST_{di} + \beta_6 BORD_{di} + \beta_7 EU_{di} + \beta_8 TRKS_i + \beta_9 FDIKS_i + \varepsilon_{di}$$

where  $EX_{di}$  is the export value from country  $d$  to country  $i$ .  $GDP_d$  ( $GDP_i$ ) is the gross domestic product of the exporting country (importing country).  $GDPCAP_d$  ( $GDPCAP_i$ ) is the gross domestic product per capita (income) of the exporting country (importing country),  $DIST_{di}$  denotes the distance (in km) between the capital cities of the exporting and importing country;  $BORD_{di}$  is a dummy variable equal to one if the exporting and the importing country are neighbouring countries (zero otherwise).  $EU_{di}$  is a dummy equal to one in case both trading partners belong to the European Union (zero otherwise). Finally we add trade-related ( $TRKS_i$  – several measures) and foreign direct investment related ( $FDIKS_i$ ) R&D spillovers to this specification, as defined above.

Our data consists of a panel of bilateral export values between 37 countries. The dimensions of the panel are determined by the exporting and the importing countries. We use data for a single year, i.e. 2004<sup>16</sup>. Countries included are Argentina, Austria, Belgium, Canada, China, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russia, Singapore, Slovakia, Slovenia, South Africa, Spain, Sweden, Switzerland, Turkey, United Kingdom and the USA. All trade data are taken from the UNCTAD (2008a) COMTRADE database. GDP and GDP per capita come from IMF (2008). Distance is expressed as the great circle distance between capital cities. R&D data are obtained from OECD (2006). Total FDI data are obtained from the UNCTAD (2008b). Bilateral FDI data are taken from UNCTAD (2008c), but missing data are supplemented by data from national statistical agencies<sup>17</sup>.

All estimations are based on a random-effects GLS estimator. Note that no fixed effects can be added since we focus on a single year.

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<sup>16</sup> This year is determined by the availability of the R&D data. We opt for not using panel data since the gravity equation is originally designed for explaining cross-country variation in exports, rather than for explaining trade evolutions over time (see Leamer and Levinsohn (1995) for a discussion).

<sup>17</sup> Details available upon request.

## 5. Results

We consecutively discuss the impact of trade and investment related knowledge spillovers on trade flows. In order to know the impact of adding knowledge spillovers to the gravity specification, we first show in Table 1 the results from the estimation of the standard gravity equation for our sample. As predicted by the theory both the exporter's and importer's GDP have a significantly positive impact on exports. The importer's income elasticity is slightly larger than the one of the exporter, although both are close to one. GDP per capita is however not significant, implying that it is country size rather the average income that determines export flows. Hence we drop these variables once we add the knowledge spillovers indicators. Also the geographical elements have the expected sign and significance. Distance between countries hampers trade as can be seen from the significantly negative coefficient for distance. Moreover countries with a common border trade more than other countries. Surprisingly perhaps, membership of the European Union does not cause an additional trade creation. Although the estimated coefficient for the EU-dummy has the right sign, it is not significantly different from zero.

**Table 1: Regression Results for the Standard Gravity Equation**

	<b>Coeff.</b>	<b>S.E.</b>	<b>z</b>	<b>Coeff.</b>	<b>S.E.</b>	<b>z</b>
<b>GDP exporter</b>	0.96	0.02	49.06 ***	0.96	0.02	48.75 ***
<b>GDP importer</b>	0.96	0.05	20.59 ***	0.96	0.05	20.65 ***
<b>GDP per capita exporter</b>				-0.01	0.03	-0.35
<b>GDP per capita importer</b>				-0.02	0.07	-0.28
<b>Distance</b>	-1.08	0.03	-36.66 ***	-1.09	0.03	-35.83 ***
<b>Constant</b>	17.72	0.37	48.22 ***	18.04	0.87	20.77 ***
<b>R<sup>2</sup> Overall</b>	0.78			0.78		
<b>Chi<sup>2</sup></b>	3648.00			3646.00		
<b>GDP exporter</b>	0.95	0.02	48.19 ***	0.95	0.02	47.84 ***
<b>GDP importer</b>	0.95	0.05	20.15 ***	0.95	0.05	20.11 ***
<b>GDP per capita exporter</b>				-0.01	0.03	-0.23
<b>GDP per capita importer</b>				-0.02	0.07	-0.21
<b>Distance</b>	-0.99	0.04	-23.04 ***	-0.99	0.04	-22.82 ***
<b>Border</b>	0.56	0.12	4.49 ***	0.56	0.12	4.47 ***
<b>EU membership</b>	0.12	0.09	1.25	0.12	0.09	1.26
<b>Constant</b>	16.98	0.46	37.27 ***	17.21	0.91	18.87 ***
<b>R<sup>2</sup> Overall</b>	0.78			0.78		
<b>Chi<sup>2</sup></b>	3713.00			3708.00		

*Estimation is based on a random-effects GLS estimator. \*\*\*, \*\* and \* respectively denote significance at the 1%, 5% and 10% significance level.*

## 5.1. Results for Trade-related Knowledge Spillovers

We now add each of the trade-related knowledge spillovers indicators discussed before one by one to the standard specification. Table 2 provides an overview of the results. As can be seen from this table, trade-related R&D spillovers appear to have a positive effect on exports regardless of how these spillovers are measured. However, the elasticities are different ranging between 0.59 and 0.95. Trade-related R&D spillovers have the largest impact on export value if they are measured using bilateral machinery and equipment imports (Eq. 3) instead of total imports (Eq. 1) as weights for the foreign R&D stocks. Taking into account the overall openness of the receiving country (Eq. 2 with total imports as weights; Eq. 4 with machinery and equipment imports as weights) reduces the impact of international R&D spillovers on exports in comparison with not taking into account the overall openness. Finally, taking both the intensity and direction of international R&D spillovers in to account (Eq. 9), leads to results in between those with and without correction for overall openness.

**Table 2: Regression Results for Trade-Related International R&D Spillovers**

	Coeff.	S.E.	z	Coeff.	S.E.	z	Coeff.	S.E.	z
GDP exporter	0.94	0.02	49.15 ***	1.08	0.02	53.37 ***			
GDP importer	0.97	0.05	20.37 ***	0.95	0.04	21.95 ***			
Distance	-1.17	0.05	-25.67 ***	-1.04	0.04	-26.16 ***			
Border	0.36	0.12	2.96 ***	0.49	0.12	4.22 ***			
EU membership	0.19	0.09	2.04 **	0.00	0.09	0.04			
Trade Spillovers (Eq. 1)	0.85	0.09	9.58 ***						
Trade Spillovers (Eq. 2)				0.59	0.04	14.96 ***			
Trade Spillovers (Eq. 3)									
Trade Spillovers (Eq. 4)									
Trade Spillovers (Eq. 9)									
Constant	9.54	0.90	10.61 ***	0.17	1.20	0.14			
R <sup>2</sup> Overall	0.78			0.81					
Chi <sup>2</sup>	4039.00			4568.00					
GDP exporter	0.92	0.02	48.40 ***	1.09	0.02	51.94 ***	0.38	0.05	7.73 ***
GDP importer	0.97	0.05	20.44 ***	0.94	0.04	21.54 ***	0.93	0.04	21.51 ***
Distance	-1.17	0.04	-26.25 ***	-0.95	0.04	-23.67 ***	-0.89	0.04	-21.59 ***
Border	0.37	0.12	3.03 ***	0.58	0.12	4.96 ***	0.64	0.12	5.41 ***
EU membership	0.18	0.09	1.95 *	-0.04	0.09	-0.48	-0.09	0.09	-1.02
Trade Spillovers (Eq. 1)									
Trade Spillovers (Eq. 2)									
Trade Spillovers (Eq. 3)	0.95	0.09	10.59 ***						
Trade Spillovers (Eq. 4)				0.68	0.05	13.78 ***			
Trade Spillovers (Eq. 9)							0.73	0.06	12.44 ***
Constant	8.37	0.93	9.00 ***	2.19	1.15	1.90 *	-0.67	1.48	-0.45
R <sup>2</sup> Overall	0.79			0.81			0.80		
Chi <sup>2</sup>	4115.00			4440.00			4316.00		

Estimation is based on a random-effects GLS estimator. \*\*\*, \*\* and \* respectively denote significance at the 1%, 5% and 10% significance level.

Apart from the same sign, similar significance and the differences in the estimated elasticities, the various measures of trade-related R&D spillovers also have a different impact on the other estimated coefficients of the gravity equation. In particular they appear to have an impact on the exporter's GDP and on the impact of EU-membership. The effect on the exporter's GDP is not surprising since both variables differ in the same dimension, i.e. the exporter dimension (while remaining constant across the importing countries). The most prominent effect is the increased elasticity for the exporter's GDP in case spillovers are measured through imports of machinery and equipment. If spillovers happen through imports of machinery and equipment, rather than through total imports, then these spillovers are able to explain part of the variation in export values, otherwise captured by variation in the exporter's income. By contrast, the exporter's GDP elasticity is more than halved when international R&D spillovers happen into a particular direction (Eq. 9). If the direction of the spillovers matter for the size of these spillovers, then the effect of the exporter's GDP on the export value is decreased in case these spillovers are constant across all exporting countries.

Next to the impact on the role of the exporter's GDP, the measurement of trade-related R&D spillovers also affect the significance of the EU-membership effect. In case spillovers happen through total imports, bilateral exports are higher if both trading partners are EU member states. However, in the alternative case that spillovers happen through imports of machinery and equipment, EU-membership does not matter for bilateral exports.

## **5.2. Results for Foreign-Investment-Related Knowledge Spillovers**

Finally, we turn to the effect of foreign-investment-related knowledge spillovers in Table 3. Contrary to the significantly positive effect of trade-related knowledge spillovers on exports, R&D spillovers through total foreign direct investments appear not to affect bilateral exports. Neither the coefficient for our foreign-investment-related spillovers indicator based on all countries in the sample (Eq. 11-A), nor the coefficient for the indicator based on the top-5 inward foreign investors (Eq. 11-B) are

significantly different from zero. However these findings do not allow us to conclude that foreign direct investments do not matter for the impact of foreign R&D on bilateral exports. Rather it is likely that the investment channel is much more complicated than assumed in this rather general macro-economic approach that is moreover constrained by data availability. As discussed in the literature overview in Section 2, the evidence regarding the role of foreign direct investments as knowledge transmission channel is much more promising if based on firm-level data. This is probably the best (and only) way to study this transmission channel.

**Table 3: Regression Results for Foreign-Direct-Investment-related International R&D Spillovers**

	<b>Coeff.</b>	<b>S.E.</b>	<b>z</b>	<b>Coeff.</b>	<b>S.E.</b>	<b>z</b>
<b>GDP exporter</b>	0.91	0.03	47.23 ***	0.91	0.03	43.66 ***
<b>GDP importer</b>	0.92	0.05	19.20 ***	0.93	0.05	19.10 ***
<b>FDI Spillovers (Eq. 11 -A)</b>	0.09	0.12	0.78			
<b>FDI Spillovers (Eq. 11 -B)</b>				0.13	0.11	1.04
<b>Distance</b>	-0.96	0.04	-22.40 ***	-0.97	0.04	-22.50 ***
<b>Border</b>	0.56	0.11	4.43 ***	0.54	0.10	4.78 ***
<b>EU membership</b>	0.10	0.09	1.03	0.10	0.10	1.07
<b>Constant</b>	12.40	0.33	33.66 ***	14.10	0.34	30.29 ***
<b>R<sup>2</sup> Overall</b>	0.78			0.78		
<b>Chi<sup>2</sup></b>	3650.00			3671.00		

*Estimation is based on a random-effects GLS estimator. \*\*\*, \*\* and \* respectively denote significance at the 1%, 5% and 10% significance level.*

## 6. Conclusion

In this paper we provided an overview of the measurement of international R&D spillovers on the value of bilateral exports. There appears to be many indicators suggested in the literature, which can be divided into trade-related and foreign-direct-investment-related knowledge spillovers depending on the transmission channel of international knowledge diffusion. We tested whether the choice of the transmission channel, as well as the choice of spillovers indicators, affect the impact of international R&D spillovers on bilateral exports. For that reason we use an extended gravity model incorporating a selection of R&D spillovers indicators used in the literature.

Our results clearly indicate that trade-related R&D spillovers have a significantly positive impact on bilateral exports, whereas we do not find evidence in favour of the foreign direct investment channel. Nevertheless, the size of the effect of trade-related R&D spillovers differs slightly across different measures. Moreover, especially the effects of exporter's GDP and EU-membership on bilateral exports appear to be sensitive to the way in which trade-related knowledge spillovers are defined.

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