International, intersectoral or both? In search for the nature of R&D Spillovers*

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Abstract

The aim of this paper is to identify the nature of R&D spillovers from an intersectoral, international as well as combined international-intersectoral perspective. We use panel data for sub-sectors of the manufacturing industry among 13 OECD countries in the period 1988 to 2006. We estimate Griliches-type knowledge production functions at the aggregate level along with two-digit industry level, where R&D investments outside the own industry enter as an explicit regressor. The endogenous variable of interest is labour productivity growth. In order to properly weight the R&D induced spillover effects, we construct different weighting schemes based on the technological and trade-based connectivity between sectors and countries respectively, as well as a combination of the two modes. Although we do not use spatial data as such, we estimate the sectoral production function models by means of spatial econometrics, which allows for a consistent treatment of weighted variables derived from the endogenous regressand as well as the set of explanatory regressors. The empirical estimate indicates that both international and domestic R&D knowledge spillovers matter for explaining the productivity growth. Spillovers from other sector is more than the spillover from same sector domestic and foreing R&D expenditures.

JEL Codes: O11, O33, O47, C23

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*This is an initial draft and we are still working on that paper

1 Introduction

This paper seeks to identify the impact of intersectoral and international R&D spillovers for economic growth among a panel of 13 major OECD countries. Building upon a detailed two-digit industry level dataset for the period 1988 to 2006 (so called EU KLEMS, see e.g. O'Mahony and Timmer (2009)) , we estimate aggregate and industry-specific knowledge production functions in the spirit of Griliches (1979). In this production function R&D investments conducted outside the industry and country in focus enter as an explicit explanatory regressor giving rise to technological externalities. These latter spillover variables thus measure the social return to R&D investments besides the private return to R&D, which can be calculated as the industry's own R&D efforts.

The role played by both private and social return on R&D in driving a nation's aggregate or sectoral growth rate is a matter of heavy research effort. Earlier contributions in the theoretical and empirical literature (on this issue) mainly hinted at the importance for own R&D activity in generating productivity gains and long-run growth. However, recently the notion of spillovers has been highlighted (see e.g. Romer, 1990, Grossman and Helpman, 1991). Thereby, social returns to R&D activity are often found to be equally high or even of greater magnitude than private returns to R&D (see e.g. Nadiri, 1993, Van Pottelsberghe de la Potterie, 1997, for an overview).

By using EU KLEMS dataset, Eberhardt et al. (2010) have shown that the ignoring the spillovers lead to biased estimated returns to R&D for a panel of industries across 10 OECD countries. However, the authors apply an unobserved common factor model for the period 1980 to 2005, which does not allow identifying the quantitative importance of R&D spillovers for different sectors.

In the conduct of this paper, we exactly aim to expand the scope of the empirical research in this direction. In doing so, besides accounting for the proper functional form of the knowledge production functions, we also put special emphasis on the appropriate weighting of intersectoral and international spillovers. For intersectoral spillovers, we apply the concept of technological distance between sectors as recently proposed by Verspagen (1997b). Based on patent information, the author derives a technological weighting matrix, which makes use of the distinction of main and supplementary IPC codes in order to identify links between the knowledge producing and knowledge receiving sector. The IPC codes are then mapped to match standard industrial classifications. We follow Verspagen (1997b) and assume that intersectoral spillovers are constant of the panel of OECD countries. However, in measuring international R&D spillovers (both inter- as well as intersectoral) we use sectoral import and export tables, which vary for each trading pair. This results in a combined international spillover weighting scheme, which can be defined as a stacked system of individual country specific sub-matrices. We apply different methods recently developed in the field of spatial econometrics, to consistently estimate the influence of trade weighted variables (both for the endogenous regressand as well as exogenous regressors with an explicit focus on R&D investments).[1]

The empirical estimate indicates that both intersectoral and international R&D knowledge spillovers matter for explaining the productivity growth. We have divided our analysis at two level. First at aggregate level where we estimated the combined model for all sectors and second at disaggregate level where we estimated the model for each sector separately. The results related to aggregate level show that not only own sector domestic R&D expenditures but also other sectors domestic, and other sectors foreign R&D knowledge stock have significant influence on productivity growth. And this effect is significant for long run but not in the short-run because of technology gap theory. The results related to disaggregate level also have the same conclusion for most of the sectors which confirms that other sectors domestic and other sector foreign R&D knowledge stock have significant influence on productivity growth.

The paper is organized as follows: Section 2 gives a short review of the theoretical and empirical literature dealing with the role of R&D and R&D spillovers for economic growth. Building upon the Griliches (1979) knowledge production as the standard workhorse model in this field of research, section 3 then derives a functional form for the growth model including own R&D efforts as well as spillover effects among the set of right hand side variables. The section then also discusses different econometric models, which are suitable for estimating the derived growth models. Section 4 then discusses the EU KLEMS and R&D dataset. The empirical results for different aggregate and industry-specific subsets of the dataset are discussed in section 5. Section 6 finally concludes.

2 Literature Review

There is a considerable debate in the literature about R&D and its spillover. This literature basically focuses on international or intersectoral spillovers but not simultaneously evaluating both except very few studies(Frantzen, 2002). In this section we will review some important studies related to R&D spillovers.

[1]As best of our knowledge there are only three studies (by Keller (1997), Verspagen (1997b) and Frantzen (2002)), who did the analysis for both intersectoral and international R&D spillovers. But Verspagen (1997b) did only for cross section of the country, the data set of Keller (1997) was old covers from 1970 to 1991 and data set for Frantzen (2002) covers from 1972 to 1994 (in this study 1988 to 2006).

2.1 International Spillovers

The study at country level data by Coe and Helpman (1995) focuses on the analysis that a country's productivity level not only depends on domestic R&D capital stock but also on R&D capital stocks of foreign trade partners. Their sample consists of 21 OECD countries plus Israel during the period of 1971 to 1990. By using pooled data they found that both domestic and foreign R&D capital stocks have important effects on total factor productivity. More specifically, their results explain that the countries with larger share of import to GDP have stronger effect of foreign R&D capital stocks on their domestic productivity. It concludes that more open economies can get larger productivity benefits from foreign R&D capital stock than less open economies.

Another paper by Verspagen (1997a) analyzed the impact of international R& D spillovers on sectoral growth patterns in 14 OECD countries and 22 sectors from 1974 to 1992. By using transaction-based Yale matrix and technology based matrix A (Verspagen, 1997b) this study found that knowledge spillovers are an important contributor to economic growth. Furthermore they study also highlights that the distinction between rent spillovers and knowledge spillovers and between two technology flow matrices is also relevant in the discussion of international R&D spillovers. Furthermore, the study also finds that knowledge spillovers are more local than rent spillovers. Finally they conclude that the US, Japan and Germany are the most influential countries in terms of contributions to other countries' TFP growth.

Verspagen (1997b) tried to identify and quantify the knowledge spillovers, by using two most widely used patenting data base, i.e. the European Patent Office (EPO) and the US Patent Office (USPO) classified patents. The analysis is based on nine OECD countries and used simple regression model, which includes direct and indirect R&D in the explanation of growth rates of total factor productivity (TFP) in a cross-sectional, cross-country panel. Both databases are quite different, from the point of view of measuring spillovers. Furthermore, the study also compares the results between transaction-based (Yale matrix) and technology based matrices (EPO and USPO). Three technology based matrices were used to identify the knowledge spillovers. Two technology-based matrices are constructed from EPO data sets (matrix A and B), and one technology-based matrix is constructed from US patent data set. Then some important points were analyzed in this study. The Yale matrix is economic based transaction (rent spillovers) while Matrix A, B and USPO are technology based (pure knowledge spillovers). There are indeed differences between these matrices in terms of spillovers. The important things to be considered here is that pure knowledge spillovers, from technology based matrices, are mostly restricted to the manufacturing sector, but flows from manufacturing to services or any other sectors may captured from transaction based (Yale matrix), which is an important advantage of transaction based matrix. Furthermore, in terms of rate of returns the Yale matrix produces a relatively high return in medium- tech sectors, but not so in the other sectors. The two measures based on EPO data yield intermediate values for the rates of return compare to USPO, which produces relatively high rates of return. In terms of extra-sectoral social rates of return, the matrix B (based on EPO) and USPO yield high values compared with the other two measures. It indicates that there are considerable differences between these matrices in terms of measures and database. Directly it is difficult to compare the technology-based matrices with transaction- based Yale matrix because of collinearity and omission of intra-sectoral spillovers analysis. But technology-based matrices are important contribution in measuring pure knowledge spillovers.

Keller (1997) have attempted to estimate both intersectoral and international R&D spillovers for eight OECD countries over the period from 1970 to 1991. The analysis is based on 13 manufacturing sectors. The main results of this study is that R&D expenditures are positively related to TFP levels and elasticity of TFP with respect to own-industry R&D is between 7 to 17 percent. Furthermore they found that R&D is more important for sectors which are lacking in conducting R&D activities and for R&D intensive sectors, there is only small gain from foreign same sector R&D because there is little trade of innovative products among competing firms. But this study do not explain which technology transmission is embodied while estimating the channels of technology transmission. It is also important to analyze further with more recent data set of productivity growth because of improvement of technology overtime.

Hanel and Zorgati (2000) analyzed the relationship between export market share and R&D spillovers for different industries of G7 countries over the period of 1974 to 1990. Most of the earlier studies show that market share depends on relative export prices and share of international R&D expenditures, but in this study they have included the inter-industry flow of R&D spillovers based on combination of R&D expenditures and patent statistics. In order to test the 'export share model' correctly, they have only concentrated on export share to EEC (European Economic Community) rather than the whole OECD. Their findings suggest that there is positive relationship between R&D spillovers and exports share exists only for low-tech industries belonging to other sector. Own country's R&D expenditures affects the export market share of US and Japan only, while spillover received from other industries contributes slightly to the competitiveness of Germany and UK only. Finally they conclude that technology spillovers received by an exporting country's industry are not often a major determinant of its share of European Economic Community (EEC) imports.

Funk (2001) re-examine the relationship between trade and R&D spillovers for 22 OECD countries. By using panel co-integration techniques developed by Kao and Chiang's (1998) and Cao's (1999), the study used two types of weighted foreign R&D stock; first, as import-weighted foreign R&D stock and second as export-weighted foreign R&D stock. The study did not find strong evidences of research spillovers among OECD countries via imports-weighted foreign R&D stock, but there is strong evidence in the favour of export-weighted foreign R&D stock. The study argues that exporters enhance their own knowledge and productivity in order to fulfil the customer demand and successfully exporting products into the competitive international market. This study was conducted at aggregate level but there can be some interesting findings if analysed at intersectoral or international levels.

Frantzen (2002) analyzed the knowledge spillovers for the panel 22 manufacturing sectors with respect to 14 OECD countries over the period of 1972-1994. This study is conducted at disaggregate level by using co-integration technique. The results indicate that spillovers are intersectoral and intrasectoral in nature. Both international and domestic R&D knowledge spillovers are important for explaining the productivity in manufacturing industries. Moreover, they have found that not only own sector domestic R&D but also other sectors' domestic, same sector foreign and other sectors' foreign R&D exercise a significant influence on TFP. Furthermore, they also found that average influence of foreign R&D was somewhat weaker than that of domestic R&D, whereas the influence of other sectors' R&D was more than that of sector R&D. In the last they also tested for the size of the economy and found that the effect of domestic R&D is stronger in large economies than in the small economies and the same effect was stronger for research intensive industries.

A study by Park (2004) empirically tests the effect of international and intersectoral R&D spillovers on total factor productivity (TFP) of two sectors that are manufacturing and non-manufacturing. Their sample consists of 14 OECD and 3 East Asian economies for the period of 1980 to 1995. They found that foreign R&D has significant effect on TFP of both sectors. Moreover, they found that domestic manufacturing R&D has a substantial intersectoral spillover for domestic non-manufacturing sectors, whereas non-manufacturing R&D have insignificant impact on other sectors. Furthermore, they have also estimated the social rates of returns to R&D that were six times greater than the private returns for manufacturing sectors. There is no direction of spillovers exists from East Asian economies to OECD but exists from OECD to East Asia.

A panel study by Madsen (2007) on technology spillover and total factor productivity (TFP) found that knowledge has been transmitted internationally through the channel of trade. Their empirical estimates show that 93 percent of the increase in TFP over the past century has been solely due to imports of knowledge. Moreover, the knowledge spillovers is an important contributing factor behind the TFP convergence among OECD countries. The study was conducted at aggregate level, but gives an important indication of spillovers at disaggregate level for further research.

A study by Scherngell et al. (2007) highlights the contribution of R&D on regional productivity at industry level. They used a panel of 203 NUTS-2 regions covering 15 EU countries over the period of 1998-2003. According to their results, TFP not only depends on its own knowledge capital stock but also on interregional knowledge spillover. More specifically two industries, electronics and chemical, produced more spillovers and have significant effects on productivity. That also confirms the R&D spillover effect from neighbouring regions at industry level.

Fischer et al. (2007) analyzed the interregional knowledge on TFP for the panel of 203 EU regions over the period of 1997-02. They used random effect panel data with spatial error model. They measured the knowledge elasticity effect within regional Cobb-Douglas production function framework, with special focus on knowledge spillover. The results of their study show that regions total factor productivity depend not only on its own knowledge capital, but also on cross-region knowledge spillover. As distance decreases the spillover effect increases. This also confirms the evidence of knowledge spillover on productivity in EU regions.

2.2 Intersectoral Spillovers

Wolff and Nadiri (1993) used the US input-output data for different industries over the period of 1947 to 1977 in order to analyze the relationships among research and development (R&D), technical change, and inter-sectoral linkages. They address three important issues. First, R&D spillover effect from one industry to other industries those buy its input. Second, whether technological progress in one industry directly affects the rate of technological progress in customers and the third is whether R&D in one industry affects its linkage structure with other industries in the economy. By using input-output framework they found significant spillovers from R&D embodied in capital stock and also that a sector's own rate of total factor productivity (TFP) growth is significantly related to the TFP of a sector's supplying industries. Furthermore, sector's degree of forward linkage with other sectors is found to be positively related to the sector's R&D intensity and its rate of TFP growth. After splitting R&D data in to a privately-financed and government-financed component, they also found that there are stronger effects from privately-financed R&D embodied in inputs than from total embodied R&D.

Nahuis and Tang (1999) empirically analyzed the role of domestic and foreign R&D on TFP growth of Netherlands at sector level. More specifically, data for eleven sectors are subdivided into services and manufacturing sectors for the years 1973 to 1992. At the first place they have estimated the aggregate model will all sectors and their results show that both domestic R&D as well as foreign R&D has a significant positive impact on productivity growth in the Netherlands. But the elasticity of TFP with respect to R&D is higher for R&D by same sector then for R&D by other Dutch sectors and for R&D by foreign sectors. In the aggregate model findings suggest that more R&D speeds up adoption of foreign technologies. The results related to disaggregate model for manufacturing and services sectors also consistent with aggregate model. The only difference they have found that R&D in the service sector helps to absorb foreign technologies, whereas R&D in manufacturing does not in case of Netherlands. They also pointed out the important gap in their study is the missing of technology flow matrix for proper measure and disclosure of various channels of R&D spillovers. In the current study we will fill the gap by using technology flow matrix, discussed in the next section.

Cincera and van Pottelsberghe de la Potterie (2001) present a critical survey on macro and micro levels studies that evaluate the impact of foreign R&D on domestic productivity growth in industrialized countries. Their survey pointed out that foreign R&D positively contribute to the productivity growth of industrialized countries either through knowledge spillovers or through rent spillovers. Furthermore, this survey also indicates the need for empirical analysis at micro level which should incorporate the services sector into the analysis. In spite of significant international spillovers the survey also identifies some important issues that underline the need for further research. For example, the timing of spillovers should also be considered or how much time is required to transform the foreign knowledge into domestic productivity growth and absorptive capacity of foreign knowledge, such as education, training mobility of resources should also be examine.

A study by Kwon (2003) at industry level analyzed the role of R&D on total factor productivity during the period of 1987-1996. This study is based on 15 Korean manufacturing industries. They tested the hypothesis that productivity in one industry depends not only on its own R&D but also on R&D of other neighbouring industries. Furthermore, they also performed a comparative analysis of the role of R&D spillover effects in advanced economies with developing countries. The main finding of this study is that the rate of return to own R&D in Korea is higher than that in the developed countries, but the rate of return to R&D spillovers is less than advanced economies. It also opens the path for research at aggregate as well as at disaggregates level.

Lu et al. (2006) analyse the Granger causality relationship between R&D and productivity growth for a panel of 90 electronics firms of Taiwan over the period of 1992 to 2000. By taking firm level data the study argues that the country level data is aggregated that cannot explain the industrial situation and may result in the loss of important information regarding microeconomic units. For the calculation of R&D spatial spillovers effect they used geographic information like longitude and latitude data for the firms at firm and the centre of gravity to measure the extent of the industrial clustering. Regarding the results of Granger causality they found that there is one way causality exists from both the R&D stock and R&D spatial spillovers to productivity growth. This study is important contribution by using geographic aspect of industrial clusters but there is enough space to extend the analysis for both industries and countries.

3 Methodology

The basic model is based on Cobb Douglas production. We follow standard practice as Griliches (1979) assumes knowledge production function with standard inputs labor L, physical capital stock K and 'knowledge capital' (Research and Development) R. Q is used for industry specific output.

$$Q = F(L, K, R) \tag{1}$$

Where R knowledge capital stock, which can be splitted in total domestic (TDR) R&D stock and total foreign (TFR) R&D stock.

$$Q = F(L, K, TDR, TFR) \tag{2}$$

If we assume a sectoral disaggregate setting in an open economy framework then TDR is splitted in to same sector domestic (SSD) and other sector domestic (OSD) R&D. Similarly TFR can be splitted in to same sector foreign (SSF) and other sector foreign (OSF) R&D. So disaggregated production can be written as follows:

$$Q = F(L, K, SSD, OSD, SSF, OSF) \tag{3}$$

The reduced form production function can be represented as following,

$$Q_{ikt} = AK_{ikt}^{\alpha} L_{ikt}^{\beta} SSD_{ikt}^{\gamma SD} OSD_{ikt}^{\gamma OD} SSF^{\gamma SF} OSF^{\gamma OF} \tag{4}$$

With,

$$SSD_{ikt} = R_{ikt}$$

$$OSD_{ikt} = W_1 R_{ijt}$$
$$SSF_{ikt} = W_2 R_{hkt}$$
$$OSF_{ikt} = W_3 R_{hjt}$$

and

$$W_1 = \sum_{j \neq k} (1 - m_{ij}) \beta_{jk}$$
$$W_2 = \sum_j S_{ihk} m_{ij}$$
$$W_3 = \sum_h \sum_{j \neq k} S_{ihj} m_{ij} \beta_{jk}$$

Ths subscripts i, k and t are used for country, sector and time period respectively. The dependent variable Q_{ikt} explains the production in country i in sector k at time period t and A is a constant. Similarly TRD, TRF, SSD, OSD, SSF and OSF are respectively,the corresponding total domestic, total foreign, same sector domestic, other sector's domestic, same sector foreign and other sectors' foreign R&D capital. These R&D spillovers variables are constructed as weighted average of other sectors and countries R&D stocks. β_{jk} is the share of patented inventions made in sector j spilling overs to sector k which also represents the constant proximity weights for all countries. m_{ij} is the share of imports from all countries in the sample in country i in sector j.[2] S_{ihj} is the share of country h in imports of good j into country i (bilateral imports with respect to industry). For estimation purpose at disaggregate level there is no sufficiently reliable information available for measuring technical distance between countries and industries. We, therefore, follow earlier disaggregate studies and base our measure of technical distance between countries reflected by bilateral import shares with respect to industries.[3]

The standard method for estimating equations (4) and (5) is the construction of Total Factor Productivity (TFP), which assumes linear homogeneity of output with respect to the factors of production, labor, physical capital and revenue based elasticities of these variables. One can easily get the estimable form by taking natural log on both sides of the equations. But it is criticized by the researchers, first because of the use of elasticities of output with respect to all inputs are imposed on the basis of outside information that is inappropriate and second constant returns to scale with respect to the labor, physical capital and revenue based elasticities of these inputs that is only valid in the case of perfect competition and also violated because of omission of relevant inputs.

Therefore, by following Frantzen (2002) we prefer test specifications that allow estimation of the average elasticities of output with respect to standard inputs (labor, capital) and

[2]These are derived from a patent-based technology flow matrix constructed by the Merit Centre of the University of Masstricht and inspired by Jaffe (1986, 1988) and is presented by Verspagen (1997b).

[3]For detail, see Frantzen (2002) about different technical weights for spillovers at disaggregate level and see Eberhardt et al. (2010) about private returns to R&D.

average elasticities of the knowledge (R&D) variables. The advantage of using this type is we do not need to impost the assumption of constant returns to scale of output with respect to labor and physical capital. After taking natural logs and rearranging the equations (4) and (5), the reduced form expressions can be written in labour intensive form as following,

$$lL_P = \psi + \alpha lK_I + \lambda lL + \gamma_D lTRD + \gamma_F lTRF \tag{5}$$

$$lL_P = \psi + \alpha lK_I + \lambda lL + \gamma_{SD} lSSD + \gamma_{OD} lOSD + \gamma_{SF} lSSF + \gamma_{OF} lOSF \tag{6}$$

Where l is used for natural log, $L_P = Y/L$ stands for labour productivity, K_I stands for capital intensity and $\lambda = \alpha + \beta - 1$, which measures the deviation from linear homogeneity and also allows us to perform hypothesis test.[4] γ_D and γ_F represents the total spillovers from domestic sectors and total spillovers from foreign sectors respectively. Similarly, γ_{SD}, γ_{OD}, γ_{SF} and γ_{OF} reresents the spillovers from same sector domestic, other sectors domestic, same sector foreign and other sectors foreign respectively. Next section is explaining about the empirical methods for estimating these spillovers.

4 Econometric Specification

The estimation of $I(1)$ variables has a long tradition in time-series modelling and has recently been adapted to panel data econometrics (see, e.g., Hamilton, 1994, Baltagi, 2008). In this section, we briefly describe the estimation of the long-run co-integration relationship among variables as well as the dynamic error correction model specification. To show this, we start from a panel data model with the following general long-run form:

$$Y_{it} = \alpha_i + \beta * \mathbf{X}_{it-j} + u_{it}, \tag{7}$$

where Y_{it} is the dependent variable of the model for $i = 1, 2, \ldots, N$ cross-sections, $t = 1, 2, \ldots, T$ is the time dimension of the model, where the index j reflects the chosen lag structure. $\mathbf{X}_{it}$ is a vector of exogenous control variables; α_i is a vector of cross-sectional fixed effects, and u_{it} is the model's residual term. If Y and $\mathbf{X}$ are co-integrated, the error term u should be stationary as $u \sim I(0)$. As pointed out in the seminal work of Engle & Granger (1987), co-integration and error correction are mirror images of each other. We may thus move from the specification of the long-run equation in eq.(7) to a dynamic specification

[4]For example the elasticity of Y with respect to L is obtained as $\beta = \lambda - \alpha + 1$, for detail see Frantzen (2002).

in first differences, which nevertheless preserves the information of the long-run equation. The resulting (Vector) error correction model (ECM) describes the dynamic process through which co-integrated variables are driven in the adjustment process to their long-run equilibrium. Thus, we allow for deviations from a stable long-run equilibrium relationship in the short-run. However, the 'error correction' mechanisms ensures the stability of the system in the long-run. The resulting ECM associated with eq.(7) in its first-order form can be written:

$$\Delta Y_{it} = \gamma_{0i} + \gamma_1 \Delta Y_{it-1} + \gamma_2 \Delta \mathbf{X}_{it-1} + \phi u_{it-1} + e_{it}, \tag{8}$$

Where Δ is the difference operator as $\Delta y_{it} = y_{it} - y_{it-1}$, e_{it} is the short-run residual and u_{it-1} is the residual term from the long-term relationships of the system. The latter is stationary for the case of a co-integration system. The coefficient ϕ can be interpreted as error correction coefficient, which drives the system to its long-run equilibrium state. Error correction arises if $\phi < 0$ in order to restore the long-run equilibrium. It is straightforward to see that if the coefficient for u is zero, the long-run information used for estimation drops out and the system in eq.(8) reduces to a short-run model. Note, that in the short-run, X may affect Y differently from how it affects Y in the long run. Hence, γ_2 in eq.(8) may be different from β in eq.(7). Finally, the ECM in eq.(8) should only contain contemporaneous terms for ΔX if the variables are assumed to be exogenous. The latter implies for our empirical case, that error correction runs from X to Y but not the other way around. The chosen lag structure in eq.(8) shows, that in our case, X is assumed to be predetermined, but not strictly exogenous.

We estimate the models in eq.(7) by means of a standard (static) Fixed Effects estimator with heteroscedasticity robust standard errors. Since the short-run model in eq.(8) includes a lagged dependent variable, here we estimate the model by means of dynamic panel data estimators in order to account for the endogeneity of the latter variable with respect to the vector of cross-sectional fixed effects (γ_{0i}). In the following, we use an analytical approach aiming to correct for the bias in the spirit of Kiviet (1995). In order to control for heteroscedasticity in this estimation step, we use bootstrapped standard errors.

5 Data and Variables

In the previous sections, we pointed out that the main focus of this work is to analyze the nature of R&D spillovers and determine whether the spillover is international, intersectoral or both. To analyze such effects, it is necessary to have reliable data on annually R&D

expenditures and annually R&D stocks of the examined industries and countries. We have mainly taken data for our study from EU KLEMS data set and the OECD. The EU KLEMS project provides a dataset on economic growth and productivity for all EU member states as well as other large economies, like the US. The database comprehends input, like labour, as well as output measures, like value added.

Our data set contains information from 13 countries and 13 manufacturing industries over a time period from 1988 to 2006. The reason to choose these year is based on the availability of data for each sector, each country and each year. All monetary variables in our dataset are expressed in millions of the local currency. Table 1 in appendix shows the countries that are included in this study. The manufacturing industries are defined by two-digit ISIC sectors and comprise sectors from classes 15-37, as shown in Table 2.

The R&D stocks are taken from EU KLEMS database, which covers the period from 1980 - 2003. Using the annually R&D expenditures of the industries, taken from OECD ANBERD database, we expand this period for all 13 countries up to 2006, by using the method suggested in O'Mahony et al.(2008) which is expressed by:

$$R_{it} = (1 - \delta)R_{it-1} + I_{it}^{R\&D}$$

Above equation shows that the actual R&D stock (R_{it}) of an industry i depends on the R&D stock (R_{it-1}) for year $t-1$, a depreciation rate (δ) and the R&D expenditures ($I_{it}^{R\&D}$) in year t. The depreciation rate was set by O'Mahony et al. (2008) at 0.12, which is in line with the empirical results shown by Nadiri & Prucha (1996).

6 Results

The major results related to 13 OECD countries and 13 manufacturing sectors are reported in this section. At the first place we have estimated our model at aggregate level (for all sectors combined), then at the second place we did the same at disaggregate level (for each sectors separately). But before estimating the final models we have perform the panel unit root test on the residual of our models at aggregate and disaggregate levels.[5] At aggregate level the t-statistic' was enough below the critical value to reject the null hypothesis of a unit-root based on an ADF regression with lags according to AIC criterion.[6] Most of the results at sectoral level also have the same kind of conclusion as in aggregate level.[7]

[5] We perform panel unit root test developed by Im, Pesaran, and Shin (1997), to test whether a variable has a unit root.

[6] The alternative hypothesis is that there are some panels which are stationary. Therefore, we also estimated the Vector Error Correction Model (ECM) for short-run and long run dynamics.

[7] All results for unit root are not reported here but are available on request.

6.1 The aggregate Model

The short-run and long run dynamic fixed effect model is estimated for all sector together (aggregate model) which is based on equation (7)and (8). As mentioned earlier that our dependent variable is labour productivity (L/Y) and independent variables of interest are spillovers from same sector domestic R&D (SSD), other sectors domestic R&D (OSD), same sectors foreign R&D (SSF) and other sectors foreign R&D (OSF). Table (1) reports the long run results of dynamic fixed effect model of equation (7) by using five different regression, which includes the spillovers one by one. All five regressions provide sensible parameter estimates on SSD, OSD, SSF and OSF.[8] Before explaining the results of parameter estimates some words about returns to scale. We have tested the linear homogeneity with respect to labour and capital. As ($\lambda = \alpha + \beta - 1$) in equation (5) is tested with the null hypothesis of ($\lambda = 0$) and we were not able to reject this hypothesis. It means there is constant returns to scale. [9]

Table 1: Long Run Fixed effects estimation (Aggregate Model)

Research and Development	Dependent Variable Labour productivity				
	1	2	3	4	5
Same Sector Domestic	**0.196**	0.060	**0.192**	0.177	0.062
	(5.11)	(1.5)	(5.01)	(4.65)	(1.59)
Other Sector Domestic		**0.354**			**0.281**
		(7.73)			(6.75)
Same Sector Foreign			0.034		-0.334
			(1.23)		
Other Sector Foreign				**0.134**	**0.410**
				(3.97)	(3.76)

Turning to the R&D spillovers variables which are our main focus of the study. The parameter estimates of the R&D spillovers from same sector domestic (SSD) is significant and sensible for all the regressions (from column 1 to 5) which shows the important contribution of R&D stock for productivity growth. If we compare the parameter estimate of SSD in regression 1 that is 0.196 with regression 2 that is 0.06 then It is clear that returns to R&D spillovers from same sector domestic is overestimating and shows the biased results in

[8]Results of all variables in the models are reported in appendix table (7), but here we have reported only spillover variables, where we allow different lag structure based AIC method.

[9]Most of the earlier studies assumed that there is CRS and ($\alpha + \beta = 1$) but we have tested it without assuming at initial.

regression 1.[10] In regression 2 there is huge difference between the parameter estimate of SSD that is 0.354 and parameter estimate of OSD that is 0.06, which indicate that there is enough domestic spillover which is coming from other domestic sectors. It also shows that the research and development in other sector contributes more than own sectors.[11]

In the first two regressions we have included only domestic spillovers but not included the spillovers from same sector foreign (SSF) R&D stocks and other sectors foreign (OSF) R&D stocks. In the third regression (column 3) we have included only SSD and SSF. The parameter estimate of SSD is slightly lower than regression 1 (almost same) and significant, but the parameter estimate of SSF is insignificant shows no spillovers from same sectors foreign countries. The interpretation could be that there is some competition effect in the same sector across the border.[12] There could be healthy competition among the same sectors which contributing into the other sectors of same and foreign countries. Now it is important to analyze the R&D stocks from other sectors foreign (OSF).

In regression 4 we have included only SSD and OSF spillover variables and both are significant showing foreign spillovers. The parameter estimate of SSD is (0.177), which is slightly lower than the parameter estimate of SSD in regression 3 and regression 1 because of positive contribution of spillover from other sectors foreign. It confirms the biased results of the regression which do not included the foreign spillover variables. Addition of foreign spillover variable OSF do not affect much to the parameter estimate of SSD but it self is positive and significantly affecting the productivity growth. It means technology flows from other foreign sectors are large than same sectors. Ignoring foreign spillovers leads to baiseddness in the estimated returns to R&D stock.[13]

Finally in regression 5 we have included all the variables related to spillovers. The parameter estimate of SSD is slightly lower than regression 2 but much lower than regression 1 and regression 2, which confirms the importance of foreign spillovers variables. The results related to OSD is almost same but parameter estimate is slightly lower than regression 2 because of the addition of foreign spillover variable (OSF). The results related to OSF

[10] Eberhardt et al. (2010) also investigated that ignoring spillovers leads to biasedness of private returns to R&D stock.

[11] Spillovers can be regarded as omitted factors in R&D stocks and in the error term.

[12] Keller (1997) also found that R&D intensive industries benefit to a lesser extent from foreign same industry R&D than for other sector domestic. One explanation by Keller (1997) that R&D intensive sectors tend to operate in a monopolistically competitive environment, where relatively high degree of appropriation by the inventors leads to lower intra-industry technology spillovers. And furthermore, there is less trade of innovation products among competing firms.

[13] These results are consistent with Eberhardt et al. (2010) and Frantzen (2002) with reference to returns to R&D stock.

Table 2: Short Run Fixed effects estimation (Aggregate Model)

Research and Development	Dependent Variable Labour productivity				
	1	2	3	4	5
Same Sector Domestic	**0.010**	0.005	**0.014**	0.010	-0.005
	(0.16)	(0.08)	(0.23)	(0.17)	-(0.08)
Other Sector Domestic		**0.091**			**0.281**
		(0.72)			(6.75)
Same Sector Foreign			**-0.042**		-0.066
			-(2.93)		-(1.09)
Other Sector Foreign				**-0.031**	0.027
				-(2.19)	(0.45)
Error Correction	**-0.169**	**-0.21**	**-0.168**	**-0.179**	**-0.242**
	(-7.21)	(-8.61)	(-7.16)	(-7.56)	(-9.71)

variable are significant and same as in regression 4 with higher parameter estimate of 0.40, but the result related to SSF is different from regression 4. One reason could be that there is underlying interdependence between SSF and OSF.[14] The parameter estimate from all R&D spillover variables from domestic country are positive significant and foreign spillover from same industry is negatively related to productivity growth but foreign spillovers from other industry (or sector) is positive and significant. It shows that there is foreign spillover from other sector and strong spillover from other domestic sectors. So, other sector domestic and other sector foreign are highly significant but same sector domestic and same sector foreign are not significant.

Now moving from long run to short run specification as presented in the dynamic model of equation (8) and we allow for deviations from a stable long run equilibrium relationship in the short-run. The error correction mechanism ensures the stability of the system in the long run. Table (2)reports the results of short-run model with vector error correction term. There are five regression by using different R&D spillover variables one by one.[15] In all the regression the ECM coefficient is significant and showing the auto correcting behaviour. But results related to spillover variables are not significant for short-run. The reason could be that time required for all industry/firms in the importing country to become aware of the competition from the new good.[16]

[14]Another possibility could be that foreign spillovers variable SSF and OSF are offsetting to each other but before reaching at final conclusion it is important to explore further as we are in a process of detail analysis for these spillovers in future.

[15]We have estimated the full model by using different lag structure of spillover variable. The detail results are not reported here but available on request

[16]Posner (1961) described three type of gap called 'foreign reaction lag', domestic reaction lag' and 'learning

6.2 The Disaggregate Model

Our next step is to analyze the impact of domestic and foreign R&D spillovers at sectoral (disaggregate) level. In the previous section of aggregate model we have assumed that the parameter estimate are same for each sector but it is too restrictive assumption. Therefore, it is important to analyze it at sectoral level. Table (3) reports the results of long-run dynamic fixed effect model based on equation (7). Each row includes R&D spillover variables.[17] all R and(9).

The behaviour of spillover variables for most of the sectors is same as in aggregate model but not for all. Consider for example the sector 1 (row 1) which represents food, beverages and tobacco. This sector has significant spillovers from other sector domestic and own sector domestic R&D but no spillovers from same sector foreign and other sector foreign. But if we consider the the industry 2, 3, 4, 5, 6, 7, 9, 11 and 13 the behaviour of spillovers variables is same as in aggregate model. Consider for example industry 6 which represents chemicals and chemical products. This sector has significant spillovers from same sector domestic (SSD), other sector domestic (OSD), same sector foreign (SSF) and other sector foreign (OSF) which is consistent with aggregate model presented in previous section.

Table (4) reports the results for short-run dynamic model for each sectors. This model is estimated in a same way as we have estimated the aggregate model for short run. R&D spillovers variables are appeared to be insignificant for all sectors and these results are also consistent with aggregate model.

7 Summary and Conclusion

In this study we investigated the nature of R&D spillovers and asked whether it is international, intersectoral or both. We have presented some strong evidences of R&D spillovers from both intersectoral and international level. For this analysis we use panel data for 13 manufacturing sectors, 13 OECD countries over the period from 1988 to 2006.

We estimate Griliches-type knowledge production functions at the aggregate and disaggregate level along with two-digit industry level, where R&D investments outside the own industry and country enter as an explicit regressor. The endogenous variable of interest is labour productivity growth. In order to properly weight the R&D induced spillover effects, we construct different weighting schemes based on the technological and trade-based con-

period gap'. All these gap explains that there must be time required for successful utilization of innovation, awareness of competition of new good and learn to produce new goods.

[17]Detail results are available on request.

nectivity between sectors and countries respectively, as well as a combination of the two modes. Although we do not use spatial data as such, we estimate the sectoral production function models by means of spatial econometrics, which allows for a consistent treatment of weighted variables derived from the endogenous regressand as well as the set of explanatory regressors. The empirical estimate indicates that both intersectoral and international R&D knowledge spillovers matter for explaining the productivity growth.

More specifically, we divided our analysis at two levels. First at aggregate level where we estimated the combined model for all sectors and second at disaggregate level where we estimated the model for each sector separately. The results related to aggregate level show that not only own sector domestic R&D expenditures but also other sectors domestic, and other sectors foreign R&D knowledge stock have significant influence on productivity growth. And this effect is significant for long run but not in the short-run because of technology gap theory. The results related to disaggregate level also have the same conclusion for most of the sectors which confirms that other sectors domestic and other sector foreign R&D knowledge stock have significant influence on productivity growth.

Our finding suggest that more R&D activities in other sectors domestic and foreign speeds up the productivity and most of the spillovers comes from other sectors. And from an international perspective, the leader-follower relationship also helps to explain the part of intersectoral and international R&D spillovers, which occurs both between and within sectors. adoption of foreign technology.

8 References

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9 Apendix

Table 3: Long Run Fixed effects estimation (Disaggregate Model)

Industry	SSD	OSD	SSF	OSF
1	**0.340**	**0.231**	0.202	-0.121
	(3.10)	(2.32)	(0.79)	-(0.39)
2	-0.075	0.067	**-0.627**	**0.688**
	(0.06)	(1.08)	-(2.78)	(2.92)
3	-0.074	**0.329**	**-0.742**	**0.667**
	-(0.94)	(2.67)	-(4.98)	(4.17)
4	0.051	**0.303**	**-0.439**	**0.507**
	(0.74)	(4.92)	-(2.53)	(3.64)
5	-0.243	**0.738**	-0.254	**0.466**
	-(2.31)	(5.34)	-(1.27)	(2.37)
6	**0.307**	**0.164**	**-1.558**	**1.681**
	(3.09)	(2.07)	-(5.43)	(5.55)
7	0.044	**0.199**	**-1.917**	**2.045**
	(0.44)	(2.23)	-(3.41)	(3.86)
8	-0.171	**0.298**	-0.411	0.470
	-(1.47)	(3.61)	-(1.78)	(1.75)
9	-0.056	**0.213**	**-0.556**	**0.678**
	-(1.10)	(3.06)	-(6.40)	(8.30)
10	0.225	**0.238**	1.840	-1.788
	(3.73)	(2.54)	(1.82)	-(1.74)
11	**0.236**	0.018	**1.016**	**-0.961**
	(3.45)	(0.21)	(3.38)	-(3.32)
12	**0.200**	0.089	-0.710	0.733
	(2.88)	(1.11)	-(0.91)	(1.01)
13	-0.040	**0.341**	**2.099**	**-2.149**
	-(0.72)	(2.42)	(2.81)	-(2.87)

Table 4: Short Run Fixed effects estimation (Disaggregate Model)

Industry	SSD	OSD	SSF	OSF
1	-0.025	0.042	-0.106	0.138
	-(0.12)	(0.14)	-(0.43)	(0.51)
2	0.035	0.010	0.159	-0.144
	(0.28)	(0.03)	(0.51)	-(0.44)
3	-0.005	-0.286	0.064	-0.077
	-(0.06)	-(0.87)	(0.43)	-(0.45)
4	-0.055	0.261	0.277	-0.183
	-(0.48)	(0.67)	(0.74)	-(0.55)
5	0.133	0.297	-0.412	0.233
	(0.21)	(0.21)	-(1.43)	(0.96)
6	-0.540	0.678	0.055	-0.031
	-(1.75)	(1.86)	(0.10)	-(0.05)
7	-0.055	0.131	0.265	-0.237
	-(0.37)	0.470	(0.48)	-(0.42)
8	0.015	0.360	0.054	-0.049
	(0.08)	(0.90)	(0.19)	-(0.15)
9	-0.011	-0.37346	0.158	-0.170
	-(0.05)	-(1.09)	(0.59)	-(0.57)
10	-0.033	-0.246	0.051	-0.057
	-(0.14)	-(0.79)	(0.08)	-(0.09)
11	0.202	-0.327	-1.069	0.816
	(0.35)	-(0.62)	-(1.08)	(0.82)
12	0.369	0.291	0.014	-0.001
	(1.41)	(0.79)	(0.03)	(0.00)
13	-0.014	0.046	0.167	-0.148
	-(0.11)	(0.16)	(0.45)	-(0.39)

Table 5: List of Countries

1	Australia
2	Denmark
3	Spain
4	Finland
5	France
6	Germany
7	Ireland
8	Italy
9	Japan
10	Netherlands
11	Sweden
12	Great Britain
13	United States

Table 6: List of Industries

	ISIC Codes	**Manufacturing Industries**
1	15, 16	Food, beverages, tobacco
2	17, 18, 19	Textiles, textile products, leather and footwear
3	20	Wood and products of wood and cork
4	21, 22	Pulp, paper, paper products, printing and publishing
5	23	Coke, refined petroleum products and nuclear fuel
6	24	Chemicals and chemical products
7	25	Rubber and plastics products
8	26	Other non-metallic mineral products
9	27, 28	Basic metals and fabricated metal products
10	29	Machinery and equipment n.e.c.
11	30, 31, 32, 33	Electrical and optical equipment
12	34, 35	Transport equipment
13	36, 37	Other manufacturing etc.
	Lowtech	ISIC 15, 16, 17, 18, 19, 20, 21, 22, 23, 25, 26, 27, 28, 36, 37
	Hightech	ISIC 24, 29, 30, 31, 32, 33, 34, 35

Table 7: Long Run Fixed effect (Aggregate Model)

Dependent Variable Labour productivity					
L.lcapint	0.673***	0.423***	0.665***	0.642***	0.408***
	(10.97)	(6.13)	(11.14)	(11.16)	(6.24)
Lemp	0.0706	-0.0266	0.0589	0.0369	0.0314
	(0.8)	-(0.28)	(0.69)	(0.44)	(0.34)
L.lrd	0.054	0.021	0.050	0.037	-0.047
	(0.76)	(0.31)	(0.73)	(0.52)	(-0.66)
L2.lrd	-0.174	-0.048	-0.157	-0.140	0.030
	(-1.75)	(-0.58)	(-1.60)	(-1.34)	-0.33
L3.lrd	0.316***	0.088	0.299**	0.281**	0.078
	(3.43)	(0.98)	(3.23)	(3.04)	(0.88)
L.lW1rd		0.527**			0.460*
		(2.84)			(2.49)
L2.lW1rd		-0.768*			-0.521
		(-2.47)			(-1.66)
L3.lW1rd		0.594**			0.343
		(3.12)			(1.77)
L.lW2rd			-0.025		-0.103
			(-1.01)		(-0.92)
L2.lW2rd			-0.0125		-0.198
			(-0.92)		(-1.60)
L3.lW2rd			0.0711**		-0.033
			(3.13)		(-0.29)
L.lW2W1rd				0.029	0.101
				(1.13)	(0.85)
L2.lW2W1rd				0.009	0.196
				(0.53)	(1.56)
L3.lW2W1rd				0.096***	0.112
				(4.13)	(0.99)
Constant	-0.559	-1.131	-0.696	-1.414*	-2.031**
	(-0.92)	(-1.84)	(-1.10)	(-2.27)	(-3.02)
N	2616	2616	2616	2616	2616

t statistics in parentheses

* p ¡ 0.05, ** p ¡ 0.01, *** p ¡ 0.001