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INTERNATIONAL R&D SPILLOVERS AND BUSINESS SERVICE INNOVATION°

Neil Foster-McGregor*, Johannes Pöschl+ and Robert Stehrer#

Abstract

A major international transmission channel of productivity increases is trade in intermediate products and services. This paper analyses international spillovers at the industry level and for the first time investigates effects from the services sector in this framework. The analysis makes use of newly available data on international input-output linkages between industries. Our results using this novel approach indicate significant positive productivity effects from innovation in knowledge intensive, high technology business services and confirm the productivity effects from international manufacturing spillovers found in the recent literature.

Keywords: Productivity, Research and Development, Business Services, Spillovers, Offshoring, Wages, Institutions

JEL classification: F14, F43, O31, O43

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1. INTRODUCTION

A large empirical literature has developed beginning in the 1970s analysing the extent of technology spillovers across firms, industries, and countries. Early studies at the industry level such as Nestor Terleckyj (1974), Zvi Griliches (1979) and F. Scherer (1982) – which tended to use information from input-output tables to measure the extent of linkages between industries – preceded the development of neo-Schumpeterian growth theories and generally came to the conclusion that an industry's technology generation has a significant impact upon the productivity of other industries. Further studies in the 1980s and 1990s tended to confirm this conclusion, though estimates varied widely (for a review of the empirical evidence see Pierre Mohnen, 1990 and M. Ishaq Nadiri, 1993). Following these earlier studies at the industry level and following the development of open economy endogenous growth theories (see Gene Grossman and Elhanan Helpman, 1991) a strand of literature aimed to estimate the importance of technology spillovers across countries, beginning with the seminal study of David Coe and Elhanan Helpman (1995). The importance of understanding the extent of international technology diffusion is clear, since the size of these technology transfers shapes the worldwide distribution of productivity. Limited spillovers likely lead to global divergence whereas large spillovers promote convergence.

Coe and Helpman (1995) in their study examine the impact of international R&D spillovers for 22 OECD countries. They construct a measure of the stock of foreign knowledge that is available to each importing country by weighting the R&D stocks of its trade partners by import shares. A measure of multifactor productivity (MFP) is then regressed on both the domestic and foreign R&D stocks, with the results suggesting that both are important sources of productivity growth. This type of analysis has been extended in a number of directions. David Coe, Elhanan Helpman and Alexander Hoffmaister (1997) consider the extent of such spillovers from developed countries to developing countries, while Olivier Lumenga-Neso, Marcelo Olarreaga, and Maurice Schiff (2005) consider the importance of indirect spillovers which occur if two countries have a common trade partner, even if they do not trade with each other directly.

The studies considering trade-related spillovers have to date concentrated on trade in goods, with the services sector largely neglected as a source of spillovers. Services are the largest sector in most developed economies however, providing a major share of intermediate inputs into the manufacturing sector, often being relatively R&D intensive and becoming increasingly traded across international borders. According to the WTO, trade in services accounted for around 20% of world trade in goods and services in 2007, a share that increases to around 50% if transactions are measured in terms of direct and indirect value added content (Joseph Francois and Bernard Hoekman, 2010). Services also provide more than 30% of the intermediate inputs of the manufacturing sector in the European Union and occupy a central position with respect to innovation. In the US, the business services sector alone is twice the size of the manufacturing sector and accounts for 25% of total US employment (J. Bradford Jensen, 2011).

The focus of this study is on research and knowledge intensive, high technology service industries, namely "Transport, storage and communications" and "Renting of Machinery & Equipment and Computer, R&D and Other Business Activities". Their annual R&D growth rates over the period 1995-2005 in the EU were around double the size of the highest ones in manufacturing.[1] It is safe to say that these two industries have tremendously changed the way business is done in the past decades. Computers have become continuously faster, enabling the use of powerful software which supports production automatisation as well as administrative processes. The greatest impact of these service industries in the last two decades however has been on communication – both within the firm and between the firm and the outside world. The internet as a new and versatile form of communication and mobile telephony are two media, without which current production techniques are almost inconceivable. It is highly questionable whether the emergence of global value chains could have happened to the observed extent without software enabling firms to communicate and transfer information without delay (e.g. machine settings for new or adapted products). Moreover, machine-to-machine communication with suppliers and customers has greatly improved just-in-time resource planning. This creation of intelligent networks along the entire value chain is often referred to as the Fourth Industrial Revolution.

In this paper, we look to fill the current gap in the literature by considering the role of these knowledge intensive, high technology service industries as a source for productivity improvements in the manufacturing sector. The approach we adopt follows the method of Wolfgang Keller (2002), with a more refined methodology on the international side. In addition to weighting R&D stocks by goods trade, we further include a measure of the services trade weighted R&D stocks of trade partners. Similar to manufacturing intermediate inputs, inputs from services sectors might enable the industry to be more productive without increasing productivity itself. While the issue of services trade has been largely ignored in the international technology spillovers literature, other studies have looked to estimate its importance to some extent. Lisa Correa (2006), for example, uses an input-output approach to analyse the impact of telecommunication diffusion on UK productivity growth, while Lars-Hendrick Röller and Leonard Waverman (2001) examine the impact of telecommunications investment on productivity growth at the aggregate level. Jens Arnold, Beata Javorcik and Aaditya Mattooc (2011) use Czech firm-level data and report a positive relationship between services sector liberalisation and the performance of domestic firms in downstream manufacturing sectors. The paper most similar to ours however is that of Gary Madden and Scott Savage (2000), who includes an interaction between the foreign R&D stock and the share of communications and computer equipment in total imports, finding that a higher share of such trade can enhance the productivity benefits of foreign R&D stocks. In our analysis we use a broader concept of services trade however. Moreover, we account for the bilateral flows of services, using a

[1] In the European countries in our sample, the annual R&D growth rate for NACE 60t64 “Transport, storage and communications” was 13.7% and for NACE 71t74 “Renting of Machinery & Equipment and Computer, R&D and Other Business Activities” 10.7%. The highest rates in manufacturing are found in NACE 25 “Rubber and Plastics” with 6.64% and in NACE 34t35 “Transport Equipment” with 5.86%.

weighting scheme similar to Keller (2002) rather than simply including an interaction of the R&D stock with an aggregate measure of services trade.

To estimate the impact of services trade on international technology spillovers we use, amongst other sources, the recently compiled World Input Output Database (WIOD) (Marcel Timmer, 2012). This database includes international input-output tables covering 40 countries and 35 industries. Since the database tracks intermediate flows across both industries and countries, it allows us to account for both spillovers across industries within a country as well as spillovers across countries and industries.

Due to data limitations, few studies to date have been able to analyse spillovers at the industry level adequately, exceptions being Keller (2002), Maurice Schiff and Yangling Wang (2006) and Yangling Wang (2007). Keller (2002) was the first to incorporate the analysis of domestic spillovers between manufacturing industries into an international setting. He constructs two international spillover components. The first measures the extent of spillovers from the same industry in other countries and is constructed using trade in advanced intermediate goods. The second variable aims to capture spillovers from other foreign industries for which he additionally uses information from the import input-output table. Keller's findings suggest that the productivity effects from international and domestic spillovers are substantial and as large as the effects of the industries' own R&D efforts. Another study by Schiff and Wang (2006) considers the impact of North-South R&D spillovers at the industry level. In addition to the direct effect of North-South R&D spillovers, they also account for indirect effects due to indirect North-South trade and direct and indirect South-South trade. Results indicate that spillovers are significant, with spillovers from North-North trade found to be stronger than those due to South-South trade. Wang (2007) shows that North-South trade related spillovers have a substantial impact on Multi Factor Productivity (MFP) in the South and that these spillovers are stronger for R&D-intensive industries. Moreover, the results document the importance of human capital for absorbing these spillovers.

The data limitations in the above approaches include a lack of time-series on input-output tables and a lack of import input-output tables for most countries. The first issue prevents the researcher from accounting for structural change in the economy, the latter forces the use of domestic tables or tables of other "similar" countries to weight imports, which is potentially misleading. The WIOD database includes import input-output tables and reports annual tables for the period 1995-2008, allowing us to overcome many of the problems faced by the above studies. A further contribution of the current paper therefore is the estimation of cross-country, cross-industry spillovers with the WIOD database, allowing us to assess these spillovers more precisely than previous papers.

Using data at the industry level for 18 countries and 10 manufacturing industries, for which full data are available over the period 1995-2005, we estimate the impact on productivity of own-industry domestic R&D, of own-industry foreign R&D, of other manufacturing industry (domestic and foreign) R&D, and of (domestic and foreign) services R&D. Our results support recent evidence of positive productivity effects from international manufacturing spillovers. Contrary to the previous studies of Keller (2002) and Carmen López-Pueyo, Sara Barcenilla-Visús and Jaime Sanaú (2008), we find that the main source of international spillovers is own-industry intermediates as opposed to other-industry intermediates. The results further highlight positive and significant spillover effects from knowledge intensive, high technology service industries. Relative to the productivity effect of the industry's own R&D, the size of the effects is about one third for the high technology service industries and two thirds for the foreign own-industry spillovers.

Spillovers stemming from research efforts in other countries however are not the only international source of productivity improvements in the home country. The strong increase in offshoring around the millennium change was largely motivated by differences in factor prices. Theory suggests that offshoring of labour intensive tasks to lower wage countries leads to productivity increases in the outsourcing country. Empirically, most authors find evidence of these productivity gains from offshoring (Peter Egger, Michael Pfaffermayr and Yvonne Wolfmayr-Schnitzer, 2001; Mary Amiti and Shang-Jin Wei, 2009), with most authors stressing the importance of services offshoring as the main source of these gains (for an overview see Bernhard Michel and Francois Rycx, 2014). Upon extending the spillover framework to include productivity effects from manufacturing and services offshoring activities motivated by factor price differences, we find quite substantial positive effects of offshoring on productivity.

The remainder of the paper is set out as follows: Section 2 describes the empirical specification; Section 3 provides information on the data used in the analysis; Section 4 presents the main results; Section 5 discusses results from a model extension and a number of robustness tests; and Section 6 concludes.

2. EMPIRICAL SPECIFICATION

2.1. BASELINE SPECIFICATION

In our model, output is produced by using labour and intermediate products and services. The intermediates can stem either from the industry itself, or from other domestic or foreign industries. Furthermore, the production of intermediate products and services is influenced by R&D investment, which brings about product or process innovations. These innovations may lead to additional consumer rents due to imperfect monopolistic pricing, creating spillovers. Trade in intermediate goods and services allows firms to profit from these spillovers generated by innovations in other industries and countries.

Following this argumentation, the productivity of an industry ultimately depends upon its own R&D investment and technological improvements transmitted via trade in intermediate inputs. In our estimation, we differentiate between intermediate products stemming from (1) the industry itself, (2) the same industry in other countries, (3) other manufacturing industries and (4) two major high technology service industries.

The baseline specification of our model looks as follows

$$log\ MFP_{ict} = \beta_1\ log\ R_{ict}^{s} + \beta_2\ log\ R_{ict}^{fs} + \beta_3\ log\ R_{ict}^{o} + \beta_5\ log\ R_{ict}^{serv} + \alpha_{ci} + \alpha_t + \varepsilon_{ict} \qquad (1)$$

where MFP_{ict} stands for multifactor productivity, R_{ict}^{s} is the R&D stock of industry i in country c and R_{ict}^{fs} denotes the variable capturing foreign spillovers imported from industry i in country c's trade partners. R_{ict}^{o} represents domestic and foreign spillovers from industries other than i, while R_{ict}^{serv} represents both domestic and foreign spillovers from the services sector. Since the shares of foreign intermediate inputs from other industries and from services industries are in most cases small and in order to reduce the number of coefficients to estimate, we aggregate the domestic and foreign inflows of intermediate inputs from other industries and the domestic and foreign inflows of services inputs. In order to control for initial differences in productivity across countries as well as industries, a full set of country-industry dummies, α_{ci}, is included. A set of time dummies, α_t, is also included to control for common shocks and productivity trends.

When constructing the spillover variables we follow existing approaches (e.g. Keller, 2002; Coe and Helpman, 1995). We will however discuss a number of improvements that have been made with respect to the existing literature. Coe and Helpman (1995) as well as Keller (2002) use bilateral intermediate input shares for the construction of foreign spillover variables. As justly criticised by Frank Lichtenberg and Bruno van Pottelsberghe de la Potterie (1998), the trade openness of the country does not play a role in these measures. Two countries with identical partner structures, of which one has a trade to GDP ratio of 50% and the other one of 5% would have the same spillover effect. Since the country involved in international trade to a greater extent should benefit more from international spillovers, Lichtenberg and van Pottelsberghe de la Potterie (1998) suggest incorporating a measure of trade openness in the spillover variable e.g. weighting the imports not by total imports but by the GDP of the recipient country. The World Input Output Database (WIOD) allows one to take care of this criticism and estimate spillover effects more accurately than previous efforts. For the first time, we are able to obtain specifically the intermediate inputs of industry *i* in country *c* from industry *j* in country *d* at time *t*. This allows us to weight each domestic or foreign donor industry precisely by its intermediate input share in total intermediates used by the receiving industry. This also deals with the trade openness-criticism as foreign intermediate shares are always expressed relative to total domestic and foreign intermediates used.

Time is another important aspect. The database contains continuous input-output tables at basic prices, allowing us to account for changes in the structure of industries. This is an improvement over many of the existing studies at the industry level, which are often severely restricted by data limitations. Input-output tables are usually only available for a few years and sometimes just a single year, disregarding important changes in the vertical specialisation of firms. More severe data limitations can also include the lack of input-output tables for some countries in the sample, as in Keller (2002). The usual response is to use tables of other "similar" countries. Since outsourced activities have certain characteristics and input requirements (e.g. labour intensive) which are different from those activities that are domestically conducted, it is in many cases misleading to assume that the input/output structure of domestic activities is similar to those of foreign suppliers. We are able to avoid these biases as we have continuous input-output tables for all countries in our sample.

Let us now turn in more detail to the construction of the spillover variables included in equation (1). The own-industry, own-country R&D stock R_{ict}^{s} is simply the unweighted R&D stock of the industry. The own-industry R&D stock of trade partners in equation (2) is weighted by the share of intermediates from industry i and country d in total intermediates used in industry i in country c. The variable INT_{icjdt} therefore denotes the value of intermediate inputs of industry *i* in country *c* from industry *j* in country *d* at time *t.* In contrast, Keller (2002) and López-Pueyo et al. (2008) use the bilateral share of country d in country c's imports in industry i. They therefore have to assume that all imported foreign intermediates produced in industry i are used as intermediates in industry i, whereas they might of course be used in other domestic industries as well.

$$R_{ict}^{fs} = \frac{\sum_{\substack{d=1 \\ d \neq c}}^{C} INT_{icidt}}{\sum_{d=1}^{C} \sum_{j=1}^{I} INT_{icjdt}} \times RD_{idt} \tag{2}$$

The other variables are constructed analogously to the latter measure. The spillover variable R_{ict}^{o} is constructed as the sum of the R&D stocks of all manufacturing industries *j* other than i, weighted by the share of each industry *j* in country d in total intermediate use of industry i in country c.

$$R_{ict}^{o} = \frac{\sum_{d=1}^{C} \sum_{\substack{j=1 \\ j \neq i \cap j \neq s}}^{I} INT_{icjdt}}{\sum_{d=1}^{C} \sum_{j=1}^{I} INT_{icjdt}} \times RD_{jdt} \tag{3}$$

Finally, the services spillover variable is constructed as the R&D stock of services sector v in country d weighted by the share of the services sector v in country d in total intermediate use of industry i in country c.

$$R_{ict}^{serv} = \frac{\sum_{d=1}^{C} INT_{icvdt}}{\sum_{d=1}^{C} \sum_{j=1}^{I} INT_{icjdt}} \times RD_{vdt} \tag{4}$$

With these specifications there are two ways for productivity to increase in industry i without its own R&D efforts increasing. First, other industries can increase their R&D activities, upgrade the quality of their products or lower their price, thereby increasing productivity in industry i which employs these products. Second, industry i can choose to import more from an industry which has a relatively higher R&D stock compared to the same industry in other countries. This will allow the industry to profit more from innovative output in this industry.

From this model, one would expect industries to primarily source from other industries close to the technological frontier. However, the last decade has been characterised by a strong increase of imports from developing countries with relatively low R&D stocks. The primary reason for this development is a difference in factor costs. The existing spillover framework will therefore be extended to incorporate differences in factor prices.

2.2. INTRODUCING PRODUCTIVITY EFFECTS FROM FACTOR PRICE DIFFERENCES

In order to complete the picture, another international channel of productivity improvements that was missing in the spillover framework will be introduced: offshoring due to factor price differences. In general, a productivity effect can arise from offshoring activities for at least two reasons. On the one hand, access to new or improved input varieties through offshoring activities can increase productivity (Amiti and Wei, 2009). Amiti and Wei (2009) go on to argue that services offshoring, especially related to computing and information services, like the import of software packages, are likely to bring about even larger benefits. This offshoring effect, which is related to product innovation, should largely be covered in our existing spillover framework.

On the other hand, there can be what Amiti and Wei (2009) describe as a compositional effect. Such an effect arises when firms relocate the relatively inefficient parts of the production processes to another country, where they can be produced more cheaply e.g. due to lower factor prices. Since the relatively inefficient parts of production are no longer produced domestically, the average productivity of the remaining workers will increase. This effect so far has been missing in the spillover framework and we will thus incorporate productivity effects from differences in labour costs in this setting. The expectation is that industries that offshore inefficiently performed labour intensive tasks to lower wage countries are more productive than those that do so to a lesser extent. The effect is complementary to the spillover effect from innovation. The main beneficiaries are expected to be high-wage countries close to the technological frontier, as they profit most from the wage differential. This is in contrast to the spillover effect, where countries away from the technological frontier are expected to benefit most from the knowledge transfer.

In order to measure the offshoring effect, the average wage of an employee in each industry and country is calculated using the Socio-Economic Account data from the WIOD. In a first step, the average wage per employee in the respective foreign partner industry is obtained and the gap relative to the wage in the offshoring industry is calculated as a percentage. Sweden thus profits relatively more from offshoring to Poland or China than the Czech Republic, as the wage differential is higher. If the gap is negative, it is set to 0 – this ensures that trade of less developed countries with, for example, the US does not have an effect on this offshoring measure. The resulting variable $WAGEgap$ is then weighted by the share of intermediate inputs that the offshoring industry receives from that partner industry, as can be seen from equation (5).

$$OFFS_{ict} = \sum_{\substack{d=1 \\ d \neq c}}^{C} \sum_{j=1}^{I} \frac{INT_{icjdt}}{\sum_{d=1}^{C} \sum_{j=1}^{I} INT_{icjdt}} \times WAGEgap_{cijd1996} \tag{5}$$

Due to the richness of the WIOD dataset, we are able to calculate the wage gap and consider input-output linkages not only between the countries in our sample, but also with respect to developing partner countries such as China, India, Indonesia, Mexico, Brazil, Russia and Turkey as well as developing countries that joined the European Union in the 2000s.[2] Moreover, not only manufacturing, but also services offshoring is taken into account. There is a possible endogeneity problem attached to the variable $OFFS$ with respect to productivity: higher profits due to higher productivity might affect wages as companies are likely to share their profits with their employees. In order to avoid this problem, we will use the wage gap in the first year of our sample for the entire period.

3. DATA

3.1. DATA SOURCES

In this paper we use data from 1995 to 2005 for 18 countries and 10 industries, which together make up a large part of the world economy.[3] Our dataset includes productivity, R&D and institutional data for these countries as well as input-output linkages between the countries and their industries.

Input-output linkages are taken from the newly constructed World Input-Output Database (WIOD) containing data on 40 countries and 35 industries. The database is the result of an effort to bring together information from national accounts statistics, supply and use tables and data on trade in goods and services. Starting from national supply and use tables (SUTs), which contain information on the supply and use of 59 products in 35 industries, detailed trade data was used to split up the SUTs by sourcing origin. The detailed bilateral trade data were differentiated by use categories (intermediates, consumption, and investment goods) using a modified version of the existing broad end-use categories. Services trade data, which are only available from Balance of Payments (BoP) statistics, were also merged to the SUTs and the differentiation into use categories is based on information from existing import use or import input-output tables. Finally, the resulting set of international SUTs was then transformed into an international input-output table using standard procedures.

Multifactor productivity data based on value added are taken from the EU Klems database. The MFP measure controls for employment across three different skill levels (low, medium, high based on

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2 All partner countries considered are: Australia, Austria, Belgium, Brazil, Bulgaria, Canada, China, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, India, Indonesia, Ireland, Italy, Japan, Latvia, Lithuania, Luxembourg, Malta, Mexico, Netherlands, Poland, Portugal, Romania, Russia, Slovak Republic, Slovenia, South Korea, Spain, Sweden, Taiwan, Turkey, United Kingdom and the United States

3 The countries in the sample are Australia, Belgium, the Czech Republic, Denmark, Finland, France, Germany, Great Britain, Hungary, Ireland, Italy, Japan, the Netherlands, Portugal, Slovenia, Spain, Sweden and the United States.

the International Standard Classification of Education) as well as investment in information and communications technology (ICT) and non-ICT capital (for more information on the construction of this index see Mary O'Mahony and Marcel Timmer, 2009). The industries "Coke, refined petroleum and nuclear fuel" and "Wood and of wood and cork" as well as "Manufacturing nec; recycling" are dropped because of large fluctuations in MFP across time. In the case of "Coke, refined petroleum and nuclear fuel" in particular, these fluctuations occurred due to the high price volatility.

The OECD STAN ANBERD database provides data on R&D expenditure at the industry level. This dataset uses the ISIC Rev. 3 industry classification, which is compatible at the 2-digit level with the NACE Rev. 1 classification used in the other databases. In order to make R&D investments comparable across time and countries, they are adjusted using purchasing power parity exchange rates and deflated using the gross fixed capital formation deflator taken from Eurostat. From the original R&D flow data, stocks are constructed using the perpetual inventory method and assuming a 10% depreciation rate. The initial R&D stock RD_o is calculated following Griliches (1979) as $RD_o = \frac{RINV_0}{g+\delta}$. Here $RINV_0$ denotes R&D investment in 1995, δ represents the depreciation rate of R&D capital and g the average growth rate of R&D expenditure over the analysed time period.

For the model extension, incorporating productivity effects from differences in factor prices, data on wages from the Socio-Economic Accounts data are taken from the WIOD dataset. For the robustness analysis we furthermore collect information on the quality of contract enforcement, property rights and courts. This variable is obtained from the Worldwide Governance Indicators (WGI), a dataset that is based on responses given by a large number of enterprise, citizens, and expert survey respondents. The aggregate indicators of governance are constructed using an unobserved components methodology described in Kaufmann et. al. (2010) and measured in units ranging from around -2.5 to 2.5, with higher values corresponding to better governance outcomes. To allow us to include the variables in logs we rescale the data such that it ranges from 1 to 6.

3.2. DESCRIPTIVE ANALYSIS

The current paper concentrates on manufacturing industries and in particular how intermediate inflows into these industries act as a channel of technology transfer. To give some indication of how important these intermediate flows are, Table 1 reports information on input-output flows for the year 2005, expressed as a share of total inputs. The data can be interpreted as the input-output matrix of the average country in the sample (weighted by intermediate inputs). Note that the input shares in the matrix do not sum up to 100% as some manufacturing and service industries were dropped and primary inputs from agriculture, mining, and petroleum and gas extraction are missing. The first thing that is apparent from Table 1 is that most intermediate inputs of an average enterprise come from other firms in the same industry, both domestic and foreign. Certain industries however are deeply interconnected and provide a lot of essential inputs for other domestic and foreign industries, like the industry "Basic Metals and Fabricated Metal" and the chemical industry.

The main contribution of the current paper is to investigate spillovers from business services to manufacturing industries, something that is largely missing from the empirical literature on international technology spillovers. Yet Table 1 highlights the importance of the services sector in providing inputs to manufacturing industries. According to Table 1, inputs from the selected services industries amount to between 10 and 20% of total inputs in manufacturing industries. In our analysis of business services, we focus on the two research and knowledge intensive, high technology service industries, namely "Transport, storage and communications" and "Renting of Machinery & Equipment and Computer, R&D and Other Business Activities". “Other Business Activities” is a rather broad category including business, legal and management consultancy, software development, technical testing and engineering activities as well as market research, advertising and architectural activities. Moreover, it contains the NACE industry “Research and experimental development on natural sciences and engineering” which is interesting from a public goods perspective, as fundamental research most likely affects productivity in the long run. As opposed to other manufacturing sectors, these two services industries provide vital inputs to *all* manufacturing industries.

Together, the two services industries were responsible for 86% of total R&D conducted in the services sector in 2005. Moreover, they exhibited an exceptionally high growth rate of R&D investment over the analysed period, as can be seen from Table 2. "Transport, storage and communications" increased its R&D investment annually by 16.8%, while "Renting of Machinery & Equipment and Computer, R&D and Other Business Activities" saw an increase of 10.8%. In comparison, the highest growth rates in manufacturing were found in "Chemicals and chemical products" with 6.8%. The R&D intensity relative to total output in 2000 was highest in "Electrical and optical equipment" with 7.4%, followed by "Chemicals and chemical products" with 4.7%. Looking at the national level, Sweden had the highest ratio of R&D expenditures to total output in the selected industries with 3.4%, followed by Finland (2.8%), the US (2.5%) and Germany (2.2%). Considering output measures, we see that 43% of the total value added in our sample is created in the US, 21% in Japan and the remaining 36% in countries of the European Union, with Germany accounting for 9.3%, Great Britain for 6.4% and France for 5.9%. The highest productivity growth between 1995 and 2000 can be observed in Hungary with an average annual growth rate of 3.1%, followed by the US with 2.8% and Finland with 2.5%. The industries exhibiting the highest average productivity growth were "Electrical and optical equipment" (5.1%), "Transport equipment" (2.9%) and "Machinery and equipment n.e.c." (2.4%).

Table 1: Domestic and Foreign Input-Output Linkages as a % of Total Inputs (weighted average across countries in sample for 2005)

Production / Use			15t16	17t19	21t22	24	25	26	27t28	29	30t33	34t35
Domestic	15t16	Food, Beverages and Tobacco	20.4	1.9	0.4	1.1	0.3	0.2	0.1	0.1	0.2	0.1
	17t19	Textiles, textile products, leather and footwear	0.1	25.9	0.6	0.3	1.0	0.3	0.1	0.2	0.3	0.5
	21t22	Pulp, Paper, Paper , Printing and Publishing	3.0	1.3	25.5	1.8	1.9	2.0	0.7	1.1	1.6	0.6
	24	Chemicals and Chemical Products	0.9	7.0	3.4	24.6	20.7	2.8	1.3	1.1	1.8	1.0
	25	Rubber and Plastics	2.0	1.5	1.7	1.9	13.9	1.0	0.7	3.1	2.7	3.5
	26	Other Non-Metallic Mineral	0.8	0.2	0.1	0.6	0.8	16.0	0.9	0.6	1.3	0.9
	27t28	Basic Metals and Fabricated Metal	2.1	1.1	1.3	1.5	3.1	3.6	36.2	19.4	8.6	10.6
	29	Machinery, nec	0.5	0.6	0.8	0.6	1.2	1.3	1.6	12.9	1.2	2.8
	30t33	Electrical and Optical Equipment	0.3	0.6	0.9	0.7	1.1	0.8	1.3	6.8	19.2	3.3
	34t35	Transport Equipment	0.2	0.2	0.2	0.2	0.3	0.3	0.4	1.3	0.4	30.4
	60t64	Transport, storage and communications	5.5	4.8	7.3	4.5	4.4	10.0	4.5	3.8	3.5	2.7
	71t74	Renting of M&E; Computer, R&D and Oth. Business Act.	7.7	7.3	13.4	12.4	7.9	9.1	6.2	8.9	12.1	6.9
Foreign	15t16	Food, Beverages and Tobacco	1.4	0.2	0.1	0.3	0.1	0.0	0.0	0.0	0.0	0.0
	17t19	Textiles, textile products, leather and footwear	0.0	10.4	0.3	0.1	0.4	0.1	0.0	0.1	0.1	0.3
	21t22	Pulp, Paper, Paper , Printing and Publishing	0.8	0.3	6.6	0.5	0.5	0.5	0.1	0.2	0.3	0.1
	24	Chemicals and Chemical Products	0.5	4.0	2.0	13.9	11.0	1.9	1.0	0.6	1.0	0.6
	25	Rubber and Plastics	0.6	0.6	0.5	0.5	3.2	0.4	0.3	0.9	0.7	1.1
	26	Other Non-Metallic Mineral	0.1	0.1	0.0	0.1	0.2	3.1	0.2	0.1	0.2	0.2
	27t28	Basic Metals and Fabricated Metal	0.4	0.3	0.3	0.5	1.0	1.3	13.6	6.3	3.0	3.6
	29	Machinery, nec	0.2	0.3	0.3	0.3	0.5	0.7	0.7	5.6	0.7	1.3
	30t33	Electrical and Optical Equipment	0.2	0.4	0.6	0.5	0.9	0.6	0.9	4.3	18.4	2.5
	34t35	Transport Equipment	0.1	0.2	0.1	0.1	0.2	0.1	0.2	0.8	0.3	11.0
	60t64	Transport, storage and communications	0.4	0.4	0.7	0.4	0.4	0.8	0.4	0.4	0.4	0.3
	71t74	Renting of M&E; Computer, R&D and Oth. Business Act.	1.1	0.7	1.9	2.2	0.8	1.0	0.6	0.9	1.8	0.7
Total			50.3	72.3	72.1	77.8	78.6	61.9	75.2	81.3	81.2	86.7

Table 2: Summary Statistics

code	Country / Industry	Average MFP growth*	Average R&D inv. growth**	R&D inv. in mn USD†	VA in mn USD‡
AUS	Australia	1.02	4.48	2,799	95,917
BEL	Belgium	0.76	4.71	3,703	50,328
CZE	Czech Republic	2.20	7.88	1,018	23,965
DEU	Germany	1.50	5.19	34,623	635,392
DNK	Denmark	-0.22	9.22	2,080	33,734
ESP	Spain	-0.80	10.35	3,771	154,438
FIN	Finland	2.47	10.70	2,940	41,804
FRA	France	2.06	3.77	19,178	398,825
GBR	United Kingdom	1.46	4.42	15,815	433,293
HUN	Hungary	3.07	10.09	378	18,451
IRL	Ireland	1.51	8.36	847	30,615
ITA	Italy	-0.34	3.33	7,214	344,426
JPN	Japan	0.35	6.22	66,999	1,394,842
NLD	Netherlands	1.77	5.27	4,398	112,486
PRT	Portugal	0.38	13.55	280	30,573
SVN	Slovenia	1.89	9.39	257	5,490
SWE	Sweden	1.49	4.99	7,170	71,680
USA	United States	2.78	5.70	161,798	2,924,160
15t16	Food, beverages and tobacco	-0.77	5.54	5,401	490,786
17t19	Textiles, textile, leather and footwear	1.09	3.98	1,497	145,088
21t22	Pulp, paper, printing and publishing	1.11	5.19	4,267	368,002
24	Chemicals and chemical products	0.53	6.75	53,849	395,501
25	Rubber and plastics	2.26	4.91	5,227	162,503
26	Other non-metallic mineral	1.58	2.32	3,020	138,946
27t28	Basic metals and fabricated metal	1.02	1.85	7,678	457,951
29	Machinery and equipment n.e.c.	2.37	5.11	21,693	285,934
30t33	Electrical and optical equipment	5.05	4.36	115,598	517,039
34t35	Transport equipment	2.87	3.94	66,222	369,497
60t64	Transport, storage and communications	1.38	16.88	4,845	1,256,813
71t74	Renting of M&E; Comp., R&D and Oth. Bus. Act.	-0.92	10.76	45,972	2,212,360

Notes: Growth numbers in %; R&D investment is based on PPP adjusted USD data which was deflated using the GFCF deflator from Eurostat; Country statistics are based on the sum of the selected industries, industry statistics on the sum over the countries in the sample; *Mean annual average growth of value added MFP between 1995 and 2005, weighted by value added; **Mean annual average growth of R&D investment between 1995 and 2005; †Based on R&D investment in 2000; ‡Based on gross value added in 2000 calculated from the WIOD database.

4. RESULTS

4.1. STATIONARITY AND COINTEGRATION PRELIMINARIES

Coe and Helpman (1995) in their study found that their data exhibited a clear trend, but that a cointegrating relationship existed between the variables, which allowed them to estimate their model in levels using OLS. They chose not to report t-statistics for their results, because at the time the asymptotic distribution of the t-statistic was unknown. As Badi Baltagi and Chihwa Kao (2000) pointed out, the OLS estimator is (super-) consistent even under panel cointegration, but has a second-order asymptotic bias that leads to invalid standard errors. Given the potential bias in the estimation technique, it is not even clear whether the coefficients have the expected sign. Baltagi and Kao (2000) recommend alternative estimation procedures, such as Fully Modified OLS (FMOLS) and Dynamic OLS (DOLS), which are able to provide valid t-statistics. Following the work of Baltagi and Kao (2000), panel cointegration techniques have become widely used in the spillover literature (Coe et al., 2009; López-Pueyo et al., 2008). Estimates from cointegrated panels have a number of advantages as they are more robust to endogeneity, omitted variables and measurement error (Anindya Banerjee, 1999; Peter Phillips and Hyungsik Moon, 2000; Baltagi and Kao, 2000).

We also make use of panel cointegration techniques and in a first step test the panel for unit roots and cointegration. The Im-Pesaran-Shin test (IPS) (Kyung Im, M. Hashem Pesaran, and Yongcheol Shin, 2003) is used to test for the existence of unit roots in the dataset. In contrast to the Levin-Lin-Chu (LLC) and the Harris-Tzavalis and Breitung tests, it relaxes the assumption of a common ρ for the whole panel and was found to have superior power. The null hypothesis of the test states that all panels have a unit root ($H_0: \rho_i = 0\ \forall i$) with the alternative hypothesis being that at least one panel is stationary.

Table 3: Panel Unit Root Test

Variable	MFP	R^s	R^{fs}	R^o	R^{serv}
IPS	1.63	2.34	-1.56*	-2.15**	-0.75
LLC	-6.48***	-9.47***	-13.33***	-13.20***	-3.60***

The values represent W-t-bar statistics of the one-sided Im-Pesaran-Shin test (2003) and the Levin-Lin-Chu test. The number of lags included in the respective tests is chosen using the Akaike information criterion (up to 5). All variables are logged. ***, **, and * denote tests being significant at the 1, 5, and 10% level respectively.

Table 3 reports results from the stationarity tests for the pooled time series. The IPS test results indicate that the null hypothesis of a unit root for all panels cannot be rejected for productivity as well as the own industry R&D stock and the services weighted R&D stock. We can therefore conclude that most of our relevant variables are not stationary.[4]

[4] Note that with the assumption of a common ρ for the whole panel, the Levin-Lin-Chu (LLC) test rejects the null hypothesis that all panels contain a common unit root in all cases.

Table 4: Westerlund ECM Panel Cointegration Tests

MFP	R^s	R^{fs}	R^o	R^{serv}	R^s_{1987}
Gt	- 5.42***	1.30	-2.43***	-0.05	-1.32***
Ga	0.46	-0.97	-1.12	-0.17	-1.70
Pt	- 7.98	-10.21***	-9.28**	-2.98	-14.11***
Pa	0.82	-1.20	-1.40**	-0.15	-1.70***

A rejection of H_0 for the Ga and Gt test-statistics should be taken as evidence of cointegration of at least one cross-sectional unit. The Pa and Pt test statistics pool information over all the cross-sectional units and a rejection of H_0 provides evidence for cointegration for the panel as a whole. All variables are logged. ***, **, and * denote tests results being significant at the 1, 5, and 10% level respectively.

Next, we perform the Westerlund error-correction-based panel cointegration tests (Damiaan Persyn and Joakim Westerlund, 2008) to test for cointegration between MFP and the spillover variables. The test results are reported in Table 4. Unfortunately the WIOD database, containing the input-output linkages necessary for the construction of the other R&D variables only goes back to 1995, limiting the number of time-series observations we can include in our cointegration tests. The shortness of the time series with a panel of only eleven years clearly poses a problem for the cointegration test. The results reject the null hypothesis of no cointegration for the whole panel (Pt and Pa) for the variables R^{fs} and R^o, but in the case of R^s, only the null hypothesis that all time-series are not cointegrated (Gt and Ga) is rejected. If we test this relationship over a longer time period, the results however change significantly. While the WIOD database is available from 1995 onwards only, the ANBERD and EU Klems databases have data since the 1980s for many countries. Hence, it is possible to test for cointegration between MFP and R^s over a longer time period as this R&D variable does not require the WIOD database for its construction. The last column of Table 4 reports results based on a longer time series starting in 1987. Using this longer time-series strengthens the results of cointegration in the panel. This finding reinforces our supposition that although the test struggles with the short time series, we nonetheless almost certainly face cointegration. Thus, we employ Dynamic OLS in order to obtain valid t-statistics for our estimates.

4.2. BASELINE RESULTS

Table 5 reports the initial results. The first two columns include the manufacturing spillover variables only, with column (i) reporting OLS results and column (ii) the DOLS results. This specification is therefore similar to existing studies at the industry level (e.g. Keller, 2002; Schiff and Wang, 2006; López-Pueyo et al., 2008). The results in these first two columns indicate that own industry R&D has a significantly positive impact on MFP. Interestingly, the coefficients on the foreign own-industry spillover variables tend to be similar in size or greater than those on the domestic own-industry spillover variables. Coefficients from the DOLS estimation are qualitatively similar to those from the OLS estimation, but are somewhat smaller. The coefficients from the DOLS estimation indicate that a 1% increase in either the domestic or foreign own-industry spillover variable increase MFP by around 0.05%.

The coefficients on the domestic R&D stock are therefore slightly smaller than those found by Keller (2002) and López-Pueyo et al. (2008), who reported coefficients between 0.08 and 0.13, and Coe et al. (2009) who reported coefficients between 0.06 and 0.10 for the whole manufacturing sector. This may be due to the more refined measure of MFP employed in this paper, which accounts for the use of ICT capital and different labour types.

In our analysis we further differentiate between contributions from foreign own-industry and other-industry spillovers and find a strong effect of own-industry spillovers, but a small and insignificant effect of other-industry spillovers.[5] The results indicate therefore that cross-country spillovers occur largely between the same industries in different countries, and that the effect of such spillovers is of a similar magnitude to those from the same industry within a country.

Table 5: Regression Results

VARIABLES	(i)	(ii)	(iii)	(iv)
R^{s}	0.057***	0.048**	0.064***	0.071***
	(3.077)	(2.233)	(3.410)	(3.147)
R^{fs}	0.069***	0.053***	0.064***	0.041**
	(4.310)	(2.886)	(4.010)	(2.389)
R^{o}	0.010	0.008	0.009	0.008
	(0.560)	(0.370)	(0.493)	(0.348)
R^{serv}			0.010**	0.023***
			(2.373)	(4.124)
Country-Industry	yes	yes	yes	yes
Time	yes	yes	yes	yes
Method	OLS	DOLS	OLS	DOLS
Observations	1936	1584	1936	1584
R-squared	0.748	0.816	0.749	0.821

t-statistics in parentheses. The dependent variable is the log of MFP. The R&D variables are also included in logs. Coefficients are estimated using ordinary least squares (OLS) with robust standard errors and dynamic ordinary least squares (DOLS) with one lead and lag of the differenced R&D variables. ***, **, and * denote coefficients being significantly different from zero at a 1, 5, and 10% level, respectively.

It is not straightforward to compare the coefficients on the cross-country spillover variables with other industry level studies, since these variables are constructed in different ways. However, the results confirm a central statement made by Keller (2002): roughly one half of the productivity effect stems from R&D conducted within an industry, with contributions of all other foreign and domestic industries accounting for an overall productivity effect of a similar size. The composition of the spillover effect

[5] For reasons discussed in section 2, we combine the domestic and foreign other-industry spillover variables.

however stands in stark contrast to the findings by Keller (2002). Keller found that the largest contributions to productivity originate from domestic other-industry spillovers, followed by foreign other-industry spillovers. In our specification, the most important source of productivity improvements are foreign own-industry spillovers while other-industry spillovers are found to be insignificant. One major reason for this difference could be the sample period – while Keller's sample covers the years 1970 to 1991, our sample only begins in 1995. From 1995 onwards, the ongoing globalisation has likely increased the importance of foreign spillovers. Moreover, the emergence of global value chains has likely increased the spillovers from firms in the same industry, as firms are also more strongly horizontally integrated. Another cause for this difference could be differences in the construction of the spillover variables, as discussed above.

In the final two columns we introduce the services spillover variable. Qualitatively, this has little effect on the remaining coefficients, with those on the domestic and foreign own-industry spillover variables being positive and significant and that on other-industry spillovers being insignificant. Quantitatively however, the results do change somewhat, particularly in the case of the DOLS estimation. In column (iv) we observe that the coefficient on the domestic own-industry spillover variable increases to 0.071, a coefficient still smaller, but closer to those reported by other industry level studies (Keller, 2002; López-Pueyo et al., 2008). The coefficient on the foreign own-industry spillover variable is found to fall however, though it remains significant at the 5% level. The coefficient on the services spillover variable is found to be positive and significant, with the size of the coefficient increasing when using DOLS estimation. Given that the R&D stock of the service industries in our sample has increased by 8.5% per year on average, this coefficient implies a total manufacturing productivity increase of 1.9% over the analysed period of 10 years, holding all else equal (the R&D stock of the service sector overall increased by a factor of 2.26, which is taken to the power of 0.023). It should further be noted that this estimate is likely a lower bound, as the usage of ICT services correlates heavily with the employment of ICT capital, which is already accounted for separately in the MFP measure.

To summarise, these initial results highlight the significantly positive productivity effects stemming from the industry's own R&D. As expected, this is the primary source of productivity improvements. The coefficient captures the firm's own R&D effort as well as intra-industry spillovers. The spillover of own-industry R&D is found to occur both within and across countries, though when accounting for services spillovers the effect of foreign own-industry spillovers are found to be somewhat lower than domestic own-industry spillovers. Regarding spillovers from the services sector, the results indicate significant productivity effects of services improvements through R&D for manufacturing industries. The size of the effect is roughly one third of the effect stemming from the industry's own R&D efforts, underlining the importance of this little reviewed channel as a source for productivity improvements.

5. MODEL EXTENSION AND ROBUSTNESS CHECKS

In this section, the results regarding our model extension, discussed in section 2.2, are presented as well as a number of additional robustness checks. Estimation (v) in Table 6 presents the results of the model extension, incorporating offshoring activities due to factor price differences in the spillover framework. The results indicate that offshoring to low income countries has a large positive impact on productivity. For the developed countries in our sample, the effect of offshoring on productivity is bigger than the combined foreign spillover effect. An observed average annual increase of 6.3% in the offshoring variable thus leads to a productivity effect of 6.6% over the analysed period. For our sample of advanced economies, this means that the relative shift of trade from countries close to the technological frontier to countries with low factor prices and further away from the frontier has increased productivity as the effect of factor-price differences tends to outweigh the spillover effect.

Moreover, the coefficient on the foreign own-industry spillover variable becomes smaller and less significant, indicating that there is a correlation between those two measures. This means that countries that simultaneously outsource and offshore heavily, trade intensively with advanced economies and thus profit a great deal from R&D spillovers as well. A further implication of this finding is that former studies focussing solely on the spillover effect and disregarding offshoring effects have likely overestimated the effect of foreign R&D spillovers on productivity.

Table 6: Results Regarding Framework Extension and Robustness Checks

VARIABLES	(v) Offshoring	(vi) Institutions	(vii) EU only	(viii) Depr. rate: 7.5%	(ix) Depr. rate: 12.5%	(x) 7.5/10.0/ 12.5%
R^s	0.059***	0.067***	0.070***	0.078***	0.064***	0.075***
	(2.900)	(3.002)	(3.018)	(3.297)	(3.010)	(3.301)
R^{fs}	0.030*	0.043**	0.056***	0.042**	0.042**	0.044***
	(1.731)	(2.506)	(2.867)	(2.527)	(2.407)	(2.599)
R^o	0.007	0.006	0.027	0.008	0.006	0.008
	(0.332)	(0.264)	(1.178)	(0.360)	(0.302)	(0.370)
R^{serv}	0.021***	0.022***	0.023***	0.022***	0.023***	0.022***
	(3.728)	(4.017)	(3.993)	(4.366)	(4.063)	(4.076)
$OFFS$	0.105***					
	(3.938)					
LAW		0.568**				
		(1.994)				
Country*Industry	yes	yes	yes	yes	yes	yes
Time	yes	yes	yes	yes	yes	yes
Method	DOLS	DOLS	DOLS	DOLS	DOLS	DOLS
Observations	1,584	1,584	1,314	1,584	1,584	1,584
R-squared	0.826	0.822	0.832	0.822	0.820	0.821

t-statistics in parentheses. The dependent variable is the log of MFP. The variables on R&D, offshoring and institutions are also included in logs. Coefficients are estimated using dynamic ordinary least squares (DOLS) with one lead and lag of the differenced R&D variables. ***, **, and * denote coefficients being significantly different from zero at a 1, 5, and 10% level, respectively.

Two further factors that have to be considered when looking at productivity and its relationship to R&D are education and institutions. The quality and level of education affects productivity not only directly but also indirectly as human capital levels are a major determinant of absorptive capacity (Hans-Jürgen Engelbrecht, 1997; Dirk Frantzen, 2000; Rod Falvey, Neil Foster and David Greenaway, 2007; Wang, 2007). In order to take direct influences of human capital on productivity into account, we control for the skill structure already in the estimation of MFP, as stated in section 3.1. Our productivity measure therefore takes into account different structures in education levels across countries and industries. Regarding indirect effects, we tried including a time-varying absorptive capacity term similar to Falvey et al. (2007) or Wang (2007). The estimation however yields no significant or very weak results and which are not reported for reasons of brevity.[6] The fact that we do not find significant indirect effects is not very

[6] To construct a measure of the absorptive capacity of an industry, the domestic education indicator was interacted with the input-output weighted foreign research stock. As a domestic education indicator, we tried two measures:

surprising for two reasons. First, the initial level of absorptive capacity is already controlled for by the interacted country-industry fixed effects. Secondly, our sample consists of relatively short time series for developed countries only. Especially in developed countries, human capital indicators are rather stable, limiting the scope for indirect effects from human capital changes over time on productivity.

Institutions are the second factor that affects the productivity-R&D nexus. In the past decade, they have been increasingly viewed as key determinants of growth and productivity (Rafael La Porta, Florienco Lopez-de-Silanes, Andrei Shleifer and Robert Vishny, 1999; Daron Acemoglu, Simon Johnson, and James Robinson, 2001). Especially property rights protection and the quality of contract enforcement and courts have been singled out as important determinants of growth (Mahmut Yasar, Catherine Morrison Paul, and Michael Ward, 2011). For companies, these factors are especially important regarding long-term investment, such as building up human resources, infrastructure and conducting R&D. The firm, for example, has to be sure that after a long phase of research, the monopoly rent of the innovation outcome is not lost. Lax law enforcement, especially with respect to patent protection, will decrease returns to R&D, usually leading to underinvestment in the country (Sunil Kanwar and Robert Evenson, 2003). Thus, high risk projects with potential for high returns are more likely to be executed in countries with high quality contract enforcement and strong property rights protection, especially in the area of intellectual property rights (Coe et al., 2009).

This theory is tested by including the World Governance Indicators index on the quality of contract enforcement, property rights and courts, LAW, in the model. Estimation (vi) provides evidence that this indicator is significantly and positively related to productivity. The results thus confirm that the security of strong law enforcement and property rights protection enables innovators to work on riskier, long-term projects where potential returns are higher.[7]

Table 6 also contains a number of additional robustness checks. Results are found to be robust to reducing the sample to the countries of the European Union only. Regression (vii) shows that only the coefficient for foreign spillovers from the same industry increases substantially. This finding is an indication of stronger spillover effects within Europe due to the highly integrated European production networks. Last but not least, we conduct a sensitivity analysis with our standard specification, given by equation (1), by varying the R&D depreciation rate, which gives a measure of how fast knowledge

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(1) the quality of tertiary education taken from Joaquim Oliveira Martins, Romina Boarini, Hubert Strauss, and Christine de la Maisonneuve (2007) and (2) secondary school completion ratios as reported in an updated version of the Barro and Lee dataset (Robert Barro and Jong-Wha Lee, 2010).

[7] Two further institutional indicators from the WGI dataset were included, capturing (1) corruption and (2) the ability of governments to implement sound policies that promote private sector development. Both coefficients were found to be insignificant und when including them alongside the index of the quality of contract enforcement, property rights and courts, LAW, the latter remains significant with a stable coefficient size.

becomes obsolete. The higher the R&D depreciation is set, the shorter is the time period in which past R&D can affect current productivity. The original rate of 10% has been set to 7.5 and 12.5% in regressions (viii) and (ix). The coefficient of the industry's own R&D stock shows some variation when using a higher depreciation rate, with the results implying a lower elasticity between the level of productivity and the R&D stock. In our last specification, we use different depreciation rates depending on the industry's technology classification, according to that developed by the OECD (2005).[8] The results again confirm the previous findings and underline the robustness of the results.

6. CONCLUSION

In this paper, the previous literature on international spillovers at the industry level is expanded to include the role of business service industries in R&D spillovers. We focus on two high technology service industries that include telecommunications and software development. These two industries exhibit R&D growth rates around twice the size of the highest ones in manufacturing and their innovations have greatly changed business processes all over the world.

Using the World Input-Output Database we are able to improve on the traditional approach of using trade in intermediates for the estimation of international spillovers to the application of direct input-output linkages between industries in different countries. With this updated method and using recent panel cointegration techniques, we first show that the two research intensive and high technology service industries not only account for a substantial part of manufacturing industries' inputs, but are also the source of positive and substantial productivity effects in the manufacturing sector. The productivity effect resulting from knowledge intensive, high technology service sector innovation is about one third of the effect generated by the manufacturing industry's own R&D.

Secondly, the results also confirm the existence of positive productivity effects stemming from international manufacturing spillovers, which were previously documented in the literature. We confirm Keller's finding that roughly one half of the productivity effects stems from the R&D conducted within the industry and the other half from other industries (Keller, 2002). Regarding the distribution of spillovers from other industries however, we find different results. While Keller found that the main sources of spillovers are domestic and foreign manufacturing industries other than the industry itself, we find evidence that the largest spillovers stem from foreign own-industry intermediates. Moreover, when reducing the sample only to the countries of the European Union, we find foreign spillovers from the

[8] The idea behind this approach is that the current knowledge base becomes obsolete much faster in high technology than in low technology industries. As a result, past R&D efforts are able to affect productivity for a shorter time period in a rapid changing environment. The depreciation rates are set to 7.5%, 10% and 12.5% for the low, medium and high technology sector, respectively.

same industry to be even higher than in the overall sample. This is an indication of stronger spillover effects within Europe due to the interrelated production scheme.

Thirdly, the model is extended to include productivity effects from offshoring due to factor price differences. We find that in addition to R&D spillovers, offshoring activities to low wage countries creates significant positive productivity effects which are found to be substantial in our sample of advanced economies.

Finally, a number of robustness checks are performed. The literature stresses the importance of education and institutions on the economic performance of a country. In our productivity measure, we thus control for the skill structure at the industry level. Secondly, we look at the quality of contract enforcement and property rights protection and find that a strengthening of these factors is associated with a positive productivity effect.

Overall the results confirm the importance of R&D spillovers from the services sector. They also show the necessity to take into account other motives for offshoring, such as factor price differences.

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