Maastricht University

UNITED NATIONS UNIVERSITY

UNU-MERIT

Working Paper Series

#2020-047

Inter-sectoral and international R&D spillovers

Rene Belderbos and Pierre Mohnen

Published 12 October 2020

Maastricht Economic and social Research institute on Innovation and Technology (UNU-MERIT)
email: info@merit.unu.edu | website: http://www.merit.unu.edu

Boschstraat 24, 6211 AX Maastricht, The Netherlands
Tel: (31) (43) 388 44 00

UNU-MERIT Working Papers
ISSN 1871-9872

Maastricht Economic and social Research Institute on Innovation and Technology
UNU-MERIT

Inter-sectoral and international R&D spillovers

This is a reprint of Simpatic Working Paper No. 2
Commission of the European Communities, Brussels, 2013

Rene Belderbos and Pierre Mohnen

UNU-MERIT

Acknowledgements

The authors thank Boris Le Hir, Huub Meijers, and Bart Verspagen for their valuable input to this work package. This paper draws liberally on Hall, Mairesse and Mohnen (2010), Mohnen (2001), OECD (2007), and Meijers and Verspagen (2010).

Inter-sectoral and international R&D spillovers

ABSTRACT

It has been well established in the literature that there are intra- and inter-sectoral knowledge spillovers, national as well as cross-border, that make the social rate of return to R&D exceed the private rate of return. Taking such spillovers into account is essential to examine the impact of R&D policies. This paper reviews the literature on (international) R&D spillovers and the various ways that have been proposed to measure such spillovers. Although distinctions have been made between knowledge spillovers due to the public good nature of knowledge on the one hand, and 'rent' or 'pecuniary' spillovers between suppliers and buyers due to the incomplete translation of R&D-induced quality improvements into the price of intermediates on the other hand, this distinction is difficult to make empirically. The variety of potential transmission channels and transmission effects – all with their measurement problems, suggests calculating spillover matrices that are sufficiently broad to capture their correlated effects. The paper proceeds by discussing the advantages and disadvantages of different spillover measures. It subsequently describes two matrices of inter-sectoral and international spillover weights based on patent citation data. It concludes with suggestions for future work.

JEL codes: O31, O32, O33

Keywords: spillovers, R&D policy, innovation, productivity, patents

1. INTRODUCTION

It has been well established in the literature that there are intra- and inter-sectoral knowledge spillovers, national as well as cross-border, that make the social rate of return to R&D exceed the private rate of return. Taking such spillovers into account is essential to examine the European-wide impact of R&D policies in the Simpatic project. One of the challenges of the Simpatic project is then to include estimates of intra-industry, inter-industry, and international spillovers (spillover matrices) to translate R&D policies and R&D multipliers into country- and European-wide productivity and growth effects. The aim of this work package is to summarize the insights generated by the literature on spillovers, and draw conclusions on the nature of spillover matrices that provide the crucial link between the micro and macro analyses.

This paper first of all reviews the literature on R&D spillovers and the various ways that have been proposed to measure such spillovers (section 2). It discusses the way in which spillovers have been conceptualised, the difference between 'pure' knowledge spillovers and transaction-based 'rent' spillovers, and the measurement of actual spillovers versus mechanisms that are likely to facilitate spillovers. It summarises the evidence on the different mechanisms and facilitators of spillovers and the evidence on international spillovers - the latter with a particular focus on trade and FDI as facilitating mechanisms. Given the series of literature reviews that are already available, our review does not have the intention to be exhaustive. Rather, the goal is to distil a number of stylised facts that should preferably be reflected in spillover matrices in order to arrive at reasonable predictions of social returns to R&D and appropriate R&D policies. What emanates from the review is the relative strength of patent-based measures as the basis for spillover matrices.

The paper proceeds by discussing the advantages and disadvantages of patent-based spillover measures more in detail (section 3). It describes two actual matrices of inter-sectoral and international spillover weights that are available and that are part of this work package. These matrices based on patent citation data and distinctions between sectors of use and origin of technologies are potential inputs for the modelling of micro-macro interaction in the Simpatic project. It concludes with suggestions for future work in the Simpatic project in this direction.

2. Industry, inter-industry, and international R&D spillovers: review and stylised facts

A number of literature reviews have been published on knowledge spillovers, such as Griliches, 1992, Mohnen (2001), Keller (2004), Hall, Mairesse and Mohnen (2010), and, partially, OECD (2007) among others. The aim of the current review is not to replicate this, but to focus more directly on the implications of extant research for the development of matrices that represent the expected magnitude of intra-industry, inter-industry and international spillovers. Hence, we will not pay detailed attention to estimation issues, precise estimates of magnitudes of rates of return, and model specifications, but we summarise what the literature has to say about the key mechanisms of spillovers and how these can be measured and incorporated in estimates of economy wide effects of R&D investments, and R&D additionality due to public policy measures. Based on the review, we distil a number of stylised facts that are preferably taking into account in the development of micro to macro spillover matrices.

This section draws quite liberally on prior work by the authors, in particular Hall, Mairesse and Mohnen (2010), Mohnen (2001), and OECD (2007). Before we proceed to the review, it is worthwhile to discuss a number of conceptual issues.

2.1 Conceptual issues

It is useful to discuss three conceptual issues related to the measurement of R&D spillovers and knowledge flows. The first relates to the difference between 'pure' knowledge spillovers and 'pecuniary' or 'rent' spillovers. The second concerns the conceptual model underlying the measurement of knowledge spillovers, and the third the difference between measuring actual spillovers and mechanisms that are assumed to facilitate spillovers.

Pure knowledge spillovers versus Rent spillovers

Pure knowledge spillovers arise if firms learn from ideas, technologies, blueprints, etc. from other firms and utilise this knowledge in their own R&D and production process. They arise through the non-rival and public good nature of (technological) knowledge. Conceptually they are pure externalities. Measures of spillovers that are independent of any economic transactions are expected to capture pure knowledge spillovers.

Pecuniary spillovers, also called 'rent spillovers' by Griliches (1992), arise if firms get access to the fruits of ideas and R&D of other firms through economic transactions, i.e. with trade, direct investment, technology payments, hiring of workers, research collaborations, and mergers and acquisitions. The most widespread form of such spillovers is when firms purchase (capital) goods that embody ideas and technological knowledge developed by other firms. Conceptually, these at best partial externalities, since firms pay to access this knowledge. If firms do not pay a price reflecting the full value of the technology, the purchase of inputs with embodied technology enhances the purchasing firms' productivity. One line of thought on this is that these spillovers should not be considered as such, since they arise out of mismeasurement: the price of inputs underestimates their value, such that we are just overestimating real productivity benefits, in the sense that productivity increase should imply technological progress in the client firm (e.g. Griliches, 1992). Keller (2004) and many other scholars, takes a more benign approach: if the cost of buying the intermediate is smaller than the opportunity cost by the firm to create the knowledge through its own R&D, the firm can be seen as benefitting from technology spillovers. In much of the literature on international spillovers using trade data, trade related pecuniary spillovers are seen as a valid mechanism to analyse international technology diffusion and productivity spillovers. There are additional reasons to do so. First, if a purchasing firm possesses complementary technologies or assets, it may benefit more from buying the inputs even if the market price of the input reflects the embodied technology in full. Second, firms utilising the higher quality, technology embodied, inputs may adapt technologies and processes to optimise the use of these inputs, creating productivity benefits. The technology embodied in the inputs may provide further technological opportunities for productivity improvement. Third, if the supplier buyer relationship involves substantial interaction, e.g. when face to face meetings are required to discuss specifications, (tacit) knowledge spillovers may occur in addition to the effects of the input supplied. Hence, pecuniary spillovers will often incorporate, or be correlated with ‘pure’ knowledge spillovers.

It can furthermore be noted that the definition of pecuniary or rent spillovers in the literature is arguably too narrow. In the literature on FDI spillovers, the strongest evidence is found for so-called ‘backward’ spillovers: technology and knowledge spillovers from (multinational) customer firms to (local) supplier firms, as more technologically able clients help set and maintain better quality standards for their suppliers (e.g. Javorcik, 2004). Such spillovers have been largely ignored by the traditional (international) spillover literature, which has tended to focus on imports. In case of customer-originating spillovers, the role of pecuniary spillovers due to mispricing are less likely to play a role or to play a different role: quality improvements may be less reflected in the price of the intermediate, as sophisticated, demanding, users providing guidance on specifications and standards are probably more likely to negotiate input prices downwards.

We conclude that the two types of spillover are hard to dissociate because knowledge flows are often concomitant with user-producer transactions and the capture of rents. Taking this in consideration, and given the Simpatic goals to study economy wide effects on output, productivity and employment, an inclusive approach to spillovers is to be preferred.

Conceptualising Knowledge Spillovers

A second issue is how we ‘model’ the process of knowledge spillovers between pairs of firms. One common and straightforward way to look at it is to see knowledge spillovers simply as a function of ‘*closeness*’ between firms (e.g. Lychagin et al, 2010). Closeness could be in terms of technologies used, skill levels and expertise of employees, or geographic distance. The closer two firms are in various dimensions, the more likely it is that knowledge spillovers take place.

A more comprehensive conceptualisation would look more specifically at characteristics of the sender and the receiver and the mechanisms through which spillovers arise, rather than just examining firms' bilateral closeness. Technology spillovers can be seen to be a function of:

1. The magnitude of knowledge outflows from the 'sending' firm (the 'supply' of spillovers). This depends on the firm' knowledge creation (usually measured as R&D expenditures) but also on the degree of 'openness' of a firm (e.g. the use of secrecy or technological complexity to shield knowledge from leaking out);
2. Mechanisms that facilitate this knowledge to become available to other firms (the 'spread' of spillovers), such as labour mobility, epistemic communities of researchers, trade fairs and conferences, inter-firm trade, etc.
3. The capacity and interest of other firms to receive this knowledge and absorb and utilise it (the 'effective demand' for spillovers), i.e. the knowledge should be relevant and firms should understand and absorb it. This will be related to internal R&D expenditures of the receiving firm and the technological proximity or overlap between the firms.

If one takes this view, conceiving spillovers as just a function of technological 'closeness' would look as a narrow perspective, taking into account essentially only the 'effective demand', while not considering the 'spread' or mechanisms involved. The implicit or explicit assumption is that if we have 'effective demand', firms are more likely to find and use some mechanism to get the relevant knowledge to flow, in particular since some mechanisms (e.g. obtaining information from published patents or from published new product introductions) are available at relatively low cost for a wide range of firms. Indeed, the use of specific mechanisms (the 'spread' of spillovers) is often endogenous to the relevance and utilisation of knowledge by the receiving firms, in particular when it concerns pecuniary spillovers involving market transactions. Similarly, 'sending' firms' perceived need to shield knowledge outflows will determine the importance of mechanisms (e.g. patent strategy, and information dissemination strategies).

While difficult to separate, conceptually it makes sense to model spillovers as a function of supply, demand and the presence of different transfer mechanisms, which will allow for greater precision in knowledge spillover estimations. In this model, geographic proximity, while likely to facilitate a number of mechanisms, is not a mechanism itself, and should be largely irrelevant if we have measured and modelled transfer mechanism and receiving firm characteristics well (e.g. Keller, 2004).

Measurement: direct spillovers versus drivers of spillovers.

A third distinction in approaches can be made between

- Analysing the *drivers of spillovers*, such as the mechanisms that are present, the relevance of the knowledge to the receiver;
- Analysing and measuring spillovers *directly*.

The first approach is taken by studies linking productivity to R&D stocks of other industries and countries, using potential facilitators/mechanisms or expected correlates of these mechanisms as weights, such as bilateral trade, language and institutional differences, foreign direct investment, overlaps in technological profiles, closeness of technologies, labour mobility, patent citations, etc. The second approach is taken by studies using survey data (in most cases Community Innovation Surveys) asking firms which sources of knowledge they have found useful in their innovation process (e.g. Crespi et al. 2008a; 2008b; Kaiser, 2002; Belderbos and Grimpe, 2012), and by studies examining inter-firm patent citations. The survey measures often have the drawback that they are not available systematically at an industry level or across countries. Patent citations, to the extent that they are not purely added by the patent examiner but are a known input to the citing firms' inventive activity, can be seen to reflect knowledge flows, although they cover a small spectrum of all actual and potential knowledge flows. Hence, there are two approaches to the use of patent citation data, which are important to distinguish for our further discussion. On the one hand, the *intensity* of patent citations between firms can be seen as a measure of 'closeness' or a proxy for the impact of several mechanisms facilitating knowledge flows. On the other hand, the *number* of citations can be regarded as an imperfect proxy for the actual volume of knowledge flows. We discuss this more in detail in section 3.

2.2 Industry, inter-industry, and international R&D spillovers

The standard approach in the literature to the assessment of knowledge spillovers has been the production function approach, treating the knowledge spillover stock as a separate input to the production process. The search has been for the relevant weights given to R&D performed by firms in (other) industries and countries, to get as close as possible to the actual knowledge flows. One approach has been to focus on specific mechanisms or economic transactions between firms. Weights for flow measures have been proposed based on input transactions (based on input output tables; Terleckyj, 1980; Goto and Suzuki, 1989), capital goods transactions (Sveikauskas, 1981), cross-hiring of R&D personnel, attendance at workshops, seminars or trade fairs, (R&D) collaborations (Belderbos et al, 2004), licensing and technology acquisition, inventions (patents, Scherer, 1982) or innovations (Sterlacchini, 1989) developed in industries of origin but used in different industries, and patent citations between industries. The intuition is that the more *j* trades with *i*, invests in *i*, collaborates with *i* or gets cited by *i*, the more it is likely to diffuse its knowledge to *i*. These indicators may (partially) or may not involve pecuniary spillovers and the latter are in practice very difficult to dissociate from pure knowledge spillovers. Since knowledge usually has important tacit and non-codified elements and is costly to transfer (e.g. Teece, 1977; Feldman and Lichtenberg, 1997), any interaction between firms that may help information to flow, may assist in effective knowledge spillovers.

Spillovers can also be measured independently of any economic transaction simply on the basis of proximities, or ‘closeness’, in various types of space. These proximities can be uncentred correlation coefficients between positions in patent classes (Jaffe, 1986), fields of research (Adams and Jaffe, 1996), qualifications of personnel (Adams, 1990) or lines of business. The simply reflect the ‘closeness’ between firms based on the expected relevance of the knowledge and the expected absorptive capacity of the receiving firm. Nooteboom et al. (2007) suggest that the knowledge bases of the firms should neither be too close nor too distant, as strong overlaps provide for fewer complementarity and learning opportunities, while large cognitive and technological distances reduce effective knowledge flows. Related literature has more generally stressed the importance of absorptive capacity for the effective utilisation of knowledge received by firms, e.g. in the FDI spillover literature and in the literature on complementarities in innovation strategies (e.g. Cassiman and Veugelers, 2006). Lokshin et al. (2008), for instance, find that the productivity impact of external R&D is a function of intramural (internal) R&D expenditures.

There still is limited unambiguous evidence on the relative performance of different transmission mechanisms and the associated different types of weighting matrices mediating knowledge flows between firms and industries. The estimated social rates of return may vary a great deal depending on the weighting matrix used (Van Meijl, 1977). Generally, since spillovers are unpriced and often accidental, effects can vary strongly. In a special issue of *Economic Systems Research* (9(1), 1997) a number of authors compare the effects (in significance and economic returns) of different types of spillover matrices, examining patent flows, patent citations, intermediate inputs and capital goods transactions, with mixed results. The best aggregator differs by sector, while the identification of spillover channels from the simultaneous use of different spillover measures quickly runs into collinearity problems. More recently, Ikeuchi et al. (2012) examine R&D spillovers between Japanese firms at the plant level and compare the role of technological proximity (derived from patent data) with trade effects (derived from input-output tables). They find the strongest and most robust spillover effects for R&D weights based on the technological relatedness between firms' R&D activities. Simultaneous inclusion of R&D stocks weighted by input-output table coefficients shows only marginally significant effects of the latter and consistent results for the technological proximity measure.[1] Peri (2005) highlights that trade data underestimate the geographic scope of knowledge spillovers, because trade faces more substantial barriers than knowledge flows in general. Patent citation data more accurately reflect the diffusion of knowledge internationally.

The likelihood of knowledge spillovers and the importance of several mechanisms of knowledge transfer is also a function of geographic distance, for instance because the tacit nature of parts of

[1] Once individual buyer-supplier transactions were taken into account for a subset of firms, supplier firms' R&D stocks were associated with stronger productivity gains. In particular in the context of Japanese firms, stable supplier relationships, for instance those within vertical business groups, have been associated with knowledge sharing and technology spillovers (Suzuki, 1993; Branstetter, 2000).

the relevant knowledge requires personal interaction. Pioneering work by Jaffe (1986) suggests that knowledge spillovers, measured by patent citations, reduce with distance. Botazzi and Peri (2003) estimate mild distance effects, with spillovers halved after 1200 kilometres. Keller (2001) estimates an exponential decay function and shows that distance matters for international knowledge spillovers. Maurseth and Verspagen (2002) find substantial border effects in regional knowledge flows between European regions. Belderbos et al. (2012) find mild distance effects in their analysis of inter- and intra-industry spillovers at the plant level in Japan. Lykachin et al. (2010) find that an exponential decay function between regions of firm inventors gives higher coefficients for the R&D stock than a non-weighted stock measure. Rosa and Mohnen (2008) find that a 10% increase in distance decreases the tacit knowledge transfer by 1.4%. In general, studies have suggested that both technological distance and geographic distance attenuate the productivity effects of R&D spillovers (Jaffe et al, 1993; Adams and Jaffe, 1996; Aldieri and Cincera, 2009), while proximity appears less crucial for the most proximate technologies (Orlando, 2004). Peri (2005) finds that technological knowledge developed by leading industries at the technology frontier, diffuses more broadly.

A number of studies have used survey data to examine direct measures of knowledge flows. Kaiser (2002) tests various ways of aggregating outside knowledge into a spillover construct on the assumption that horizontal (intra-industry) spillovers should be associated with high scores for horizontal sources of knowledge indicated by firms in innovation surveys (i.e. from competitors) and the vertical (inter-industry) spillovers are associated with vertical sources of knowledge (i.e. from customers and suppliers). Uncentred correlations of firms' characteristics or skill mix predict inter-industry spillovers better than the Euclidian distance between firm characteristics or geographic distance between firms. Crespi, Criscuolo, Haskell and Slaughter (2008) also use direct measures of knowledge flows, as they are revealed in the innovation surveys, for explaining TFP growth in the UK. They find that knowledge spillovers from competitors and suppliers contribute to TFP growth, in addition to intra-firm technology transfers. Belderbos and Grimpe (2012), using German innovation survey data, find positive productivity effects of knowledge flows from domestic customers and competitors.

The literature on personnel mobility as a mechanism of knowledge spillovers is more limited. This may in principle be an important channel, since individual researcher acts as a carrier of tacit knowledge, which otherwise is more difficult to transfer. There are two approaches: either researcher mobility across firms or countries brings with it the transmission of knowledge, or alternatively, researchers do not move, but their personal connections help knowledge to diffuse across borders. Almeida and Kogut (1999) discuss this phenomenon and provide an empirical example. Positive effects of hiring R&D personnel are found by Moen (2005), Kerr (2008), Magnani (2006), and Maliranta, Mohnen, and Rouvinen (2010).

While other firms' R&D generally is a potential source of knowledge spillovers with positive productivity consequences for the 'receiving' firms, R&D spillovers may in some cases also be negative. Bloom et al. (2013) test the hypothesis that R&D of firms that are close competitors in product markets may negatively affect productivity of rival firms due to a market stealing effect. When new products and technologies developed by the rival firm renders existing products and technologies of a firm obsolete, the firm's technology and products become less productive and do not generate the same demand. Negative effects can in general occur in the short term if there are adjustment costs in the short run implementing the new knowledge and integrating this in new, potentially substituting, products of the firm. Similarly the social rate of return to R&D is reduced when R&D is used as a mere strategy to pre-empt competition or when patent races lead to duplicative R&D (Jones and Williams, 1998; Hall et al, 2010). Potential negative R&D spillovers, if these occur, are most likely to occur for 'horizontal' spillovers within narrowly defined industries. The absence of market rivalry provides greater incentives for productivity and growth enhancing knowledge exchange and spillovers.

International knowledge diffusion

International R&D spillovers are transmitted through the same channels as those documented in the literature on technology transfer: international trade in final goods, intermediate inputs, capital goods, especially if it comes with manpower training to operate the new machines and to assimilate new production and management techniques, foreign direct investment (FDI), migration of scientists, engineers, educated people in general, or their attendance at workshops, seminars, trade fairs and the like, publications in technical journals and scientific papers, referencing other publications, invention revelations through patenting, international research collaborations or international mergers and acquisitions, foreign technology payments, i.e. royalties on copyrights and trademarks, licensing fees, the purchase of patents, the payments for consulting services and the financing of R&D conducted abroad (Hall et al, 2010).

While all these mechanisms can be important, the literature has predominantly focused on the role of intermediate goods trade and FDI. A highly cited study of the impact of international R&D spillovers on TFP was conducted by Coe and Helpman (1995). In this study, conducted for 22 developed countries, they used the share of imports from the sending country as weights to aggregate the R&D, confining the possible set of sending countries to the G-7 economies (Canada, France, Germany, Italy, Japan, the UK, and the US). They found substantial spillover effects, with roughly a quarter of the benefits from R&D in G-7 countries accruing to their trading partners. Their study has been criticised and revisited in many subsequent studies. Keller (1998) cast doubt on the trade-related interpretation of Coe and Helpman’s R&D spillover by showing that significant foreign R&D spillovers can be obtained when the weights in the construction of the spillover are random rather than based on import shares. This result suggests that the important identifying variation was in the total amount of external R&D rather than being mediated by trade. Lichtenberg and van Pottelsberghe (1998) criticise Coe and Helpman’s weighting of the foreign R&D stocks by means of the proportion of total imports originating from the foreign R&D sources for being too sensitive to the aggregation of the data and propose instead to normalise the imports from the recipient country by the GDP of the sending country. Kao, Chiang and Chen (1999), using cointegration techniques between the TFP and R&D variables, could not replicate Coe and Helpman’s results.[2]

In later work, different weights have been used to estimate international knowledge spillovers.

---

[2] Abdelmoula (2009) on the other hand, showed persistent foreign R&D spillover effects when adding spatial correlations (via a spatial lag model or a spatial error model).

Verspagen (1997) shows that matrices combining trade data and patent data (the latter to measure technological proximity) have improved properties in measuring relevant international technology flows. Keller (2001) allows for different transfer mechanisms, including bilateral language skills (the percentage of population mastering English), FDI and imports. He finds an important role for the ease of communication represented by language skills. Studies examining the role of capital goods imports, rather than all trade, have obtained empirically strong results (Xu and Wang, 1999). Another stream of literature examining potential 'learning by exporting' effects, relating export to subsequent firm productivity, has overall provided mixed results (e.g. Belderbos and Grimpe, 2012). While the international knowledge diffusion literature has focused on knowledge spillovers from suppliers associated with intermediate and capital goods purchasing, the export learning literature in contrast examines the role of (foreign) customers and competitors as sources of knowledge. What emanates from the literature is that spillovers from exports (learning from foreign competitors and clients) are most likely to occur if the foreign market is more sophisticated. Using survey evidence on knowledge sourcing, by German firms, Belderbos and Grimpe (2012) find positive productivity effects for knowledge coming from foreign competitors as well as foreign customers, although learning from domestic clients has the strongest productivity effects in the German context. Crespi et al. (2008), while not being able to distinguish between foreign and domestic sourcing, find positive effects of customer spillovers, which are more pronounced for firms with prior exporting activities.

Keller (2004) in his literature review concludes that overall the evidence demonstrates that trade facilities international technology diffusion. Yet whether trade is also the best predictor or mechanism of knowledge flows and spillovers is highly debatable. The findings in several studies mentioned *supra* suggest better properties for patent citations as indicators for international knowledge diffusion. A few studies have sought to 'validate' that trade affects knowledge flows, by considering patent citations as expressions of actual knowledge flows and correlating trade, in particular imports, with patent citations. While Eaton and Kortum (1996) find little robust associations, Sjöholm (1996) finds a clear association between trade and citations.

Another channel for knowledge spillovers that has received abundant attention is foreign direct investment. Here foreign affiliates of multinational firms are the conduit of international knowledge spillovers and knowledge transfers. Foreign affiliates tend to be more productive than their domestic counterparts, as affiliates can draw on the transfer of technological and other intellectual assets from the parent. These affiliates in turn can be a source of knowledge spillovers to local firms. The empirical literature on the spillover and productivity effects of FDI has produced mixed evidence on the impact of FDI on the performance of local firms. A number of studies have shown positive effects of FDI on host country labour productivity (e.g. Globerman 1978) and product and process innovations (e.g. Bertschek 1995) for developed countries. Studies have provided less support for spillovers in developing countries. Haddad and Harrison (1993) did not find evidence of productivity increasing technology spillovers from foreign-owned subsidiaries to local firms in Morocco. Aitken, Hanson, and Harrison (1997) found evidence of a limited form of spillovers of multinational investment in Mexico in terms of the development of export channels. Xu (2000) using micro data on US affiliates abroad finds positive spillover effects of US investments on host country productivity. Surveys (Görg and Strobl, 2001; Görg and Greenaway, 2004) of this expanding literature suggest that in general there is little impact of inward FDI on developing country (firms') productivity on average, with positive results restricted for developed economies.

A comprehensive study of spillovers of FDI takes into account whether these affiliates conduct R&D. Guellec and Van Pottelsberghe (2001) find a positive impact of foreign R&D, as measured by the ratio of host country invented patents with a foreign assignee, on host countries' productivity growth; this effect is more pronounced in countries with higher domestic expenditures on R&D. The most recent studies have suggested that spillovers are conditional on a productivity or technology gap between domestic firms and the foreign affiliates that is not too large (Görg and Greenaway, 2004, 181). If foreign affiliates utilise complex technologies or if the skill base of domestic firms is too limited, the lack of absorptive capacity restricts the intensity of spillovers. An important limitation of most of these studies is that they have focused on horizontal –same industry- spillovers while vertical spillovers to suppliers and customers are often not well taken into account (e.g. OECD, 2007). The latter gap has been addressed by more recent studies. Whereas the traditional literature on international technology diffusion/spillover literature has emphasised the role of imports of intermediate goods (spillovers from suppliers), recent work on FDI spillovers (e.g. Javorcik, 2004) has emphasised the role of ‘backward’ spillovers from affiliates of multinational firms to local suppliers, as foreign firms aim to develop a local supply base for their activities and demand quality standards to be met.

FDI not only potentially provides knowledge spillovers to local firms in host countries. Foreign direct investment can also be a source of ‘reverse’ knowledge transfer and be used as an instrument of international knowledge *sourcing*. Van Pottelsberghe and Lichtenberg (2001) provide evidence for outward FDI as another channel of international R&D spillovers to the country engaged in FDI. Branstetter (2001) finds that knowledge flows from the US to Japan, as measured by patent citations, increase if Japanese firms operate affiliates in the US. Griffith et al. (2006) find that UK firms with R&D activities in the US benefit from spillovers due to the growth of the US knowledge stock. Belderbos, Lokshin and Sadowski (2011) provide an overview of this literature, and find evidence for the Netherlands that productivity effects to multinational firms’ domestic operations due to engagement in foreign R&D is predominantly observed if the domestic industry is behind the R&D frontier. The relative importance of domestic and foreign R&D contributions to total factor productivity growth depends on the relative importance of the domestic and foreign knowledge stocks (the R&D frontier) and is moderated by firms’ domestic R&D expenditures and related absorptive capacity (van Pottelsberghe and Lichtenberg, 2001; Belderbos, Lokshin, Sadowski, 2011). Criscuolo (2009) finds that knowledge sourcing through foreign R&D by (German) multinational firms, can subsequently lead to spillovers to other firms in the home country if these are collocated with the multinational firm.

A final remark on multinational firms and the returns to (policy induced) R&D, relates exactly to the fact that firms are present (with R&D) in multiple countries. On the one hand, this presence of multinational firm will increase international knowledge diffusion (including tacit knowledge) and may increase the return to R&D and R&D policies at the European level. On the other hand, multinational firms' coordination of R&D activities across (European) countries also offers a challenge to European policies, as R&D expenditures in a country may not only respond to domestic R&D incentives but also to R&D policies in other countries. Research on R&D location decisions has found that the location of such projects across European countries and regions is quite sensitive to the presence of R&D tax incentives (Belderbos et al. 2014). Countries may compete for R&D investments through tax and other incentives. R&D incentives may then lead to a shift in R&D across countries rather than a net increase in R&D, reducing the European-wide multiplier. This is a consideration that is best attended in the micro analysis.

Stylised facts

Based on the review of the literature above, we can summarise a number of stylised facts that measures of industry and international spillovers should preferably take into account:

- Although distinctions have been made between knowledge spillovers due to the public good nature of knowledge on the one hand, and 'rent' or 'pecuniary' spillovers between suppliers and buyers due to the incomplete translation of R&D-induced quality improvements into the price of intermediates on the other hand, this distinction is difficult to make empirically. Rent spillovers will usually have elements of 'pure' spillovers and pure spillovers can also take place in the course of economic transactions.
- The variety of potential transmission channels and transmission effects – all with their measurement problems - suggests calculating spillover matrices that are sufficiently broad to capture their correlated effects.
- Knowledge spillovers can be measured directly (through patent citations or survey evidence) and their intensity can be estimated from various measures of 'proximity' between firms, industries and countries, and/or various measures of interaction and transfer mechanisms between them (e.g. trade, FDI).
- The literature on trade and international knowledge diffusion appears to have largely ignored the 'backward spillovers' from customers to suppliers. These have been found to be of importance in the FDI literature and the literature on 'learning by exporting'. Sophisticated demand and customers can be a source of spillovers and ideas for innovation.
- Foreign direct investment as well as trade can be sources of international knowledge diffusion. These effects can occur both in case of inward FDI (knowledge spillovers from

foreign investors) and outward FDI (active knowledge sourcing abroad), and imports of technology embodied goods, as well as export and export learning.

- There is little robust comparative evidence on the relative roles of different mechanisms of (international) knowledge spillovers. Patent citation data appear more powerful indicators of international knowledge diffusion as compared to trade data, in particular since trade data are biased in geographic space due to substantive remaining cross-border barriers.
- Spillovers are larger if the quality of the R&D is greater (i.e. the firms, industries, countries where the spillovers originate are at the technology frontier).
- Spillovers are moderated by the absorptive capacity of the receiving firms/countries. Developing countries benefit less than developed countries from international knowledge diffusion (e.g. exports, imports, FDI).
- Spillovers depend on the technological proximity between the firms or industries. Two industries with a similar knowledge base will benefit more from inter-industry spillovers than industries drawing on very different bodies of knowledge. Knowledge should be relevant to the receiving industry and firm.
- Spillovers may be weak or negative between firms with highly overlapping knowledge bases (as there is little to learn), and in case firms are direct product market competitors (through market stealing and R&D duplication effects). The absence of market rivalry provides greater incentives for productivity and growth enhancing knowledge exchange and spillovers. This includes exchanges and knowledge flows, sometimes purposeful, with suppliers and clients, or in general with firms from different, but technologically related industries.
- Spillovers are localised and decay in distance, in particular if noncodified, tacit, knowledge is more important for the technology/ industry. The role of distance can be reduced by intensive use of transfer mechanisms such as trade and FDI. The role of geographic distance is often confounded with the effect of other types of 'distance' such as shared languages and institutions.

3. Patent-based spillover indicators: Advantages and Disadvantages

In this section, we discuss the advantages and disadvantages of patent data to derive inter-industry and international spillover weights. We then proceed by highlighting the main characteristics of two specific matrices developed for potential use in the Simpatic project to translate micro effects of R&D policies into country and European wide effects.

Patent (citation) data as indicators of knowledge spillovers

The great advantage of patent (citation) based measures is that they allow for construction of spillover matrices that cover in a systematic manner intra-sectoral, inter-sectoral and international dimensions. Patent citation data can be used to calculate direct measures of flows of technological knowledge, while the intensity of patent citations between industries and countries can also be taken as a correlate of various other transfer mechanisms affecting knowledge spillovers. Prior work suggests that patent citation data are better predictors of international knowledge flows than trade data (Ikeuchi et al, 2012, Peri, 2005). More particularly, the fact that patent citation data at their core are very imperfect but direct indicators of knowledge flows, creates valuable properties: patent citation data will incorporate both the importance of the technology (e.g. as it relates to the 'frontier' status of the technology, the relevance of the technology for the receiving firm or industry, and most likely the inherent absorptive capacity of the receiving firm and industry. These are all stylised facts of the international knowledge diffusion process that a spillover matrix preferably takes into account. Patent indicators also contain detailed information on the technological content of inventions, and the location of owners and inventors. Patent data are objective in the sense that they have been processed and validated by patent examiners; and patent data are easily available from patent offices and cover long time series (e.g. Pavitt, 1985; Basberg, 1987; Griliches, 1990).

Patent citation measures have been utilised in various streams of research. The intensity of patent citations between technology fields has been used to establish the technological relatedness between technologies and sectors (e.g. Belderbos, Leten, Van Looy, 2007). Country and industry specific patent citations have been used as revealed measures of the ease of technology transfer between countries for specific industries, and have been shown to be relevant indicators in the context of multinational firms' R&D location decisions (Belderbos, Lykogianni and Veugelers, 2008). International and inter-regional patent citations have been used to evaluate the effect or proximity on knowledge flows (e.g. Jaffe, 1989; Maurseth and Verspagen, 2002; Belenzon and Schankerman, 2012). Patent citation indicators have been used to validate the role of trade mediating international knowledge spillovers (Sjöholm, 1996). Finally, an exercise by the Canadian patent office to assign to each patent most likely industries of origin (based on the assignee/applicant) and industries of use (based on the described potential utilisation of the invention) has allowed the calculation of technology flow data between industries (e.g. Johnson, 2002).

Like any indicator, patent indicators are also subject to a number of drawbacks: not all inventions are patented and those that are patented vary in their technical and economic value and importance (Trajtenberg, 1990; Lanjouw et al, 1998; Gambardella, 2008). Patent citations only measure part of knowledge flows, and are more representative in industries with a high propensity to patent. Concordances of patents to industries (e.g. Smoch et al, 2003) are until now restricted to manufacturing industries, such that it is difficult to establish patent based spillovers for services industries. The often used original classification of patents into industry of origin and industry of use (Johnson, 2002), although updated, is more than 20 years old and therefore less likely to reflect technological developments in more recent years, and it is Canadian-based and therefore possibly not so accurately reflecting the technology flow scheme of other countries.

Patent citations are an imperfect measure of knowledge flows. The legal purpose of references to other patents is to indicate which parts of the knowledge described can be claimed by the patent and which parts have been claimed by prior patents and publications. Patent references restrict the scope of patent claims to novelty and represent a link to the pre-existing knowledge base upon which patents have been built (Criscuolo and Verspagen, 2008; Jaffe et al, 2004). This feature has been used by prior studies (e.g. Narin et al, 1997) to justify the use of patent references as information source affecting the knowledge base of patent applicants. One critique to this particular use of patent references is that the prior art section of patents includes references provided by patent applicants while filing their patents as well as references added later on by patent examiners during their search for relevant prior art (Alcacer and Gittelman, 2006). The problem is that patent applicants may not know part of the references cited in the prior art of their patents, especially some references made by patent examiners (Brusoni et al, 2005). However, surveys of USPTO patent inventors (Jaffe et al, 2004; Fleming and Sorenson, 2004; Tijssen et al, 2000) have shown that inventors are aware of a significant part of the patents and scientific articles that are cited in the prior art of their patents, including some of the references made by patent examiners. In a survey of USPTO patent inventors, Jaffe et al (2004) found that patent inventors have a moderate to high familiarity with more than 50% of the cited patent references. Given that, on average, 63% of patent references in USPTO patents are provided by patent examiners (Alcacer and Gittelman, 2006), this shows that patent applicants are also aware of part of the patent references that are added by patent examiners. Using data on EPO patents and responses to the Community Innovation Survey (CIS) for a sample of French firms, Duguet and MacGarvie (2005) find a positive correlation between the number of references in firms' patents and the intensity to which firms have sourced external knowledge.

There are several ways to employ patent and patent citation data to measure technology spillovers:

1. The patent data classification in sectors of use (SOU) and industries of origin (or industries of manufacture, IOM, Johnson, 2002) can be used to construct general 'proximity' or 'technology flow probability' matrices describing likely knowledge flow intensities across industries. Because these originator-user linkages between sectors of origin and sectors of use will often be established through trade relationships (e.g. improvements in power equipment benefitting public utilities), this measure will in addition be correlated with the presence of pecuniary spillovers. The measure lacks an international dimension, which will have to be added from a different source (see below). The Johnson/Canadian index does include all industries of use such that on the receiving side a full spectrum of industries can be considered.

2. Patent citation data linked to inventor locations can be used to derive weights for the magnitude of international knowledge flows. Using concordances of technology fields to industries where patents are most likely to originate, the international technology flow

matrix can be given an industry dimension (e.g. Belderbos, Lykogianni, and Veugelers, 2008). Since the citations reflect knowledge flows between industries where inventions and new technology originate, these measures are more reflective of 'pure' knowledge spillovers that can arise without trade mediation. A citation matrix will have to be limited to manufacturing as only concordances exist between manufacturing industry of origin and technology fields. A combination with the Johnson concordance in 1) could address this problem and extend the matrix to services industries of use. The approach with any of these measures is that relative *intensities* of patent citations between countries and industries (e.g. relative to the number of patents filed) proxy for the importance of knowledge spillovers (due to various mechanisms, proximity and other factors) and are used as weights mediating the effects of industry and country R&D.

3. One can use patent citation data as a *direct measurement*, a direct expression, of knowledge flows. Hence, one does not consider relative intensities of citations, but absolute numbers of citations as an indicator of the volume of knowledge flows. If one chooses this approach, basically the number of citations can be used directly in the production function, substituting for R&D stocks. At the same time, citations will be a function of absorptive capacity such that this capacity (e.g. interactions with internal R&D) is no longer an issue. This approach is likely to exacerbate the drawbacks of patent data, in the sense that direct measurement of knowledge flows is not really feasible in industries with a low propensity to patent. If one instead uses intensities, scaling citations with patent stocks in the industries, this bias can be addressed.

Technology flow matrices based on patent citations and sector of use and origin data

In this paragraph we describe two available matrices that can serve as weights for inter- and intra-industry spillovers within and across national borders. We draw on Meijers and Verspagen (2010) who originally developed the matrices. The excel file with these matrices are available upon request and are part of this work package.

The first matrix (IOM/IOM) focuses on patent citations between industries of manufacture (origin), both for the cited and citing patent.. It is the more conventional technology spillover matrix, most representative of 'pure' knowledge spillovers. R&D (patent output) in sector i is cited in a patent issued by sector j and hence indirectly is supposed to affect the knowledge base and hence productivity in sector j. Citations indicate the knowledge flow from sector i to sector j. The largest number of citations is expected within the confines of the same industry. Meijers and Verspagen (2010) provide as an example a patent describing a new computer (originating in the computer industry) that cites a patent describing a new chip (originating in the semiconductor industry).

The second type of matrix (IOM/SOU) goes one step further in combining the pure knowledge and the pecuniary dimensions of spillover. It describes both the knowledge flows measured by patent citations and the horizontal and vertical inter-industry transaction flows. This matrix combines the Johnson (2002) relationships between industry of origin and industry of use with (cross-border) patent citation information between patent classes. More precisely, Johnson (2002) assigned to each patent class a distribution of industries of manufacture (IOM) and a distribution of sectors of use (SOU). A patent classified in a certain patent class is thus likely to be produced in a certain number of industries and used in another set of industries. A patent citation is thus split into a number of industries of manufacture that correspond to the cited patent and a number of sectors of use that correspond to the citing patent. An example is a patent describing originating in the chemical industry, describing a chemical that is added to cement (to improve its performance) that is cited by a patent describing a new way of laying concrete floors with sector of use the construction sector.

In the Johnson (2002) matrix there are no service sectors among the IOM sectors, such that only manufacturing sectors can be considered as sources of knowledge spillovers. One particular advantage of the SOU matrices is that services sectors are considered on the receiving end. Both types of matrices capture international technology flows but only regarding the patent citation, i.e. a patent issued in industry I in country k can be cited by another patent classified in sector class j in country l. However, a major limitation is that the split of the patent in IOM (industry j applying for the citing patent) and SOU (the sector using the patented technology of industry j) does not have an international dimension. In other words, the sector of use is regarded as situated in the same country as the industry of the citing patent. Hence, to capture international spillovers due to economic transactions between industries creating and using technologies, it may be opportune to rely on alternative indicators, such as trade based transaction matrices.

Both matrices are derived from PATSTAT patent data in 2005, using patent families for which the authorities involved included the USPTO, the EPO, or the WIPO, and patents filed since 1990. Matrices are calculated for every year in the period 1990-2003, using fixed 5 year citation lags. In addition to European countries, citations to and from the rest of the world are also included. Industries in the Johnson (2002) classification are mapped into the 30 industries of the NEMESIS model. The calculation takes into account that a patent can have multiple inventor countries and multiple technology classes: in that case the fractional method of allocating patents to countries and sectors is used. Citations are considered at the patent family level (using narrowly defined equivalents of patents), omitting duplicate citations.

Table 1 describes aggregate citation numbers between countries for the year 2003. Since aggregates are used (based on the country of inventor) the sector of origin and sector of use matrices provide identical results in this case. The dominance of Germany in the volume of citations (cited and citing) is remarkable, but this largely reflects Germany's share in patent applications. Also apparent is that domestic citations are still most important for the larger countries, while for the smaller countries (facing relatively larger foreign R&D stocks and patent stocks), foreign citations are much more important. In general, cross-border citations are roughly in 'balance' for the European countries, with a reasonable balance between incoming and outgoing citations.

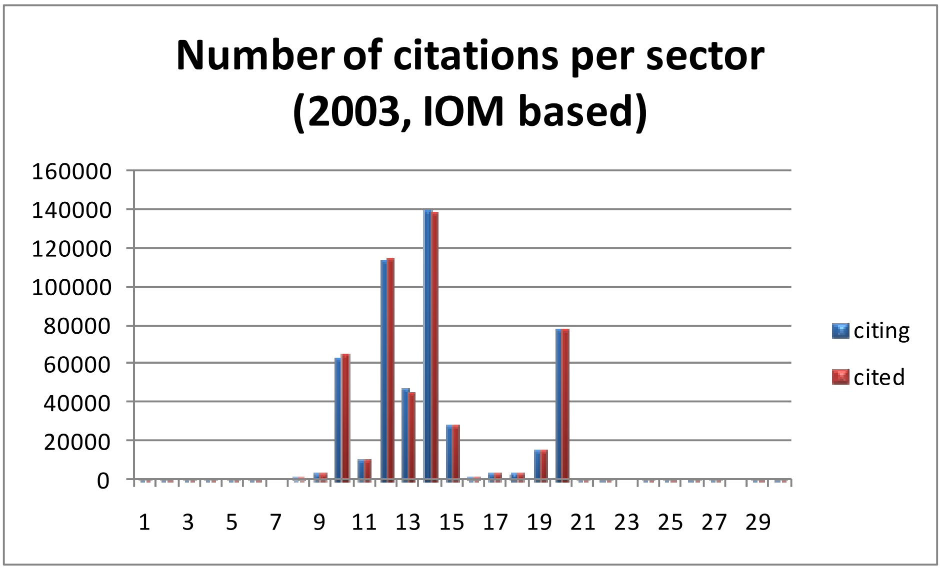
Table 1: aggregate (logged) number of patent citations as a percentage of total (logged) patent citations, 2003

		Citing								
	2003	DE	FI	FR	GB	IT	NL	SE	ROEU	SUM
Cited	DE	45.0	0.3	2.7	1.8	1.3	1.0	0.7	2.6	55.4
	FI	0.5	0.9	0.2	0.2	0.0	0.1	0.2	0.2	2.2
	FR	2.3	0.1	5.0	0.7	0.3	0.2	0.2	0.6	9.2
	GB	2.4	0.2	0.8	6.4	0.3	0.5	0.3	0.8	11.9
	IT	0.9	0.1	0.3	0.2	1.6	0.1	0.1	0.3	3.5
	NL	1.2	0.1	0.3	0.5	0.1	3.6	0.1	0.4	6.4
	SE	0.9	0.2	0.2	0.3	0.1	0.1	1.5	0.3	3.6
	ROEU	2.4	0.1	0.6	0.6	0.3	0.3	0.2	3.3	7.8
	SUM	55.6	2.0	10.0	10.7	4.0	6.0	3.3	8.4	100.0

Source: Meijers and Verspagen (2010)

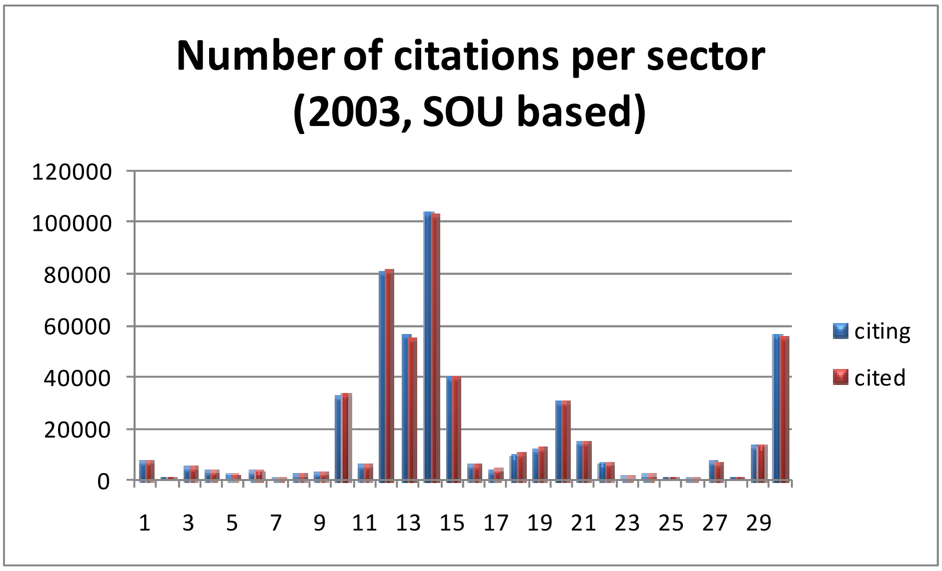
Figures 1 and 2 show the number of citations in 2003 depending on the sector of origin and sector of use. The sector codes are provided in the appendix to this report. Obviously, using the sector of use approach, citations are more spread out over services sectors, with nonmarket services (such as administration and defence, sector 30) and business services (sector 29) among the industries applying technology most often. This is at the expense mainly of the category of 'other manufacturing'. What is also striking is that industries are quite balanced in the citations they make and the citations they receive (although the numbers hide some differentiation in this regard).

Figure 1



Source: Meijers and Verspagen (2010)

Figure 2



Source: Meijers and Verspagen (2010)

There are several alternatives for further development of spillover matrices in this direction and which are open for discussion in the Simpatic setting. One could for instance go one step further and conceive of a matrix linking sectors of use (both for the citing and cited patent). The use of a technology (patent) in sector i (perhaps followed by the technology being embodied in the sector output) affects the productivity of sector j if the use of a technology (patent) by sector j draws on the technology (patent) used in sector i. An example is a patent describing a chemical that is added to cement (to improve its performance) and has as sector of use the cement industry, that is cited by a patent describing a new way of laying concrete floors with sector of use the construction sector. One important point to note with the sector of use matrix is that knowledge spillovers get detached from sectoral R&D expenditures. E.g. in the example the chemical technology originates in the chemical industry and is due to R&D conducted there, but this is not reflected in the matrix, since the cited patents is classified in the cement industry. Of course, the using industry may also have to engage in R&D to apply the technology (in cement), but it is clear that this approach departs from the general approach to construct matrices that mediate between R&D expenditures of industries and countries.

Based on the stylised facts listed in the previous section and the advantages and disadvantages of patent data, we suggest the following:

- Combining industry of origin as the cited patent and industry of use as the citing patent. This would have the advantage that spillovers weights are available for all (receiving) industries, while the link between R&D in originator industries and the spillovers indicators is not severed. In terms of the example listed above, we would examine a patent originating in the chemical industry and the result of R&D efforts there describing the use of a chemical to fortify concrete, that is cited by a patent describing a new way to construct concrete floors, used in the construction industry. Conceptually this appears as an attractive way to measure technology spillovers to a broader spectrum of industries.
- The use of absolute numbers creates important scale sensitivity in the citations numbers, and the latter cannot be seen as 'weights'. For instance, it would be interesting to see if, given the number of patents originating in Germany, German patents are cited relatively much by, or cite relatively much, patents originating in other countries. The same logic applies to numbers at the industry level. Scaled measures also control for a 'propensity to patent' bias in the direction of patent intensive industries. Using scaled measures as weights implies that the matrix contains indicators of relative 'closeness' in international and technology/industry space. Defining weights as intensities of citation patterns by

defining them as deviations from expected citations based on the number of patents in the citing and cited industry/country. Once the matrices are transformed into intensity weights, these weights can be used to calculate relevant external R&D stocks (see Leten, Belderbos, van Looy, 2007 and Peri, 2005 for a discussion of possible weights).

- Another possibility is to use patent citation to capture primarily ‘pure’ knowledge spillovers, while combining these with cross-border trade transaction data across industries (e.g. the world input output database, Timmer, 2012) to measure pecuniary spillovers

4. Conclusions

The presence of intra- and inter-sectoral knowledge spillovers, national as well as cross-border, implies that the social rate of return to R&D exceeds the private rate of return. Taking such spillovers into account is essential to examine the European-wide impact of R&D policies in the Simpatic project. This paper reviewed the literature on (international) R&D spillovers and the various ways that have been proposed to measure such spillovers. Although distinctions have been made between knowledge spillovers due to the public good nature of knowledge on the one hand, and ‘rent’ or ‘pecuniary’ spillovers between suppliers and buyers due to the incomplete translation of R&D-induced quality improvements into the price of intermediates on the other hand, this distinction is difficult to make empirically and rent spillovers usually have elements of ‘pure’ spillovers. The variety of potential transmission channels and transmission effect – all with their measurement problems, suggests calculating spillover matrices that are sufficiently broad to capture their correlated effects. In this regard, there is evidence that patent-based indicators are better able to capture knowledge spillovers than trade-based indicators. The review suggested a number of stylised facts that indicators of knowledge spillover should preferably take into account. These relate to the importance of the strength of the technology of the source of the spillover, the absorptive capacity of the receiver of the spillovers, the potentially negative R&D spillovers if firms are direct competitors on product markets, the possibility of two-sided international knowledge flows due to foreign direct investment, and the often ignored effects of spillovers from customers to suppliers. Spillovers are also partly endogenous, as firms position themselves as best as they can to benefit from technology spillovers.

The paper proceeded by discussing the advantages and disadvantages of patent-based indicators of knowledge spillovers and concludes that the advantages outweigh the disadvantages. The great advantage of patent (citation) based measures is that they allow for construction of spillover matrices that cover in a systematic manner intra-sector, inter-sector and international dimensions. Patent citation data can be used to calculate direct measures of flows of technological knowledge, while the intensity of patent citations between industries and countries can also be taken as a correlate of various other transfer mechanisms affecting knowledge spillovers. More particularly, the fact that patent citation data at their core are very imperfect but direct indicators of knowledge flows, creates valuable properties: patent citation data will incorporate both the importance of the technology (e.g. as it relates to the 'frontier' status of the technology), the relevance of the technology for the receiving firm or industry, and most likely the inherent absorptive capacity of the receiving firm and industry.

We subsequently described two available matrices of inter-sectoral and international spillover weights based on patent citation data and classification of technologies into sectors of origin and sector of use, which are potential inputs for the micro-macro interaction in the Simpatic project. Finally, we offered suggestions for additional patent-based knowledge spillover matrices, using patent citations between sectors of use (citing patents) and sectors of origin (cited patents). This would allow including knowledge spillovers from manufacturing industries to extend to services industries – a feature that is generally difficult to incorporate but that can be important in the context of the macro analyses in the Simpatic project. In order to account for international rent spillovers, this IOM/SOU matrix could possibly be complemented with the world input output database (see Timmer, 2012).

References

Abdelmoula, M. (2009). *R&D et externalités: Une comparaison européenne*. PhD dissertation, Université Panthéon-Assas Paris II.

Acs, Z., Audretsch, D. & Feldman, M., 1994. R&D spillovers and recipient firm size. *The Review of Economics and Statistics*, 76, pp.336-340.

Adams, J.D. (1990). Fundamental stocks of knowledge and productivity growth. *Journal of Political Economy* , 98 (3), 673–702

Adams, J. D. & Jaffe, A. B., 1996. Bounding the effects of R&D: An investigation using matched establishment-firm data. *Rand Journal of Economics* 27, pp.700-721.

Aitken, B., G.H. Hanson, and A.E. Harrison, 1997. Spillovers, foreign investment, and export behavior, *Journal of International Economics*, 43(1-2), 103-132.

Alcacer, J. and Gittelman, M. (2006), How do I know what you know? Patent examiners and the generation of patent citations, *Review of Economics and Statistics*, 88(4): 774–779.

Aldieri, L. & Cincera, M., 2009. Geographic and technological R&D spillovers within the triad: micro evidence from US patents. *Journal of Technology Transfer*, 34(2): 196-211.

Almeida, P., and B. Kogut (1999), Localization of Knowledge and the Mobility of Engineers in Regional Networks. *Management Science* 45 (7), 905-917.

Audretsch, D. & Feldman, P., 1996. R&D spillovers and the geography of innovation and production. *American Economic Review* 86, pp.630-640.

Autant-Bernard, Corinne, 2011, Quantifying Knowledge Spillovers Using Spatial Econometric Models, *Journal of Regional Science*, Vol. 51, No. 3, 471-496.

Basberg, B.L., 1987, Patents and the Measurement of Techno-logical Change: A Survey of the Literature, *Research Policy*, 16(2), 131-41.

Belderbos, R. and C. Grimpe, 2012. *Learning by Exporting, Learning by Non-Exporting*, paper presented at the Academy of Management Conference, 2012.

Belderbos, R., B. Lokshin and B. Sadowski, 2011, *The Returns to Foreign R&D*, paper presented at the 2011 EARIE conference.

Belderbos, R.,. V. van Roy and F. Duvivier, 2013. International and Domestic Technology Transfers and Productivity Growth, *Industrial and Corporate Change*, 22 (1), 1-12, 2013.

Belderbos B, Van Roy V, Leten B, Thijs B, 2014. Academic Research Strengths and Multinational Firms' Foreign R&D Location Decisions: Evidence from R&D Investments in European Regions, *Environment and Planning A*, forthcoming, 2014.

Belderbos. R., B. Ito and R. Wakasugi 2008. Intra-firm Technology Transfer and R&D in Foreign Affiliates: Substitutes or Complements? Evidence from Japanese Multinational Firms, *Journal of the Japanese and International Economies*, 22 (3), 310–319.

Belderbos. R., E. Lykogianni and R. Veugelers, 2008. Strategic R&D Location in European Manufacturing Industries, *Review of World Economics*, 14 (2), 1-24.

Belderbos, R., B. Lokshin and M. Carree (2004), R&D cooperation and firm performance, *Research Policy*, 33(10), 1477-1492.

Belenzon S. and A. Schankerman (2012), 'Spreading the Word: Geography, Policy and University Knowledge Diffusion', *The Review of Economics and Statistics*, forthcoming.

Bernstein, J. I. (1989), The Structure of Canadian Inter-industry R&D Spillovers, and the Rates of Return to R&D, *Journal of Industrial Economics*, XXXVII (3), 315-328.

Bernstein, J. I. (1996), International R&D spillovers between industries in Canada and the United States, *Canadian Journal of Economics*, 29, Special issue, 463-467.

Bernstein, J. I., and P. Mohnen (1998), International R&D Spillovers Between U.S. and Japanese R&D Intensive Sectors, *Journal of International Economics*, 44, 315-338.

Bertschek, Irene, 1995. Product and Process Innovation as a Response to Increasing Import and Foreign Direct Investment, *Journal of Industrial Economics*, 43(4), 341-57

Bloom, N., Schankerman, M. & Van Reenen, J., 2013. Identifying technology spillovers and product market rivalry. *Econometrica*, forthcoming

Bottazzi L., G. Peri (2003), "Innovation and spillovers in regions: evidence fromEuropean patent data", *European Economic Review*, 47, 687-710.

Branstetter, L., 2000. Vertical Keiretsu and Knowledge Spillovers in Japanese Manufacturing: An Empirical Assessment. *Journal of the Japanese and International Economies*, 14(2), pp.73-104.

Branstetter, L., 2001. Are knowledge spillovers international or intra-national in scope? Microeconometric evidence from Japan and the United States. *Journal of International Economics* 53, pp. 53-79.

Brusoni, S., Criscuolo, P., Guena A., 2005. The knowledge bases of the world's largest pharmaceutical groups: What do patent citations to non-patent literature reveal? *Economics of Innovation and New Technologies* 14 (5), 395-415.

Cassiman, B. and R. Veugelers (2006), In search of complementarity in innovation strategy: Internal R&D and external knowledge acquisition, *Management Science*, 52(1), 68-82.

Cincera, M. and B. van Pottelsberghe de la Potterie (2001), International R&D spillovers: A survey, *Cahiers Economiques de Bruxelles*, 169, 3-32.

Coe, D. T. and E. Helpman (1995), International R&D Spillovers, *European Economic Review*, 39, 859-887.

Coe, D., E. Helpman and A. Hoffmaister (2009), International R&D Spillovers and Institutions, *European Economic Review*, 53, 723-741.

Crespi, G., C. Criscuolo, J. Haskel and M. Slaughter (2008a), Productivity growth, knowledge flows and spillovers, NBER working paper 13959.

Crespi, G., Criscuolo, C., & Haskel, J. (2008b). Productivity, exporting and the learning by exporting hypothesis: direct evidence from UK firms. *Canadian Journal of Economics Vol 41 (2)* , pp. 619-638.

Criscuolo, P. (2009), 'Inter-firm reverse technology transfer: the home country effect of R&D internationalization', *Industrial and Corporate Change*, 18, 869-899.

Criscuolo P., Verspagen B., 2008. Does it matter where patent citations come from? Inventor versus examiner citations in European patents. *Research Policy* 37, 1892-1908.

Duguet, E. and M. MacGarvie, 2005, How well do patent citations measure flows of technology? Evidence from French innovation surveys, *Economics of Innovation and New Technology*, 14(5), 375-393.

Duranton, G. and H. G. Overman, 2005, Testing for Localization Using Micro-Geographic Data, *Review of Economic Studies* 72 (4), 1077-1106.

Eaton, J. and S Kortum (1996), Trade in ideas: patenting and productivity in the OECD, *Journal of International Economics*, 40, 251-278.

Feldman, M. P., & F. R. Lichtenberg (1997), *The Impact and Organization of Publicly-Funded Research and Development in the European Community.* Working Paper Series 6040. National Bureau of Economic Research, Inc.

Fleming, L. and O. Sorenson, 2004, Science as a map in technologival search, *Strategic Management Journal*, 25(8/9), 909-928.

Furman, J., Kyle, M., Cockburn, I. & Henderson, R., 2005. Public & Private Spillovers, Location and the Productivity of Pharmaceutical Research,*Annales d'Economie et de Statistique*, 79/80, 167-190.

Gambardella, A., Harhoff, D., Verspagen, B., 2008. The value of European patents. European Management Review 5(2), 69-84.

Globerman, S. 1979, Foreign direct investment and ‘spillover’ efficiency benefits in Canadian manufacturing industries, *Canadian Journal of Economics*, 12, 42-56.

Görg, H. & D. Greenaway, 2004. Much Ado about Nothing? Do Domestic Firms Really Benefit from Foreign Direct Investment?, W*orld Bank Research Observer*, 19(2), 171-197.

Görg, H. & Strobl, E., 2001. Multinational Companies and Productivity Spillovers: A Meta-Analysis. *The Economic Journal*, 111, F723-F739.

Goto, A. & Suzuki, K., 1989. R&D capital, rate of return on R&D investment and spillover of R&D in Japanese manufacturing industries. *Review of Economics and Statistics* 71, 555-564.

Griffith, R., Harrison, R. and J.Van Reenen, J., 2008. How special is the special relationship? Using the impact of US R&D spillovers on UK firms as a test of technology sourcing. *American Economic Review*, 96(5), 1859-1875.

Griffith, R., S. Redding, and J. van Reenen, 2003, R&D and absorptive capacity: theory and empirical evidence. *Scandinavian Journal of Economics*, 105(1), 99-118.

Griffith R., S. Redding, J. Van Reenen, 2004, Mapping The Two Faces Of R&D: Productivity Growth In A Panel Of OECD Industries. *Review of Economics and Statistics*, 86(4), 883-895.

Griliches, Z. (1990), Patent statistics as economic indicators:a survey, *Journal of Economic Literature*, 28(4), 1661-1707.

Griliches, Z. (1992), The search for R&D spillovers, *Scandinavian Journal of Economics*, 94, 29-47.

Haddad, Mona & Harrison, Ann, 1993. Are there positive spillovers from direct foreign investment? : Evidence from panel data for Morocco, *Journal of Development Economics*, 42(1), 51-74

Hall, B., Mairesse, J. & Mohnen, P., 2010., “Measuring the returns to R&D », in the *Handbook of the Economics of Innovation*, B. H. Hall and N. Rosenberg (editors), Elsevier, Amsterdam, 1034-1082.

Haskel, J., Pereira, S. & Slaughter, M., 2007. Does Inward Foreign Investment Boost the Productivity of Domestic Firms? *The Review of Economics and Statistics*, 89(3), 482-496.

Ickeuchi K., R. Belderbos, K. Kukao, Y.G. Kim and H.U. Kwon (2012), Sources of private and public R&D spillovers: Technological, geographic and relational proximity, paper presented at the 2012 APIC conference, Seoul, South Korea.

Jaffe, A.B. (1986), Technological opportunity and spillovers of R&D: Evidence from firms' patents, profits, and market value, *American Economic Review*, 76(5), 984-1001.

Jaffe, A. B., Trajtenberg, M. & Henderson, R., 1993. Geographic localization of knowledge spillovers as evidenced by patent citations. *Quarterly Journal of Economics* 108, 577-598.

Jaffe, A., Trajtenberg, M., Fogarty, M., 2004. Knowledge spillovers and patent citations: Evidence from a survey of inventors. *American Economic Review* 90(2), 215-218.

Javorcik, B. S., 2004. Does Foreign Direct Investment Increase the Productivity of Domestic Firms? In Search of Spillovers through Backward Linkages. *American Economic Review* 94(3), 605-627.

Johnson, D. K. (2002), "The OECD Technology Concordance (OTC): Patents by Industry of Manufacture and Sector of Use", *OECD Science, Technology and Industry Working Papers*, 2002/5, OECD Publishing

Jones, C. and J. Williams. (1998) "Measuring the Social Rate of Return to R&D", *Quarterly Journal of Economics*, 113(4), 119-35.

Kaiser, U. (2002), Measuring knowledge in manufacturing and services: An empirical assessment of alternative approaches, *Research Policy,* 31(1), 129-149.

Kao, C., Chiang, M., Chen, B. (1999). International R&D spillovers: An application of estimation and inference in panel cointegration. Oxford Bulletin of Economics and Statistics 61, 691–709.

Keller, W. (1997), Are International R&D Spillovers Trade-Related? Analyzing Spillovers Among Randomly Matched Trade Partners, *European Economic Review*, 42, 1469-1481.

Keller, W. (2004), International Technology Diffusion, *Journal of Economic Literature*, XLII, 752-782.

Kerr, William R. (2008), Ethnic scientific communities and international technology diffusion. *Review of Economics and Statistics* 90(3), 518–537

Klette, T. J., 1996. R&D, scope economics, and plant performance. *Rand Journal of Economics* 27, pp.502-522.

Kugler, M., 2006. Spillovers from foreign direct investment: Within or between industries? *Journal of Development Economics* 80, pp.444-477.

Lanjouw, J. O., A. Pakes and J. Putnam (1998) "How to Count Patents and Value Intellectual Property: Uses of Patent Renewal and Application Data," *The Journal of Industrial Economics*, XLVI (4), 405-33.

Leten, B., Belderbos, R., & Van Looy, B. (2007). Technological Diversification, Coherence, and Performance of Firms. *Journal of Product Innovation Management*, 24(6), 567–579.

Lichtenberg, F. and B. Van Pottelsberghe de la Potterie (1998), International R&D Spillovers: A Comment, *European Economic Review*, 42(8), 1483-1491.

Lokshin, B., Belderbos, R. & Carree, M., 2008. The Productivity Effects of Internal and External R&D: Evidence from a Dynamic Panel Data Model. *Oxford Bulletin of Economics and Statistics*, 70(3), pp.399-413.

Los, B. and B. Verspagen (2000), R&D Spillovers and productivity: Evidence from U. S. manufacturing industries. *Empirical Economics* 25, 127-148.

Lychagin, S., Pinkse, J., Slade, M. E., & Van Reenen, J. (2010). *Spillovers in space: does geography matter?* NBER working paper No. w16188, National Bureau of Economic Research.

Magnani, E. (2006), Is workers' mobility a source of R&D spillovers? Evidence of effects of innovative activities on wages, *International Journal of Manpower*, 27(2), 169–188.

Maliranta, M., P. Mohnen and P. Rouvinen (2010), "Is inter-firm labor mobility a channel of knowledge spillovers? Evidence from a linked employer-employee panel?", *Industrial and Corporate Change*, 18(6), 1161-1191.

Maurseth, P.B. and Verspagen, B., 2002. Knowledge Spillovers in Europe: A Patent Citation Analysis, *Scandinavian Journal of Economics* ,104 (4), 531–545.

Meijers, H. and B. Verspagen (2010), "Construction of technology flow matrices", paper presented at a DEMETER workshop in Athens, September 2010.

Møen, J. (2005), Is mobility of technical personnel a source of R&D spillovers?, *Journal of Labor Economics*, 23(1), 81–114.

Mohnen, P., 2001, International R&D Spillovers and Economic Growth, in *Information Technology, Productivity, and Economic Growth International Evidence and Implications for Economic Development*, Matti Pohjola (ed.), Oxford University Press, 50-71.

Narin, F., Hamilton, K., Olivastro, D., 1997. The increasing linkage between U.S. technology and public science. *Research Policy* 26, 317-330.

Nooteboom, B., W. Van Haverbeke, G. Duysters, V. Gilsing, and A. van den Oord (2007), Optimal cognitive distance and absorptive capacity. *Research Policy* 36 (7), 1016-1034.

OECD. 2007, *Intellectual Assets and International Investment: A stocktaking of the evidence*, Report to the OECD Investment Committee DAF/INV/WD(2007)6, Paris, OECD.

Odagiri, H. and Murakami, N., 1992. Private and quasi-social rates of return on pharmaceutical R&D in Japan, *Research Policy* , 21, 335-345,1992.

Orlando, M., 2004. Measuring spillovers from industrial R&D: on the importance of geographic and technology proximity. *Rand Journal of Economics* 35, pp.777-786.

Pavitt, K., 1985, Patent Statistics as Indicators of Innovative Activities: Possibilities and Problems, *Scientometrics*, 1985, 7(1-2), 77-99.

Peri, B., 2005. Determinants of Knowledge Flows and Their Effect on Innovation." *Review of Economics and Statistics*, 87(2):308-322.

Rosa, J. and Mohnen, P. (2008), Knowledge transfers between Canadian business enterprises and universities: Does distance matter?, *Annales d'Économie et de Statistique*, 87/88, 303-324.

Rouvinen, P. (2002), The Existence of R&D Spillovers: A Cost Function Estimation With Random Coefficients, *Economics of Innovation and New Technologies*, 11(6), 525-542.

Scherer, F. M. (1982), Interindustry technology flows and productivity growth. *Review of Economics and Statistics* 64, 627-634.

Schmoch, U., Laville, F., Patel, P., & Frietsch, R. (2003). Linking Technology Areas to Industrial Sectors: Final Report to the European Commission , DG Research.

Sjöholm, F. (1996), International transfer of knowledge: The role of international trade and geographic proximity, *Weltwitschaftliches Archiv,* 132 (1), 97-115.

Sterlacchini, A. (1989), R&D, innovations and total factor productivity growth in British manufacturing, *Applied Economics*, 21, 1549-1562.

Suzuki, K., 1993. R&D spillovers and technology transfer among and within vertical keiretsu groups: Evidence from the Japanese electrical machinery industry. *International Journal of Industrial Organization*, 11(4), pp.573-591.

Sveikauskas, L. (1981), "Technology inputs and multifactor productivity growth", *Review of Economics and Statistics*, 63, 275-282.

Teece, David J, 1977. Technology Transfer by Multinational Firms: The Resource Cost of Transferring Technological Know-how, *Economic Journal*, 87(346), 242-61.

Terleckyj, N. (1980), Direct and indirect effects of industrial research and development on the productivity growth of industries, in J. Kendrick and B. Vaccara (eds.), *New Developments in Productivity Measurement and Analysis*. University of Chicago Press, Chicago.

Tijssen, R.J.W., Buter, R.K., van Leeuwen Th.N., 2000. Technological relevance of science: An assessment of citation linkages between patents and research papers. Scientometrics 47(2), 389-412.

Timmer, M. (2012), The world input-output database (WIOD): Contents, sources and methods, European Commission 7th Framework Programme (http://www.wiod.org/publications/papers/wiod10.pdf).

Trajtenberg, Manuel, 1990**,** "A penny for your quotes: Patent citations and the value of inventions". *RAND Journal* of *Economics,* 21: 172-187.

van Meijl, H. (1997), Measuring intersectoral spillovers: French evidence, *Economic Systems Research*, 9(1), 25-46.

van Pottelsberghe, B. and F. Lichtenberg (2001), Does foreign direct investment transfer technology across borders? *Review of Economics and Statistics*, 83(3), 490-497.

Verspagen, B. (1997), Estimating international technology spillovers using technology flow matrices. *Review of World Economics* 133(2), 226-248.

Xu, B. (2000), "Multinational Enterprises, Technology Diffusion, and Host Country Productivity Growth", *Journal of Development Economics,* 62: 477-493.

Xu. B. and X. Wang, 1999, Capital Goods Trade and R&D Spillovers in the OECD, *Canadian Journal of Economics*, 32(5), 1258-1274.

Appendix. NEMESIS-EUROSTAT NACE Concordance Table

NEMESIS	EUROSTAT NACE
1 Agriculture	Agriculture, forestry and fishing
2 Coal and Coke	Mining and quarrying (to be split)
3 Oil & Gas Extraction	Mining and quarrying (to be split)
4 Gas Distribution	Electricity, gas, steam and hot water supply (to be split)
5 Refined Oil	Manufacture of coke, refined petroleum products and nuclear fuel
6 Electricity	Electricity, gas, steam and hot water supply (to be split)
7 Water Supply	Collection, purification and distribution of water
8 Ferr & non Ferrous Metals	Manufacture of basic metals
9 Non Metallic Min Products	Manufacture of other non-metallic mineral products
10 Chemicals	Manufacture of chemicals, chemical products and man-made fibres
11 Metal Products	Manufacture of fabricated metal products, except machinery and equipment
12 Agr & Indus Machines	Manufacture of machinery and equipment n.e.c.
13 Office machines	Manufacture of office machinery and computers
14 Electrical Goods	Manufacture of electrical machinery and apparatus n.e.c. + Manufacture of radio, television and communication equipment and apparatus
15 transport Equipment	Manufacture of transport equipment
16 Food, Drink & Tobacco	Manufacture of food products, beverages and tobacco
17 Tex., Cloth & Footw.	Manufacture of textiles and textile products + Manufacture of leather and leather products
18 Paper & Printing Products	Manufacture of pulp, paper and paper products; publishing and printing
19 Rubber & Plastic	Manufacture of rubber and plastic products
20 Other Manufactures	Manufacture of wood and wood products + Manufacture of medical, precision and optical instruments, watches and clocks + Manufacturing n.e.c.
21 Construction	Construction
22 Distribution	Wholesale and retail trade; repair of motor

	vehicles, motorcycles and personal and household goods
23 Lodging & Catering	Hotels and restaurants
24 Inland Transports	Land transport; transport via pipelines
25 Sea & Air Transport	Water transport + Air transport
26 Other Transports	Supporting and auxiliary transport activities; activities of travel agencies
27 Communication	Post and telecommunications
28 Bank, Finance & Insurance	Financial intermediation
29 Other Market Services	Real estate, renting and business activities
30 Non Market Services	Public administration and defence; compulsory social security + Education + Health and social work + Other community, social and personal service activities + Private households with employed persons + Extra-territorial organizations and bodies

The UNU-MERIT WORKING Paper Series

2020-01 *Debating the assumptions of the Thirlwall Model: A VECM analysis of the Balance of Payments for Argentina, Brazil, Colombia, and Mexico* by Danilo Spinola

2020-02 *The La Marca Model revisited: Structuralist Goodwin cycles with evolutionary supply side and balance of payments constraints* by Danilo Spinola

2020-03 *Uneven development and the balance of payments constrained model: Terms of trade, economic cycles, and productivity catching-up* by Danilo Spinola

2020-04 Time-space dynamics of return and circular migration: Theories and evidence by Amelie F. Constant

2020-05 *Mapping industrial patterns and structural change in exports* by Charlotte Guillard

2020-06 *For real? Income and non-income effects of cash transfers on the demand for food* by Stephan Dietrich and Georg Schmerzeck

2020-07 *Robots and the origin of their labour-saving impact* by Fabio Montobbio, Jacopo Staccioli, Maria Enrica Virgillito and Marco Vivarelli

2020-08 *STI-DUI innovation modes and firm performance in the Indian capital goods industry: Do small firms differ from large ones?* By Nanditha Mathew and George Paily

2020-09 *The impact of automation on inequality across Europe* by Mary Kaltenberg and Neil Foster-McGregor

2020-10 *What matters in funding: The value of research coherence and alignment in evaluators' decisions* by Charles Ayoubi, Sandra Barbosu, Michele Pezzoni and Fabiana Visentin

2020-11 *The productivity impact of business visits across industries* by Mariacristina Piva, Massimiliano Tani and Marco Vivarelli

2020-12 *Technological revolutions, structural change & catching-up* by Jan Fagerberg and Bart Verspagen

2020-13 *Semi-endogenous growth models with domestic and foreign private and public R&D linked to VECMs with evidence for five countries* by Thomas Ziesemer

2020-14 *The economic impact of public R&D: an international perspective* by Luc Soete, Bart Verspagen and Thomas H.W. Ziesemer

2020-15 *Taking the challenge: A joint European policy response to the corona crisis to strengthen the public sector and restart a more sustainable and social Europe* by Jo Ritzen, Javi Lopez, André Knottnerus, Salvador Perez Moreno, George Papandreou and Klaus F. Zimmermann

2020-16 Migration of higher education students from the North Africa Region to the United Kingdom by Samia Satti Osman Mohamed Nour

2020-17 Overview of the Sudan Uprising by Samia Satti Osman Mohamed Nour

2020-18 *Inter-country Distancing, Globalisation and the Coronavirus Pandemic* by Klaus F. Zimmermann, Gokhan Karabulut, Mehmet Huseyin Bilgin and Asli Cansin Doker

2020-19 *How does innovation take place in the mining industry? Understanding the logic behind innovation in a changing context* by Beatriz Calzada Olvera & Michiko Iizuka

2020-20 Public universities, in search of enhanced funding by Jo Ritzen

2020-21 Ph.D. research output in STEM: the role of gender and race in supervision by Giulia Rossello, Robin Cowan and Jacques Mairesse

2020-22 Labour market effects of COVID-19 in sub-Saharan Africa: An informality lens from Burkina Faso, Mali and Senegal by Racky Balde, Mohamed Boly, and Elvis Avenyo

2020-23 *Occupational sorting and wage gaps of refugees* by Christopher F Baum, Hans Lööf, Andreas Stephan and Klaus F. Zimmermann
2020-24 *Policy opportunities and challenges from the Covid-19 pandemic for economies with large informal sectors* by Rajneesh Narula
2020-25 *Economic gender gap in the Global South: how institutional quality matters* by Elena Bárcena-Martin, Samuel Medina-Claros and Salvador Pérez-Moreno
2020-26 *How important is GVC participation to export upgrading* by Gideon Ndubuisi and Solomon Owusu
2020-27 *Patterns of growth in structuralist models: The role of the real exchange rate and industrial policy* by Gabriel Porcile, Danilo Spinola and Giuliano Yajima
2020-28 *COVID-19, Lockdowns, and Africa's Informal Sector: Lessons from Ghana* by Elvis K. Avenyo, John Nana Francois and Tatenda P. Zinyemba
2020-29 *The political economy of public research, or why some governments commit to research more than others* by Andrea Filippetti and Antonio Vezzani
2020-30 *Economic preferences across generations and family clusters: A large-scale experiment* by Shyamal Chowdhury, Matthias Sutter and Klaus F. Zimmermann
2020-31 International student mobility decision-making in a European context by Talitha Dubow, Katrin Marchand, Melissa Siegel
2020-32 *Supply and demand in Kaldorian growth models: a proposal for dynamic adjustment* by Guilherme R. Magacho and Danilo Spinola
2020-33 *Productive efficiency, technological change and catch up within Africa* by Emmanuel B. Mensah, Solomon Owusu and Neil Foster-McGregor
2020-34 *Optimal social distancing in SIR based macroeconomic models* by Yoseph Getachew
2020-35 *Towards a new index of mobile money inclusion and the role of the regulatory environment* by Godsway Korku Tetteh, Micheline Goedhuys, Maty Konte and Pierre Mohnen
2020-36 *Segmented paths of welfare assimilation* by Yip-Ching Yu and Zina Nimeh
2020-37 *Self-selection in physical and mental health among older intra-European migrants* by Amelie F. Constant and Nadja Milewski
2020-38 *The role of innovation in industrial dynamics and productivity growth: a survey of the literature* by Mpehmet Ugur and Marco Vivarelli
2020-39 *Does gender matter for promotion in science? Evidence from physicists in France* by Jacques Mairesse, Michele Pezzoni and Fabiana Visentin
2020-40 *Automation, globalisation and relative wages: An empirical analysis of winners and losers* by Antonio Francesco Gravina and Neil Foster-McGregor
2020-41 *Stagnant manufacturing growth in India: The role of the informal economy* by Gbenoukpo Robert Djidonou and Neil Foster-McGregor
2020-42 *Intra-EU migration: Shedding light on drivers, corridors and the relative importance of migrant characteristics* by Miriam Mack, Sarah Roeder, Katrin Marchand and Melissa Siegel
2020-43 *Roots of dissent: Trade liberalization and the rise of populism in Brazil* by Francesco Iacoella, Patricia Justino and Bruno Martora
2020-44 *The role of domestic-firm knowledge in foreign R&D collaborations: Evidence from co-patenting in Indian firms* by Nanditha Mathew, Lorenzo Napolitano and Ugo Rizzo
2020-45 *Is sub-Saharan Africa deindustrializing?* by Emmanuel B. Mensah

2020-46 *Does value chain participation facilitate the adoption of industry 4.0 technologies in developing countries?* by Michele Delera, Carlo Pietrobelli, Elisa Calza and Alejandro Lavopa

2020-47 *Inter-sectoral and international R&D spillovers* by Rene Belderbos and Pierre Mohnen