Knowledge Spillovers and Output per Worker: An Industry-level Analysis for OECD Countries

Bournakis, Ioannis and Christopoulos, Dimitris and Mallick, Sushanta

Middlesex University, London, UK, Panteion University, Athens, Greece, Queen Mary University London, UK

5 October 2015

Knowledge Spillovers and Output per Worker:
An Industry-level Analysis for OECD Countries

Abstract

The paper analyses the impact of knowledge spillovers on output per worker at the industry level using a primal production function approach. The paper make three different contributions in the international spillovers literature: first identifies trade related spillovers under alternative assumptions regarding the information transferred through imports; second, explores the importance of horizontal and vertical FDI in knowledge spillovers and third looks at how institutional factors determine the impact on FDI related spillovers on productivity. The main findings of the paper are: international knowledge spillovers are an important driver of industry output per worker; the economic size of this effect is smaller the more restrictive the assumptions are about the amount of information embodied in imports; the elasticity of output with respect to spillovers is not negligible but it is definitely lower than industry's own R&D; the effect of spillovers on productivity is mainly driven by high technology industries; gains from FDI spillovers are horizontal, high protection of intellectual property rights and the ease of doing business increase substantially the effectiveness of both horizontal and vertical FDI related spillovers.

Keywords: Productivity**;** R&D; Knowledge Spillovers; FDI; Intellectual Property Rights

JEL Classification: E24; F1; F6; O3; O4.

1. Introduction

Improving the level of productivity is widely regarded as the main source of welfare and economic prosperity. Over the last fifty years, economic literature has identified various drivers of productivity in an attempt to understand the sources of persistent productivity differentials across countries. Historically, developed nations followed a strategy of physical and human capital deepening in stimulating growth and higher levels of per capita income (van Aark et al.,1993; Dougherty and Jorgenson 1996; McAdam et al.2010). As countries approach the international technological frontier, to remain in a high growth trajectory they must invest in the generation of new knowledge and ideas through Research and Development (R&D).[1]

In parallel with the investigation of channels that create new knowledge, the research agenda has focused on the importance of knowledge diffusion (Syverson, 2011) as an equally crucial driver of productivity. Coe and Helpman (1995), Keller (1998, 2004, 2010), León-Ledesma (2005) (among others) consider international trade as a conduit for the diffusion of foreign knowledge, which in turn improves productivity performance. Trade and mainly imports increase contacts with foreign producers which enhances knowledge spillovers.

R&D also generates gains via higher social returns to innovation; the importance of the social returns to R&D always depends on the effective transmission of the existing knowledge. Knowledge spillovers can be either national or international in scope, with special importance to laggard countries (Mancusi, 2008) as it provides access to technological expertise and advanced know-how without incurring the cost associated with research fertility. Although the existence of knowledge spillovers are acknowledged in the production process, to quantify their contribution to output is not straightforward (Hall et al. 2010). To start with, research appropriability is not always granted and since knowledge is a

[1] See Romer (1986) and Aghion and Howitt (1998) for some of the most original developments in the theory of endogenous growth. See also Corrado and Hulten (2010) for a recent overview of this literature.

non-excludable good it can easily spill over to agents that have not bear the cost of innovation input. In this case, the social rate of R&D return[2] is usually bigger than it is initially expected even if it is not accurately measured (Van Meijl, 1997). A common thread in the literature is that imports and FDI are the main channels of international knowledge transmission but an effective measure of international knowledge transfer encounters substantial frictions (Van Pottelsberghe and Lichtenberg, 2001; Keller, 2010). First, knowledge spillovers are basically externalities[3] which are not easily codifiable as the amount of information embodied is tacit in nature. Therefore, the diffusion of knowledge through imports and FDI is not an automatic process. Second, a key objective derived from the previous consideration is how to construct appropriate pools of international knowledge spillovers. This issue remains highly controversial and puzzling (Keller 1998; Coe and Hoffmaister, 1999; Funk, 2001; Falvey et al. 2004), which casts serious doubts about the real economic impact of knowledge spillovers on productivity. To contribute to this agenda the present study relaxes the assumption (Coe and Helpman, 1995; Coe et al. 1997, Engelbrecht, 1997) that a unit of imports always contain the full amount of knowledge used to produce it, instead we assume that the scale of information transferred from the source to destination country varies thus alternative weighting schemes used to measure knowledge spillovers. We employ industry level data, which is rather limited in the current spillovers literature for 12 manufacturing industries in 14 OECD countries. The important but few industry level studies (Bernstein and Yan, 1997; Park, 2004; Schiff and Wang, 2006; Acharya and Keller, 2009) do not address the controversial issue of measuring alternative pools of international spillovers but rely on a universal index of knowledge spillovers assuming that a unit of trade provides full information about the knowledge required to produce it.

[2] The latter effect is of special interest to policy makers that design polices associated with R&D subsidies and R&D related tax exemptions.
[3] Knowledge diffusion might also happen via transactions such as royalties, licences and copyrights. In this case, the existence of actual data can make easier the measure of technology transfer.

Our paper incorporates in the spillovers literature an institutional dimension. The existence of an appropriate institutional environment is potentially a crucial productivity driver as it determines on how efficiently foreign knowledge is utilised in the domestic production. Earlier studies (Coe et al.1995; Keller, 1998; Kao et al., 1999) as well as a more recent one (Agn and Madsen, 2013) focus on various transmission channels of knowledge spillovers while they neglect the institutional status in the recipient country. Coe et al. (2009) with use of country data show that the potential of knowledge transfer depends on the degree of patent protection in the host country. The persistent cross-country as well as cross-industry productivity differentials imply that the evolution of the spillover-led productivity process is not always straightforward and there are still many unexplored components in this puzzle. One of these components is how the institutional framework in the recipient country interacts with the traditional transmission channels. In particular, the present paper looks at the ease of doing business and protection of intellectual property rights as conditions for the effective absorption of FDI related spillovers.

The paper encompasses industry level data to overcome standard bias inherited in highly aggregate data (Hall et al., 2010). We do not assume within country homogeneity but allow for industries to have different capabilities in absorbing spillovers. In a similar line of argument, we explore the possibility that spillovers can also be intra-national as imitation of knowledge can also occur across industries within country.

Methodologically, we use a primal approach following Griliches (1979) in specifying a production function whose technological parameter is modelled as function of human capital, domestic knowledge and international R&D spillovers. The two channels of knowledge spillovers considered are trade (Ang and Madsen, 2013; Yasar, 2013) and FDI (Carr et al., 2001; Branstetter, 2006; Havranek and Irsova, 2011) recognising that international exchange of goods and factors embody substantial information about foreign

R&D stock. We construct four indices of international spillovers that allow for different weighting schemes depending on the scale of information embodied in the standard transmission channel of imports. We also test whether the effect of FDI related spillovers increases if the host country offers a business friendly environment with strong protection of intellectual property rights.

The remainder of this paper is organised as follows: section 2 presents the analytical framework; section 3 shows the measurement of knowledge spillovers; section 4 discusses the data with the econometric specification; section 5 presents results from import and FDI related spillovers, including results from the institutional aspect of spillovers and section 6 concludes.

2. Theoretical Framework

2.1 The Production Function: The Benchmark Model

We assume a standard industry-level production function of the form:

$$Q_{i,c,t} = A_{i,c,t}\left(L\right)_{i,c,t}^{\alpha_1}\left(K\right)_{i,c,t}^{\alpha_2}\left(M\right)_{i,c,t}^{\alpha_3} \tag{1}$$

where A, L, K and M stand for Hicks neutral technical progress, labour, fixed capital and intermediate materials. Parameters α_1, α_2 and α_3 are to be estimated and represent shares of labour, fixed capital and intermediate materials to output.[4] Subscript $i = 1,...,I$ indexes industry, subscript $c = 1,...,C$ indexes country and subscript $t = 0,...,T$ indexes time. Expressing both sides of (1) in per worker units and taking logs (letters in lower cases) we get:

$$q_{i,c,t} = a_{i,c,t} + \alpha_2 k_{i,c,t} + \alpha_3 m_{i,c,t} \tag{2}$$

[4] See McAdam et al. (2012) for a useful guide regarding methods that can be used to overcome empirical uncertainties in estimating these functions.

Total Factor Productivity (TFP) $a_{i,c,t}$ is then modelled as:

$$\begin{aligned} a_{i,c,t} \equiv \ln\mathrm{TFP}_{i,c,t} &= \lambda_i + \eta_c + \beta \ln h_{i,c,t} + \gamma \ln r_{i,c,t} \\ &+\phi \ln\mathrm{DSP}_{i,c,t} + \theta \ln\mathrm{ISP}_{i,c,t} + u_{i,c,t} \end{aligned} \tag{3}$$

Equation (3) states that TFP in industry *i*, in country *c*, at year *t* depends on human capital,[5] industry *i*'s R&D stock per worker $r_{i,c,t}$, domestic knowledge spillovers ($\mathrm{DSP}_{i,c,t}$) and international knowledge spillovers ($\mathrm{ISP}_{i,f,t}$). Parameters ϕ and θ capture the responsiveness of TFP with respect to domestic and foreign spillovers, respectively. We use our different indices of international spillovers each of them depending on a different weighting scheme. [6] Parameters λ_i and η_c capture unobserved industry and country specific idiosyncrasies that drive productivity. Finally, equation (3) is augmented with a stochastic error term with zero mean and constant variance, $u : \mathrm{IID}(0, \sigma^2)$. The current framework adopts most of the key features of the primal approach (Ortega-Argiles et al., 2009; Rogers, 2010; McAdam and Willman, 2013)[7] in estimating output but industry *i*'s knowledge stock and associated knowledge spillovers are determinants of TFP instead of direct inputs in the production function.[8] Merging (2) with (3) yields:

$$\begin{aligned} q_{i,c,t} &= \lambda_i + \eta_c + \alpha_2 k_{i,c,t} + \alpha_3 m_{i,c,t} + \beta \ln h_{i,c,t} + \gamma \ln r_{i,c,t} \\ &+\phi \ln\mathrm{DSP}_{i,c,t} + \theta \ln\mathrm{ISP}_{i,c,t} + u_{i,c,t} \end{aligned} \tag{4}$$

[5] We follow a long tradition in the literature of growth empirics (Benhabib and Spiegel, 1994; Islam, 1995) by including human capital in the TFP equation instead of an input in the production function.

[6] The weighting scheme implies that there are different interpretations of the amount of information transferred and received between sender and recipient country. Section 3 describes the four alternative weighting schemes used in this study.

[7] See also Griliches (1979), Griliches (1980) and Griliches and Mairesse (1984) for earlier studies using the production function approach.

[8] See Eberhardt et al. (2013) use a different approach without using specific international knowledge spillovers rather focusing on the establishment of an econometric correlation between output and unobserved factors which are attributed to spillovers. Their estimation technique is a variation of the Pesaran et al. (2006) estimator used in this paper, see section 4.

To sum up, the parameters to be estimated- in this extended production function- are of: traditional production inputs (α_2) and (α_3), human capital (β), industry's own R&D stock (γ), domestic spillovers (ϕ) and international spillovers (θ). Note parameter θ will be estimated separately for each different pool of knowledge spillovers

3. Measurement of Knowledge Spillovers

R&D does not always lead to new inventions thus research outcomes are not normally protected, which permits us to further explore hypotheses associated with the amount of information transferred through imports. A set of four international spillovers indices is defined to capture whether different proportions of knowledge are transferred in the domestic industry based on whether knowledge is regarded as a pure public or private good.

We first start with domestic spillovers from R&D stock[9] across industries in the same country. This index assumes that the flow of inter-industry R&D spillovers is parallel to the flow of commodities. The size of domestic R&D spillovers is analogous to the degree of "technological proximity" (Branstetter, 2001) between industries *i* and *j*.[10] The index of domestic R&D spillovers is defined as follows:

$$\text{DSP}_{i,c,t} = \sum_{i \neq j} \omega_{i,j,c} R_{j,c,t} \tag{7}$$

[9] R&D stock is computed as follows: $R_{i,t} = (1 - \delta) R_{i,t-1} + RDS_{i,t-1}$, where *RDS* indicates R&D Spending expressed into 1995 USD prices applying the GDP deflator, δ is the annual depreciation rate of R&D stock taken as common for all industries at 15%. The R&D stock series is initiated from a steady state formula identical to the one derived for physical capital: $\Delta R_{i,t} = 0 \Rightarrow RDS_{i,t} \approx (g_i + \delta) R_{i,t-1}$ or for the initial period $R_{i,t=0} = \dfrac{RDS_{i,t=0}}{g_i + \delta}$.

[10] R&D activity in industries of intermediate inputs supplier facilitates gains for downstream industries. The stronger is the degree of engagement between these two types of industries, the greater is the potential of R&D spillover.

where ω is an element of the Leontief inverse matrix. The inverse matrix is generated from an input-output table that describes sales and purchases of commodities between industry i and j within country c. [11]

To address the various controversies related to the measurement of international knowledge spillovers, we construct a set of indices using different assumptions for the amount of knowledge transferred and received through imports (Falvey et al., 2004). The first index assumes that the knowledge embodied in foreign R&D stock is a public good thus a unit of imports incorporates the entire information used for the production of this product whereas this information becomes available in full to all agents in the industry of the recipient country. This index is identical to the one used in Coe et al. (1995) and Coe et al. (1997) and it is written as:

$$\mathrm{ISP1}_{i,c,t} = \sum_{f} s^{i}_{c,f,t} R_{i,f,t} \tag{8}$$

where s stands for the bilateral import share between country c and f in industry i.

The assumption that knowledge transfer to recipients countries has no limitations is too strong. A large strand of literature (Griffith et al. 2004; Cameron et al. 2005; Augier et al., 2013) argues that the benefit of spillovers is larger if domestic industries have certain characteristics. In that case to get the spillover effect we need to scale the information transferred with import penetration in industry i. Therefore, the second index examines whether the benefit from international knowledge is greater- in two hypothetical recipient countries with the same import share s in industry i - the greater is industry i's import penetration. The second index is written as:

$$\mathrm{ISP2}_{i,c,t} = \left(\frac{imp_{i,c,t}}{x_{i,c,t}} \right) \sum_{f} s^{i}_{c,f,t} R_{i,f,t} \tag{9}$$

[11] We prefer this weighting for domestic spillovers instead of averaging R&D stock in country c. Industrial linkages have been found to be of particular importance for technical progress and productivity (Wolff and Nadiri, 1993).

The ratio $\left(\frac{imp_{i,c,t}}{x_{i,c,t}}\right)$ stands for import penetration.

The third index considers the case that knowledge in the sender country *f* is not a pure public good thus the amount of R&D information transferred in a unit of import from country *f* to *c* is limited. To capture the limited transfer, we scale foreign R&D stock with foreign output. The index is written as:

$$\text{ISP3}_{i,c,t} = \sum_f s^i_{c,f,t} \left(\frac{R_{i,f,t}}{x_{i,f,t}}\right) \tag{10}$$

The fourth index takes the combination of having both limited transmission of foreign knowledge through a unit of imports and different degree of information availability in industries of recipient countries. In this specification, the amount of indigenous R&D knowledge embodied in importing commodities is larger the higher is the degree of import penetration in industry *i* in country *c*. This index is written as:

$$\text{ISP4}_{i,c,t} = \left(\frac{imp_{i,c,t}}{x_{i,c,t}}\right) \sum_f s^i_{c,f,t} \left(\frac{R_{i,f,t}}{x_{i,f,t}}\right) \tag{11}$$

We construct two indices to capture how domestic industries can benefit from the advanced technological expertise of multinationals affiliates hosted in the domestic economy.[12] The first index is a measure of horizontal FDI (HFDI), which is defined as the share of inward FDI to output in industry *i*:

$$\text{HFDI}_{i,c,t} = \frac{\text{FDI}^{inw}_{i,c,t}}{x_{i,c,t}} \tag{12}$$

where x measures output in industry *i*.

[12] See Fosfuri et al. (2001) for theoretical and Javorcik (2004), Bitzer and Kerekes (2008), Javorcik and Spatareanu (2008), Blalock and Gertler (2008) and Keller and Yeaple (2009) for empirical evidence on FDI related spillovers.

There is also scope for vertical FDI knowledge spillovers through knowledge transfer from multinational affiliates in downstream sectors towards industrial suppliers in local upstream sectors in order the former group to benefit from better quality inputs purchased from the latter. Backward Industrial linkages are measured as per index (7). The index of vertical FDI (VHFI) is specified as:

$$\mathrm{VFDI}_{i,c,t} = \sum_{i \neq j} \omega_{i,j,c} \left(\frac{\mathrm{FDI}^{inw}_{j,c,t}}{x_{j,c,t}} \right) \qquad (13)$$

4. Empirical Analysis

4.1 Data Coverage

The period covered is 1987-2007 for 12 manufacturing industries (ISIC Rev.3 Classification) in 14 OECD countries (Table 1). Production data are taken from EUKLEMS database (2009 release) and the variables used are gross output (GO), total hours worked by employees (H_EMPE), intermediate material inputs (II) and gross fixed capital stock (GFCK). The exact methodology used for the construction of GFCK can be found in Timmer et al. (2007). Variables are expressed into constant 1995 prices using the following price deflators, output price index (GO_P), capital price index (Ip_GFCF) and material price index (II_P). Then we convert values into USD using PPP exchange rates from OECD-National Accounts.

Data for R&D expenditure are taken form OECD- ANBERD database. The time span of ANBERD is currently available up to 2007, which basically dictates the time coverage of the whole study. The series of R&D stock described in the previous section is generated from R&D expenditures expressed in 1995 USD prices converted with PPP exchange rates. The pool of foreign R&D stock is calculated from 18-OECD countries and data for bilateral import shares specified in equations (8)-(11) are taken from STAN Bilateral Trade database (2009).

Table 1: Data Coverage

Countries-Indexed with *c*	Industry Code ISIC Rev3	Description
Australia	15t16	Food
Austria	17t19	Textiles
Canada	21t22	Printing and Publishing
Denmark	23	Coke
Spain	24	Chemicals
Finland	25	Rubber and Plastics
Germany	26	Other non-Metallic
Italy	27t28	Basic Metals
Japan	29	Machinery
Netherlands	30t33	Electrical and Optical Equipment
Slovenia	34t35	Transport Equipment
Sweden	36t37	Other Manufacturing
UK		
USA		

Foreign Partners used for the calculation of $R_{i,f,t}$: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Ireland, Korea, Japan, The Netherlands, Portugal , Spain, Sweden, UK, USA

4.2 Preliminary Evidence

Appendix A1 shows a scatter plot for average values of output per worker for each sector. The higher level of output per worker is in the chemical industry followed by Food and Transport. On the other hand, industries with the lower level of output per worker are textiles and other manufacturing. Appendix A2 shows output per worker by country. Accordingly, Italy and USA have the higher average value of output per worker in the period 1987-2007. Germany, Japan, the Netherlands and UK maintain a very similar level of output per worker for this period. Countries that can be identified as productivity outliers are Denmark and Slovenia. To further understand the distribution of R&D stock among partners, Table 2 displays average values of R&D stock by industry for the 18 partners used to calculate the pool of international spillovers. USA is an R&D leader with an average stock in most sectors almost triple from Japan, which is the country with second highest stock in the sample. In

Europe, UK has the highest R&D stock on average with France and Germany to follow. Appendix A3 summarises statistics for the remaining variables and Appendix A4 shows pairwise correlations for ISP1-ISP4. As expected the spillover indices are highly correlated with each other suggesting that they should enter regressions interchangeably to avoid multi-collinearity.

Table 2:R&D Stock in 18 OECD Countries, 1987-2007

Country	15t16	17t19	21t22	23	24	25
Australia	1,369	475	570	78	3,073	235
Austria	516	72	165	595	360	230
Belgium	686	478	284	427	19,990	461
Canada	1,229	746	1,653	1,803	7,857	429
Denmark	837	35	47		3,484	155
Finland	710	167	508	213	3,757	364
France	3,553	1,129	810	10,830	62,030	5,080
Germany	4,256	2,865	1,253	4,091	46,320	5,799
Ireland	461	1,265	47		941	84
Italy	792	357	108	523	7,422	3,757
Japan	19,570	8,346	5,916	8,343	194,100	18,480
Korea	862	2,098	91	636	4,994	2,686
Netherlands	4,742	629	169	455	27,960	383
Portugal	67	46	158	68	164	3
Spain	934	302	255	421	7,489	752
Sweden	1,222	131	1,958	101	10,220	395
UK	5,117	1,532		13,960	71,070	1,275
USA	23,430	6,225	16,840	86,940	308,400	14,600
	26	**27t28**	**29**	**30t33**	**34t35**	**36t37**
Australia	380	3,793	1,134	3,890	3,149	491
Austria	149	233	253	1,180	416	68
Belgium	593	4,019	2,060	12,690	1,796	437
Canada	215	5,355	1,538	32,510	18,180	1,086
Denmark	1,483	257	1,757	3,339	1,012	380
Finland	357	1,315	2,303	6,437	993	146
France	2,341	12,010	9,123	81,150	107,800	1,635
Germany	7,870	5,528	60,590	41,900	61,820	1,068
Ireland	91	128	154	2,333	96	46
Italy	577	1,206	8,169	11,920	13,580	262
Japan	22,660	95,690	57,700	279,500	101,200	11,640
Korea	54	1,659	20,450	28,380	9,586	296
Netherlands	163	2,642	1,965	32,070	7,680	125
Portugal	14	44	76	357	81	4
Spain	503	1,635	1,800	8,353	8,945	577
Sweden	276	3,284	7,251	15,310	15,560	197
UK	2,341	18,440	15,950	91,120	78,490	1,214
USA	23,920	72,600	51,190	673,500	1,759,000	8,917

Values are in millions of 2000 PPP USD. The formulae for the construction of R&D stock are given in equations (12)-(14).

4.3 Econometric Estimation

A standard Pooled OLS (POLS) estimator requires the error term ($u_{i,c,t}$) to be both uncorrelated over time and across sections. The dedicated knowledge spillovers literature ignores the importance of cross-sectional dependence in the error term when estimating specifications similar to (4), which can lead to substantial downward bias in the spillover effect.[13]. If one ignores cross-sectional dependence $corr\left(u_{i,t}u_{j,t}\right) = \rho$ where $\rho \neq 0$ for industry $i \neq j$ then the issue raised is whether spillover variables in the production function measure knowledge externalities or just reflect data dependencies due to misspecification and cross-sectional heterogeneity (Kapetanios et al. 2009). Eberhardt et al. (2013) point out that if estimation does not accounted for cross-sectional dependence then resulting estimates more likely cofound the true effect of own R&D capital (*r*) with what might be a mix of spillover effects and other unobserved phenomena. To illustrate the case of cross-sectional dependence in the error term, consider the model:

$$y_{i,t} = b_{0i} + \mathbf{b}'\mathbf{X}_{i,t} + u_{i,t} \qquad (14)$$

Parameter b_0 is an intercept that imposes homogeneity for simplicity of exposition, this can be extended to include observed common effects, such year and country dummies. $\mathbf{X}$ is a vector of ($k \times 1$) regressors inputs and $\mathbf{b}'$ are parameters to be estimated. The multifactor structure of the error term due to cross-sectional dependence is now described as: $u_{i,t} = \lambda'\boldsymbol{\rho}_i + \varepsilon_{i,t}$, where $\boldsymbol{\rho}_i$ is the ($m \times 1$) unobserved common factor effects and ε is the standard idiosyncratic error independently distributed of $\mathbf{X}$. The estimation technique must account for non-zero loadings in $\boldsymbol{\rho}$ otherwise the estimates are biased and inconsistent (Coakley et al. 2006).

We first test for cross-sectional dependence (CD) in (4) following Pesaran (2004), which develops a pair-wise correlation coefficient in OLS residuals that without controlling for cross-

[13] In an production function like (4) industries can be subject to common unobserved macroeconomic shocks in year *t*. Therefore empirical estimation should be able to establish real knowledge spillover effects that are disentangled from data dependencies due to empirical misspecification.

sectional dependence. Table 3 reports CD results for specification (4) that include spillovers indices (9)-(13) interchangeably. The null hypothesis $H_0 : \rho_{i,j} = \rho_{j,i} = \mathrm{cov}(\hat{u}_{i,t}\hat{u}_{j,t}) = 0$ for industry $i \neq j$ is easily rejected in all specifications indicating the existence of cross-sectional dependence in our data. We also test for serial correlation in the residuals using the Arellano and Bond (1991) test, results are shown in Appendix B1.

Table 3: Cross Section Dependence (CD) Test, Pesaran (2004)

Model	CD-test	p-value	corr	abs(corr)
Specification with *ISP1*	50.52	0.00	0.109	0.557
Specification with *ISP2*	51.49	0.00	0.124	0.555
Specification with *ISP3*	53.31	0.00	0.115	0.556
Specification with *ISP4*	53.69	0.00	0.129	0.558

We now turn to the estimation technique of (4) in the presence of cross-sectional dependence. Pesaran (2006) augments the pooled OLS estimator with cross-sectional average of both y and $\mathbf{X}$ to proxy for the linear combination of unobserved common effects. We refer to this estimator as the Common Correlated Effects Mean Group Estimator (CCEMG)[14], which allows for unobservables to have a different impact across *i* (Appendix B2). Results from CCEMG are shown in Table 4.

Another source of bias for (4) is the existence of systematic feedback effects between output and production inputs. The exogeneity assumption might still fail if one assumes that higher productivity is likely to impact on industry's future purchase of inputs. This implies: $E\left(u_{i,c,t+1} \mid k_{i,c,t}\right) \neq 0$ and $E\left(u_{i,c,t+1} \mid m_{i,c,t}\right) \neq 0$ where E is the conditional expectations operator. In other words, an unobserved mechanism can drive both the error term in (4) and inputs, causing simultaneity bias. A similar interpretation of endogeneity applies for the spillover variables. To relax this moment condition we use an instrumental two step GMM estimator. GMM estimator also controls for unobserved measurement errors in the construction of all variables in (4). Given the

[14] Monte Carlo experiments in Pesaran (2006) show the asymptotic efficiency of CEMG under slope heterogeneity.

evidence of no serial correlation in second and thirds lags, we use as instruments values of the endogenous variables in periods (t-2) and (t-3) under the assumption that productivity shocks at time *t* are uncorrelated with input choices in previous periods. The validity of the instruments is assessed by the Anderson LM test of under-identification and the Hansen-J (1982) test of over-identifying restrictions. As shown at the bottom of Table 5 we cannot reject the null hypothesis of instrument validity while the null hypothesis of the LM test that the matrix of reduced-form coefficients in the first-stage regression is under-identified is rejected at high levels of significance.

5. Results

5.1 Results from CCEMG and GMM

We first focus on CCEMG results in Table 4, the coefficients of capital and materials are between 0.39 and 0.40, the assumption of CRS is rejected as pointed out at the bottom of the table. Note CCEMG is taking into account panel heterogeneity and the estimates shown in Table 4 are cross-section averages. This means that the picture for individual cross-sections might vary substantially but one should be cautious in drawing inference from individual cross-section estimates (Pedroni, 2007). Indicatively, Appendix C list coefficients for the 12 individual industries. Accordingly, 25% of industries exhibit increasing returns to scale, 15% exhibit constant returns while the remaining 60% operate under decreasing returns.

Table 4: Common Correlated Effects Mean Group Estimator (CCEMG), Equation (4).

	1	2	3	4
k	0.390***	0.400***	0.374***	0.399***
	(0.02)	(0.02)	(0.02)	(0.03)
m	0.410***	0.389***	0.391***	0.388***
	(0.02)	(0.02)	(0.02)	(0.02)
h	0.033***	0.026	0.033*	0.043***
	(0.02)	(0.02)	(0.02)	(0.02)
r	0.186***	0.130***	0.153***	0.143***
	(0.03)	(0.03)	(0.03)	(0.03)
DSP	0.006	0.005	0.004	0.003
	(0.01)	(0.01)	(0.01)	(0.01)
ISP1	0.036**			
	(0.02)			
ISP2		0.029**		
		(0.01)		
ISP3			0.01**	
			(0.01)	
ISP4				0.01*
				(0.01)
CRS	36.85/0.00	42.66/0.00	41.15/0.00	42.74/0.00
N	2753	2753	2753	2753
N_g	152.000	152.000	152.000	152.000
Avg_n	18.112	18.112	18.112	18.112
chi2	650.962	644.643	663.482	660.111

Robust standard errors in parentheses with * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The dependent variable q is the log of gross output per hour worked. Regressions include an intercept and year fixed effects. CRS refers to constant returns to scale for capital and materials, chi2(1) and p-values are reported. Coefficients of cross-section average regressors are not reported as they are not interpretable in an economic way. They only capture the impact of the unobserved common factor. *N_g* is the total number of observations in each cross-section. *Avg_n* is the number of observations for regressions from which these averages are constructed.

The coefficient of human capital (h) is positive as expected and statistically significant in all specifications of Table 4. The elasticity of output with respect to human capital is between 2.6% and 4.3%. This result complies quite well with findings from cross-country estimates about the role of human capital on productivity measures (Benhabib and Spiegel, 1994 and Miller and Upadhyay, 2000). The impact of industry's own R&D stock r is positive and statistically significant in all columns of Table 4. The coefficient of r is between 0.13 and 0.186, which indicates an R&D elasticity of 18.6% at the highest end. With regard to r in the GMM estimates of Table 5, the coefficient is again statistically significant but with a lower magnitude at the range of 4.6% and 5.2%.

R&D elasticities from both CCEMG and GMM are in line with previous firm level studies (Bertelsman, 1990; Hall and Mairesse, 1995; Rogers, 2010) but lower from industry level studies (Higon, 2007 (i.e.33%); Acharya and Keller, 2009 (i.e. 27%)). Regarding domestic R&D spillovers (DSP), the coefficient is found statistically insignificant in all but two specifications. The finding of insignificant domestic spillovers is compatible to the core proposition of the neoclassical trade theory that assumes no (if not negative) cross-industry productivity effects (Harrigan, 1997 and Nickell et al., 2008) while it contradicts Branstetter (2001) that found learning gains from the innovative activity of other domestic counterparts. A more technical reason for the insignificance of the DSP coefficient is likely to be the inappropriateness of input-output tables to capture the true degree of interaction across domestic industries.

Turning to the estimates of international spillovers ISP1-ISP4, the results are positive and significant in all specifications. In the CCEMG estimator the knowledge spillover has elasticity between 1% and 3.6%. The size of this elasticity is 3.6% if we assume that the entire amount of knowledge embodied in foreign R&D stock transferred through imports.[15] If we assume that the effect of spillover is analogous to the degree of import intensity in the domestic industry the elasticity reduces to 2.6%. With more restrictive assumptions about the amount of knowledge transferred from source to destination the elasticity is reduced even more to 1%. These results indicate that there are spillover effects even after controlling for the presence of cross–sectional dependence-a key omission of the previous literature- whose size depends on the assumption made about the amount of information sent and received through importing commodities. Our results regarding import related spillovers stand somewhere in the middle from Keller (2002); Acharya and Keller (2009) on the one hand, who find foreign spillovers often to exceed domestic R&D gains and Eberhardt et al. (2013) on the other hand, who conclude that spillovers are inseparable from industry's own R&D when cross-sectional dependence is taken into account. The CCEMG estimates

[15] This elasticity value is almost identical to the total unweighted foreign R&D stock elasticity found in Coe and Helpman, 1995 and Coe et al. 2009.

indicate that the effect of spillovers is significantly lower from own R&D but the former is far from being viewed as negligible. In the GMM results, Table 5 the elasticity of output per worker with respect to spillover variables is always half of that of *r* with the exception of specification 3.

Table 5: GMM Estimator, Equation (4).

	1	2	3	4
k	0.636***	0.676***	0.648***	0.669***
	(0.06)	(0.06)	(0.06)	(0.06)
m	0.633***	0.623***	0.650***	0.633***
	(0.02)	(0.02)	(0.02)	(0.02)
h	0.084***	0.080***	0.062*	0.071***
	(0.02)	(0.02)	(0.03)	(0.03)
r	0.048**	0.046**	0.048**	0.052**
	(0.01)	(0.01)	(0.00)	(0.00)
DSP	0.014	0.015	0.029**	0.023**
	(0.01)	(0.01)	(0.01)	(0.01)
ISP1	0.025**			
	(0.01)			
ISP2		0.022*		
		(0.01)		
ISP3			0.065***	
			(0.02)	
ISP4				0.024***
				(0.01)
N	2502	2428	2352	2278
adj. R^2	0.9986	0.9986	0.9984	0.9985
F	13101.77	13799.04	7911.88	11975.99
Hansen Test	10.02	14.69	11.54	15.72
p-value	0.44	0.26	0.64	0.26
LM Test	4605.81	4447.14	152.30	1922.60
p-value	0.00	0.00	0.00	0.00

Clustered robust standard errors in parentheses with * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The dependent variable *q* is the log of gross output per worker. All specifications are estimated with the two step feasible GMM estimator. The instruments used are *k*, *m*, *h*, *r*, DSP, and ISP in periods (t-2) and (t-3). Regressions include an intercept, country, industry and time fixed effects. The Hansen statistic of over-identification tests whether the including instruments as a set are valid, thus exogenous. LM Anderson (1984) is a likelihood ratio test of under-identification referring to whether excluded instruments are relevant.

5.2 SUR Estimates and Results for Low and High Technology Groups

In the presence of industry heterogeneity[16] and cross-sectional dependence in the residuals another feasible estimator is the Seemingly Unrelated Regression (SUR) that allows coefficients to vary across industries. The CCEMG estimator in Table 5 assumes heterogeneity, nonetheless we can estimate (4) for each individual industry using SUR to obtain a more comprehensive idea about the effect of R&D in each specific industry. This approach also permits us to explore whether the pattern of results varies if we divide industries into groups of low and high technology. To save space here we show and discuss results only for the first international spillover index (ISP1).[17]

With reference to traditional inputs, chi(2) test in the last column of Table 6 indicates that only 3 out of twelve industries exhibit constant returns to scale. Turning to the variables of primary interest, Tables 6 confirm the existence of substantial heterogeneity across industries as far the impact of own R&D (r) and spillovers are concerned. The effect of own industry's R&D is positive and statistically significant in the high tech group (Chemicals, Machinery, Electrical equipment and Transport) plus three industries from the low tech group. Regarding DSP, coefficients are positive and statistically significant in three out twelve industries overall. The coefficient of ISP1 is significant only in the group of high tech industries with the highest elasticity to be in Chemicals and Electrical Equipment (13.5 and 14.6%, respectively). These results indicate that international exchange of ideas tends to benefit more high tech industries while low tech industries are less capable of absorbing productivity gains from foreign knowledge stock. The lack of absorptive capacity in the low tech group is mainly due to limited within industry R&D activity, which becomes an impediment in facilitating into domestic production international technological advancements.

[16] The Breusch-Pagan (1979) statistic (9876/p-value=0.00) rejects the null hypothesis of panel homogeneity (zero variance in u) across sections indicating the existence of substantial differences across industries and countries.

[17] SUR estimates for ISP2, ISP3 and ISP 4 have only minor variations and are not shown in the paper. They are available from the authors upon request.

Table 6: SUR Estimates for Individual Industries, Equation (4)

	k	*m*	*h*	*r*	DSP	ISP1	CRS
High Tech Group							
Chemicals	0.666***	0.462***	0.054**	0.1353	-0.0314	0.072*	3.50
	(0.03)	(0.03)	(0.033)	(0.00)	(0.01)	(0.04)	(0.06)
Machinery	0.725***	0.464***	0.0363**	0.0238*	-0.0228	0.330***	262.39
	(0.04)	(0.02)	(0.02)	(0.01)	(0.01)	(0.04)	(0.00)
Electrical Equipment	0.194***	-0.177***	0.264*	0.146***	0.0718	0.132*	0.88
	(0.05)	(0.03)	(0.1)	(0.04)	(0.05)	(0.05)	(0.34)
Transport Equipment	0.573***	0.405***	-0.003	0.0210*	-0.0332	0.018**	31.6
	(0.05)	(0.02)	(0.03)	(0.01)	(0.018)	(0.01)	(0.00)
Low Tech Group							
Food	0.980***	0.413***	-0.021	-0.065***	0.066***	-0.004	3.83
	(0.05)	(0.03)	(0.01)	(0.00)	(0.01)	(0.03)	(0.05)
Textiles	0.514***	0.557***	0.015**	-0.036*	0.003	0.115	2.91
	(0.04)	(0.03)	(0.02)	(0.01)	(0.02)	(0.07)	(0.08)
Printing	0.327***	0.421***	0.063**	0.0405**	0.084***	0.019	183
	(0.03)	(0.03)	(0.03)	(0.01)	(0.02)	(0.02)	(0.00)
Coke	0.389***	0.415***	0.075**	-0.195***	0.151**	-0.059*	0.54
	(0.04)	(0.02)	(0.06)	(0.01)	(0.05)	(0.03)	(0.46)
Rubber and plastics	0.678***	0.462***	0.023**	-0.0779**	-0.045	-0.082*	2.76
	(0.05)	(0.03)	(0.03)	(0.02)	(0.01)	(0.05)	(0.09)
Non-Metallic Miner.	0.473***	0.426***	-0.0448	0.146***	0.005*	0.0963**	0.06
	(0.04)	(0.04)	(0.02)	(0.02)	(0.02)	(0.04)	(0.34)
Basic Metals	0.578***	0.564***	0.007*	0.006*	-0.019	-0.066*	17.03
	(0.02)	(0.02)	(0.02)	(0.00)	(0.00)	(0.03)	(0.00)
Other Manufacturing	0.364***	0.401***	-0.0372	0.0465**	-0.049	-0.04***	26.11
	(0.06)	(0.03)	(0.02)	(0.01)	(0.02)	(0.05)	(0.00)

Standard errors in parentheses with * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Number of observations: 197. The dependent variable q is the log of gross output per hour worked. Regressions include an intercept, country, and time fixed effects. CRS refers to the hypothesis of constant returns to scale: $\mathrm{H}_0 : \alpha_2 + \alpha_3 = 1$.

5.3 FDI Related Spillovers

The empirical approach that associates FDI with knowledge spillovers relies on micro-econometric evidence, which assumes that any measure of FDI embodies the amount of knowledge and ideas existing in multinational subsidiaries (Aitken and Harrison, 1999; Xu, 2000; Haskel et al.2007; Keller, 2009). Javorcik (2008) find evidence of substantial technological externalities from FDI that impact on domestically owned firms, which can further boost aggregate industry productivity. Nonetheless, the literature of FDI spillovers is rather puzzling as recent studies are not always conclusive with some of them (Javorcik and Spatareanu, 2008 and Blalock and Gertler, 2008) to document even negative FDI effects on domestic productivity. Atiken and Harisson (1999) attribute the negative impact of FDI to inverse effects induced from foreign competition. However, studies with negative results of FDI on domestic productivity use standard within effects fixed estimators with controlling neither for cross-sectional dependence in the panel nor for potential endogeneity bias between FDI decisions and domestic productivity.

The approach of the present study is to replicate specification (4) with CCEMG and GMM estimators including indices of horizontal FDI (HFDI) and vertical FDI (VFDI). For comparability Tables 7 and 8 show estimates from specifications that include both import and FDI spillovers. The number of observations is now smaller as FDI data are available from 1990 onwards. Table 7 reports CCEMG estimates and shows the existence of statistically significant Horizontal FDI effects on productivity. The estimates of HFDI are in the order of 1.6 to 1.8% while the coefficients of import induced spillovers are between 0.8%-1.5%. When (4) is estimated with GMM using as instruments the values of endogenous variables in periods (t-2) and (t-3), HFDI coefficients are in the range of 1.8-3.4% and again slightly higher than ISP coefficients which are between 1 to 1.2% across all specifications. Turning to VFDI spillovers, all coefficients are statistically different from zero in the CCEMG Table 7 but their economic impact (i.e. 0.07% and 0.08%) is smaller from both HFDI and import induced spillovers. The VFDI estimates are turned insignificant in the GMM estimates in

Table 8. Our HFDI results are in line with Keller and Yeaple (2009) –though with a much smaller FDI elasticity in the present study - whose analysis also confirms the existence of horizontal FDI spillovers contrary to previous studies. Our results are more likely different from previous literature that fails to find positive FDI spillovers on productivity because we draw evidence from an OECD sample where absorptive capacity is -by default- stronger from that one of developing countries. With reference to the weak effect of VFDI, which becomes insignificant when endogeneity bias is accounted for, our justification lies within two reasons, first the current VFDI index employs input-output table to measure the interaction across industries but this can be a misleading approach if multinationals do not have the same pattern of sourcing with domestic industries. The second reason stresses that technology transfer through vertical FDI is not free of charge thus cannot be easily identifiable from indices that measure the presence of FDI in upstream and downstream industries (Keller, 2010). To capture knowledge spillovers from vertical FDI we need to subtract from the local supplier's revenue any contractual payment for selling materials and services to multinationals. This artifact measurement issue can only be addressed with information from firm or plant level data.

Table 7: FDI Spillovers, Common Correlated Effects Mean Group Estimator (CCEMG), Equation (4)

	1	2	3	4	5	6	7	8
k	0.340***	0.373***	0.357***	0.391***	0.368***	0.397***	0.403***	0.411***
	(0.04)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.04)	(0.03)
m	0.374***	0.395***	0.354***	0.394***	0.341***	0.380***	0.364***	0.419***
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
h	0.053**	0.024	0.010	0.032	0.002	0.014	0.003	0.020
	(0.03)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)	(0.03)
r	0.222***	0.159***	0.162***	0.163***	0.195***	0.189***	0.152***	0.145***
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
DSP	-0.015	0.20**	0.008	0.11	-0.13	0.10	-0.11	0.09
	(0.10)	(0.08)	(0.09)	(0.06)	(0.08)	(0.07)	(0.07)	(0.07)
ISP1	0.014***	0.013***						
	(0.00)	(0.00)						
ISP2			0.015***	0.012***				
			(0.00)	(0.00)				
ISP3					0.008**	0.006		
					(0.00)	(0.00)		
ISP4							0.015***	0.009***
							(0.00)	(0.00)
HFDI	0.017***		0.018***		0.016***		0.017***	
	(0.00)		(0.00)		(0.00)		(0.00)	
VFDI		0.008**		0.008**		0.007**		0.007**
		(0.00)		(0.00)		(0.00)		(0.00)
N	1907	1981	1907	1981	1907	1981	1907	1981
*N*_g	115.000	119.000	115.000	119.000	115.000	119.000	115.000	119.000
g_avg	16.583	16.647	16.583	16.647	16.583	16.647	16.583	16.647
chi2	262.224	322.843	303.309	333.198	282.875	385.661	284.460	385.230

Robust standard errors in parentheses with * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The dependent variable q is the log of gross output per hour worked. Regressions include an intercept and year fixed effects. Coefficients of cross-section average regressors are not reported as they are not interpretable in an economic way. They only capture the impact of the unobserved common factor. *N* is the total number of observations in each cross-section. *Avg n* is the number of observations for regressions from which these averages are constructed.

Table 8: FDI Spillovers, GMM Estimator, Equation (4)

	1	2	3	4	5	6	7	8
k	0.668***	0.670***	0.679***	0.684***	0.673***	0.673***	0.682***	0.686***
	(0.04)	(0.04)	(0.03)	(0.03)	(0.04)	(0.04)	(0.04)	(0.04)
m	0.597***	0.605***	0.590***	0.601***	0.615***	0.625***	0.602***	0.614***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.014)	(0.01)	(0.01)	(0.01)
h	0.115***	0.106***	0.122***	0.113***	0.122***	0.114***	0.129***	0.122***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
r	0.12**	0.13**	0.08*	0.10**	0.04**	0.04**	0.06*	0.039*
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.05)	(0.00)
DSP	0.006	0.006	0.015	0.014	0.010	0.011	0.019*	0.019
	(0.010)	(0.010)	(0.011)	(0.011)	(0.011)	(0.011)	(0.012)	(0.012)
ISP1	0.011**	0.023**						
	(0.00)	(0.01)						
ISP2			0.012**	0.017**				
			(0.00)	(0.00)				
ISP3					0.010**	0.037***		
					(0.00)	(0.01)		
ISP4							0.012**	0.024**
							(0.00)	(0.01)
FDI	0.022**		0.018**		0.034**		0.024**	
	(0.01)		(0.00)		(0.01)		(0.01)	
VFDI		0.005		0.004		0.007		0.005
		(0.00)		(0.00)		(0.00)		(0.00)
N	1556	1556	1508	1508	1556	1556	1508	1508
adj. R^2	0.9992	0.9992	0.9992	0.9992	0.9991	0.9991	0.9992	0.9992
F	23388	17102	21386	16022	15798	14152	16897	14215
Hansen Test	17.485	19.877	16.022	18.887	15.920	18.030	14.766	17.685
p-value	0.231	0.134	0.312	0.169	0.318	0.205	0.394	0.222
LM Test	1163.232	1142.523	1540.039	1327.336	2100.853	1393.059	2029.860	1362.230
p-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Clustered robust standard errors in parentheses with * p < 0.10, ** p < 0.05, *** p < 0.01. The dependent variable *q* is the log of gross output per hour worked. All specifications are estimated with the two step feasible GMM estimator. The instruments used are *k, m, h, r*, DSP, ISP, FDI and VFDI in periods (t-2) and (t-3). Regressions include an intercept, country, industry and time fixed effects. The Hansen statistic of over-identification tests the hypothesis that the set of including instruments is valid, thus instruments are exogenous. LM Anderson (1984) is a likelihood ratio test of under-identification tests the hypothesis that excluded instruments are relevant.

5.5 Knowledge Spillovers and Protection of Intellectual Property Rights

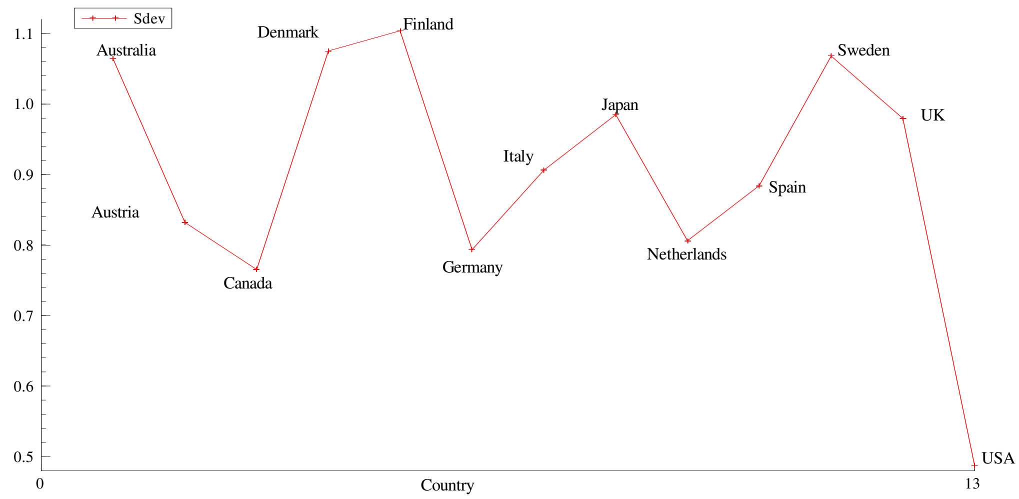
This section examines whether country specific institutions affect FDI knowledge spillovers. More specifically, we focus on two different institutional aspects: (i) the patent protection legislation and (ii) the ease of doing business. In a Schumpeterian growth model, a firm's decision to innovate depends on the difference between post and pre-innovation rents (Aghion et al., 2013). Post-innovation rents are primarily determined from the legal system of patent protection. Likewise, technology transfer from an MNC's headquarters towards its local subsidiaries is heavily dependent on recipient country's legal system. An environment with increased protection of patent rights can stimulate within MNC technology transfer making local subsidiaries more innovative compared to domestic firms, hence inward FDI is upgraded to a major productivity driver. Park and Lippoldt (2005) claim that increased protection of intellectual property rights (i.e. copyrights on books, music, software, patent rights on inventions, and trademark rights on business symbols and names) encourage rights-holders to be less restrained of international technology transfer.[18]

The objective of our econometric specification is to unveil whether spillover effects from HFDI and VFDI are affected from the strength of patent protection and the ease of doing business. The institutional indices are country specific without industry variation. The index of patent protection (*Rights*) is developed by Park and Lippoldt (2005) and takes values from zero (weakest) to five (strongest). It is an unweighted sum of five separate scores for coverage (inventions that are patentable; membership in international treaties; duration of protection; enforcement mechanisms; and restrictions. Figure 2 plots cross-country variability of this index over the period (1960-2010). A large standard deviation (Sdev) shows that data values are far away from the mean while a small Sdev means that points are close to each other. Values very close to zero imply no deviation. Finland, Denmark, and Australia present the highest variation in the sample with Sweden, Japan, Italy and

[18] These considerations are empirically confirmed in Schneider (2005) that legal system positively affects the innovation rate with this effect to become stronger in developed countries, while Coe et al. (2009) show that the legal system affects the outcome of the innovative activity by determining the type of R&D undertaken.

Austria to follow. With the exception of USA whose Sdev is close to zero (0.48) -implying insignificant changes during 1960-2010- the *Rights* index has time variations even within a group of developed OECD countries. To the contrary, the score for the ease of doing business (World Bank, 2007) has almost no time variation.

Figure 1: Standard Deviation of Intellectual Property Rights Index (*Rights*), 1960-2010



Our empirical strategy is to see how these two institutional factors interact with industry measures of HFDI and VFDI in stimulating productivity. To this end, we follow Coe at al. (2009) and divide the sample of countries into groups of high, medium and low based on the relative ranking of their score (Appendix D classifies countries of the sample, which is now reduced to the period 1987-2004[19] based on the easiness of doing business). Then we define two dummy variables, high (hi) and low (lo) that are interacted with the FDI variables. A second hypothesis to be tested is whether simultaneously high degree of patent protection and relatively easy procedures in doing business can improve productivity from FDI related spillovers. To save space regressions in Table 9 include only ISP1 from import related spillovers.[20]

[19] Our production data covers up to 2007 so we could not make use of institutional data after that year.
[20] Results from the remaining import related indices are very similar and can be provided from the authors upon request.

Table 9: Spillovers and Institutions, Pooled OLS (POLS) Estimators, Equation (4)

	1	2	3	4	5
k	0.518***	0.490***	0.168***	0.488***	0.586***
	(0.05)	(0.05)	(0.01)	(0.05)	(0.07)
m	0.618***	0.632***	0.295***	0.630***	0.615***
	(0.00)	(0.00)	(0.01)	(0.00)	(0.01)
h	0.104***	0.073***	0.054***	0.068***	0.123***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)
r	0.00602**	0.008***	0.007***	0.009***	0.007
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
DSP	0.0354***	0.086***	0.048***	0.088***	0.024**
	(0.00)	(0.00)	(0.01)	(0.00)	(0.01)
ISP1	0.0265***	0.067***	0.01*	0.070***	0.009
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
FDI	0.0275***	0.014**		0.037***	
	(0.00)	(0.00)		(0.006)	
VFDI			0.093*		0.159**
			(0.08)		(0.07)
Rights	0.481***				
	(0.02)				
Hi×HFDI		0.057***			
		(0.01)			
Lo×HFDI		-0.007			
		(0.01)			
Hi×VFDI			0.091*		
			(0.07)		
Lo×VFDI			-6.322***		
			(0.92)		
PP×Hi×HFDI				0.006***	
				(0.00)	
PP×Lo×HFDI				-0.009***	
				(0.00)	
PP×Hi×VFDI					0.035**
					(0.01)
PP×Lo×VFDI					-0.815***
					(0.24)
N		1933	1904	1933	1826
R^2		0.998	0.733	0.998	0.999
F		48833.61	191.14	48386.81	16374.16
p-value		0.000	0.000	0.000	0.000

Standard errors in parentheses consistent for arbitrary heteroscedasticity with * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Regressions include an intercept, country, industry and year fixed effects.

Estimates in Table 9 are from a standard pooled OLS (POLS) with, country, industry and time dummies. CCEMG estimator is not applicable in this case as hi and lo dummies are perfectly collinear with fixed effects. The autonomous coefficient of ($Rights$) in column (1) is positive and statistically significant. This implies that a highly protective system of intellectual property rights encourages investment in projects with high returns whose effects in productivity is crucial. Similar results are found with TFP measures in Coe et al. (2009). The interaction terms of hi×HFDI and lo×HFDI in the first lower panel of the Table 9 have opposite signs. These interaction coefficients should be interpreted relative to middle ranked countries as follows: countries with a relatively easier set of procedures in doing business can benefit more from FDI related spillovers while countries with a relatively harder set of such procedures in doing business struggle to exploit FDI related gains. This pattern remains the same for both horizontal and vertical FDI measures. Regarding coefficients of triple interaction terms in the second lower panel of Table 9 suggest that high protection of patent rights in association with a relatively easier environment in doing business generates beneficial productivity effects. Similar results are obtained in the triple interaction with VFDI where the size of the estimated coefficient is relatively bigger than that of HFDI. Overall, Table 9 shows institutional heterogeneity whose impact on industry productivity varies substantially within OECD countries. This heterogeneity is more likely to be derived from variations in the ease of doing business given that most of OECD countries have gradually adopted a highly protective system of property rights. The latter remark leaves great scope for policy design towards reforms that can simplify rules and procedures in the broader business environment. Our industry level results are in harmony with considerations and findings from country levels studies on economic performance [21] and institutions stressing the importance of a well-functioning institutional framework as a prerequisite for growth and prosperity.

[21] See Acemoglu et al.(2005) for a historical overview on this matter.

4 Conclusions

The present paper analyses the impact of knowledge spillovers on output per worker using an approach directly derived from an augmented production function. The key objective of the paper is to identify the importance of international spillovers under alternative assumptions regarding the information transferred through imports. The paper also explores the importance of horizontal and vertical FDI in knowledge spillovers as well as how the institutional environment impact on FDI related spillovers. Through various specifications and robustness tests, the key findings of the paper can be summarised as follows: international knowledge spillovers are an important driver of industry output per worker; the economic size of this effect is smaller the more restrictive the assumptions are about the amount of information embodied in imports; the elasticity of output with respect to spillovers is not negligible but it is definitely lower than industry's own R&D; the effect of spillovers on productivity is mainly driven by high technology industries as SUR estimates have shown; low tech industries are weak in absorbing knowledge spillovers. The study has not revealed substantial gains from intra-industry domestic spillovers. Horizontal FDI is an important vehicle for productivity improvements. The gains from horizontal FDI increase with the degree of protection of intellectual property rights in the recipient country and the degree of easiness of doing business. These institutional factors are also crucial conditions for the implementation of vertical FDI related spillovers.

Overall our results indicate that international knowledge spillovers exist and imports together with FDI are crucial vehicles for diffusion of foreign knowledge. Present findings are robust to econometric estimations that account for cross-sectional and endogeneity bias, which has not been very common in the traditional literature. Nonetheless, there are some constant caveats that apply when one seeks to provide interpretation of the present findings. First, we need more direct technology indicators associated with respect to FDI in order to provide more direct links between knowledge diffusion and productivity. Data on patent citations and licences can be more informative on how domestic firms benefit from foreign know-how. Second, an issue that still remains under-investigated is to disentangle FDI knowledge spillovers from FDI competition enhancing effects. These issues are paths for future research.

A policy message is also clear from the present study: trade and multinational enterprises can improve productivity at the industry level but these gains are bigger if there is an appropriate institutional environment. Given that evidence in this study is drawn from high-income OECD countries where protection of intellectual property rights is already strong, the policy focus must be on simplifying the procedures for doing business. Policy reforms towards this direction can yield substantial FDI related gains.

References

Acharya, Ram C., and Wolfgang Keller. 2009. Technology transfer through imports. *Canadian Journal of Economics/Revue Canadienne d'Économique* 42 (4): 1411-48.

Aghion, Philippe, and Peter Howitt. Endogenous growth theory, 1998. *MIT Press-Barro, RJ, Sala-I-Martin, X.: Economic Growth* 2 : 71-102.

Aghion, Philippe, Peter Howitt, and Susanne Prantl. 2013. *Patent Rights, Product Market Reforms, and Innovation*.

Anon Higon, Dolores. 2007. The impact of R&D spillovers on UK manufacturing TFP: A dynamic panel approach. *Research Policy* 36 (7): 964-79.

———. 2007. The impact of R&D spillovers on UK manufacturing TFP: A dynamic panel approach. *Research Policy* 36 (7): 964-79.

Benhabib, Jess, and Mark M. Spiegel. 1994. The role of human capital in economic development evidence from aggregate cross-country data. *Journal of Monetary Economics* 34 (2): 143-73.

———. 1994. The role of human capital in economic development evidence from aggregate cross-country data. *Journal of Monetary Economics* 34 (2): 143-73.

Bitzer, Jürgen, and Monika Kerekes. 2008. Does foreign direct investment transfer technology across borders? new evidence. *Economics Letters* 100 (3): 355-8.

Blalock, Garrick, and Paul J. Gertler. 2008. Welfare gains from foreign direct investment through technology transfer to local suppliers. *Journal of International Economics* 74 (2): 402-21.

Branstetter, Lee. 2006. Is foreign direct investment a channel of knowledge spillovers? evidence from japan's FDI in the united states. *Journal of International Economics* 68 (2): 325-44.

Branstetter, Lee G. 2001. Are knowledge spillovers international or intranational in scope?: Microeconometric evidence from the US and japan. *Journal of International Economics* 53 (1): 53-79.

Breusch, Trevor S., and Adrian R. Pagan. 1979. A simple test for heteroscedasticity and random coefficient variation. *Econometrica: Journal of the Econometric Society*: 1287-94.

Burnside, Craig, Martin Eichenbaum, and Sergio Rebelo. 1995. Capital utilization and returns to scale. In *NBER macroeconomics annual 1995, volume 10.*, 67-124MIT Press.

Cameron, Gavin, James Proudman, and Stephen Redding. 2005. Technological convergence, R&D, trade and productivity growth. *European Economic Review* 49 (3): 775-807.

———. 2005. Technological convergence, R&D, trade and productivity growth. *European Economic Review* 49 (3): 775-807.

Carr, David L., James R. Markusen, and Keith E. Maskus. 2001. Estimating the knowledge-capital model of the multinational enterprise. *American Economic Review* 91 (3): 693.

———. 2001. Estimating the knowledge-capital model of the multinational enterprise. *American Economic Review* 91 (3): 693-708.

Coakley, Jerry, Ana-Maria Fuertes, and Ron Smith. 2006. Unobserved heterogeneity in panel time series models. *Computational Statistics & Data Analysis* 50 (9): 2361-80.

Coe, David T., and Elhanan Helpman. 1995. International r&d spillovers. *European Economic Review* 39 (5): 859-87.

Coe, David T., Elhanan Helpman, and Alexander W. Hoffmaister. 2009. International R&D spillovers and institutions. *European Economic Review* 53 (7): 723-41.

———. 1997. North-south R & D spillovers. *The Economic Journal* 107 (440): 134-49.

De La Potterie, Bruno Van Pottelsberghe, and Frank Lichtenberg. 2001. Does foreign direct investment transfer technology across borders? *Review of Economics and Statistics* 83 (3): 490-7.

———. 2001. Does foreign direct investment transfer technology across borders? *Review of Economics and Statistics* 83 (3): 490-7.

Doraszelski, Ulrich, and Jordi Jaumandreu. 2013. R&D and productivity: Estimating endogenous productivity. *The Review of Economic Studies* 80 (4): 1338-83.

Dougherty, Chrys, and Dale W. Jorgenson. 1996. International comparisons of the sources of economic growth. *The American Economic Review*: 25-9.

Eberhardt, Markus, Christian Helmers, and Hubert Strauss. 2013. Do spillovers matter when estimating private returns to R&D? *Review of Economics and Statistics* 95 (2): 436-48.

Engelbrecht, Hans-Jürgen. 2002. Human capital and international knowledge spillovers in TFP growth of a sample of developing countries: An exploration of alternative approaches. *Applied Economics* 34 (7): 831-41.

———. 1997. International R&D spillovers, human capital and productivity in OECD economies: An empirical investigation. *European Economic Review* 41 (8): 1479-88.

Falvey, Rod, Neil Foster, and David Greenaway. 2004. Imports, exports, knowledge spillovers and growth. *Economics Letters* 85 (2): 209-13.

Fosfuri, Andrea, Massimo Motta, and Thomas Rønde. 2001. Foreign direct investment and spillovers through workers' mobility. *Journal of International Economics* 53 (1): 205-22.

Funk, Mark. 2001. Trade and international R&D spillovers among OECD countries. *Southern Economic Journal*: 725-36.

Ginarte, Juan C., and Walter G. Park. 1997. Determinants of patent rights: A cross-national study. *Research Policy* 26 (3): 283-301.

Girma, Sourafel, David Greenaway, and Katharine Wakelin. 2001. Who benefits from foreign direct investment in the UK? *Scottish Journal of Political Economy* 48 (2): 119-33.

———. 2001. Who benefits from foreign direct investment in the UK? *Scottish Journal of Political Economy* 48 (2): 119-33.

Good, David H., M. Ishaq Nadiri, and Robin C. Sickles. 1996. *Index Number and Factor Demand Approaches to the Estimation of Productivity*.

Griffith, Rachel, Rupert Harrison, and John Van Reenen. 2006. How special is the special relationship? using the impact of US R&D spillovers on UK firms as a test of technology sourcing. *The American Economic Review*: 1859-75.

Griffith, Rachel, Stephen Redding, and John Van Reenen. 2004. Mapping the two faces of R&D: Productivity growth in a panel of OECD industries. *Review of Economics and Statistics* 86 (4): 883-95.

Griliches, Zvi. 1980. R & D and the productivity slowdown. *The American Economic Review*: 343-8.

———. 1979. Issues in assessing the contribution of research and development to productivity growth. *Bell Journal of Economics* 10 (1): 92-116.

———. 1979. Issues in assessing the contribution of research and development to productivity growth. *The Bell Journal of Economics*: 92-116.

Griliches, Zvi, and Haim Regev. 1995. Firm productivity in israeli industry 1979–1988. *Journal of Econometrics* 65 (1): 175-203.

Grossman, Gene, and Elhanan Helpman. 1991. Innovation and growth in the world economy.

Hall, Bronwyn H., and Jacques Mairesse. 1995. Exploring the relationship between R&D and productivity in french manufacturing firms. *Journal of Econometrics* 65 (1): 263-93.

———. 1995. Exploring the relationship between R&D and productivity in french manufacturing firms. *Journal of Econometrics* 65 (1): 263-93.

Hall, Bronwyn H., Jacques Mairesse, and Pierre Mohnen. 2009. *Measuring the Returns to R&D*.

Hansen, Lars Peter. 1982. Large sample properties of generalized method of moments estimators. *Econometrica: Journal of the Econometric Society*: 1029-54.

Harrigan, James. 1997. Technology, factor supplies, and international specialization: Estimating the neoclassical model. *The American Economic Review*: 475-94.

Hodrick, Robert J., and Edward C. Prescott. 1997. Postwar US business cycles: An empirical investigation. *Journal of Money, Credit, and Banking*: 1-16.

Javorcik, Beata S. 2008. Can survey evidence shed light on spillovers from foreign direct investment? *The World Bank Research Observer* 23 (2): 139-59.

Javorcik, Beata Smarzynska. 2004. Does foreign direct investment increase the productivity of domestic firms? in search of spillovers through backward linkages. *The American Economic Review* 94 (3): 605-27.

———. 2004. Does foreign direct investment increase the productivity of domestic firms? in search of spillovers through backward linkages. *The American Economic Review* 94 (3): 605-27.

Javorcik, Beata Smarzynska, and Mariana Spatareanu. 2008. To share or not to share: Does local participation matter for spillovers from foreign direct investment? *Journal of Development Economics* 85 (1): 194-217.

Kao, Chihwa, Min-Hsien Chiang, and Bangtian Chen. 1999. International R&D spillovers: An application of estimation and inference in panel cointegration. *Oxford Bulletin of Economics and Statistics* 61 (S1): 691-709.

Keller, Wolfgang. 2010. International trade, foreign direct investment, and technology spillovers. *Handbook of the Economics of Innovation* 2 : 793-829.

———. 2004. International technology diffusion. *Journal of Economic Literature*: 752-82.

———. 2000. Do trade patterns and technology flows affect productivity growth? *The World Bank Economic Review* 14 (1): 17-47.

———. 1998. Are international R&D spillovers trade-related?: Analyzing spillovers among randomly matched trade partners. *European Economic Review* 42 (8): 1469-81.

Keller, Wolfgang, and Stephen R. Yeaple. 2009. Multinational enterprises, international trade, and productivity growth: Firm-level evidence from the united states. *The Review of Economics and Statistics* 91 (4): 821-31.

Klump, Rainer, Peter McAdam, and Alpo Willman. 2012. The normalized CES production function: Theory and empirics. *Journal of Economic Surveys* 26 (5): 769-99.

———. 2008. Unwrapping some euro area growth puzzles: Factor substitution, productivity and unemployment. *Journal of Macroeconomics* 30 (2): 645-66.

Kneller, Richard, and Mauro Pisu. 2007. Industrial linkages and export spillovers from FDI. *The World Economy* 30 (1): 105-34.

León-Ledesma, Miguel A., Peter McAdam, and Alpo Willman. 2010. Identifying the elasticity of substitution with biased technical change. *The American Economic Review* 100 (4): 1330-57.

Liu, Xiaohui, and Trevor Buck. 2007. Innovation performance and channels for international technology spillovers: Evidence from chinese high-tech industries. *Research Policy* 36 (3): 355-66.

McAdam, Peter, and Alpo Willman. 2013. Medium run redux. *Macroeconomic Dynamics* 17 (04): 695-727.

Miller, Stephen M., and Mukti P. Upadhyay. 2000. The effects of openness, trade orientation, and human capital on total factor productivity. *Journal of Development Economics* 63 (2): 399-423.

Nickell, Stephen, Stephen Redding, and Joanna Swaffield. 2008. The uneven pace of deindustrialisation in the OECD. *The World Economy* 31 (9): 1154-84.

Ortega-Argilés, Raquel, Marco Vivarelli, and Peter Voigt. 2009. R&D in SMEs: A paradox? *Small Business Economics* 33 (1): 3-11.

Paquet, Alain, and Benoıt Robidoux. 2001. Issues on the measurement of the solow residual and the testing of its exogeneity: Evidence for canada. *Journal of Monetary Economics* 47 (3): 595-612.

Park, Walter G., and Douglas Lippoldt. 2005. International licensing and the strengthening of intellectual property rights in developing countries during the 1990s. *OECD Economic Studies* 40 (1): 7-48.

Pedroni, Peter. 2007. Social capital, barriers to production and capital shares: Implications for the importance of parameter heterogeneity from a nonstationary panel approach. *Journal of Applied Econometrics* 22 (2): 429-51.

Pesaran, M. Hashem. 2006. Estimation and inference in large heterogeneous panels with a multifactor error structure. *Econometrica* 74 (4): 967-1012.

Pesaran, MH. 2004. *General Diagnostic Tests for Cross Section Dependence in Panels*.

Rogers, Mark. 2010. R&D and productivity: Using UK firm-level data to inform policy. *Empirica* 37 (3): 329-59.

Romer, Paul M. 1986. Increasing returns and long-run growth. *The Journal of Political Economy*: 1002-37.

Schiff, Maurice, and Yanling Wang. 2006. North-south and south-south trade-related technology diffusion: An industry-level analysis of direct and indirect effects. *Canadian Journal of Economics* 39 (3): 831-44.

Schneider, Patricia Higino. 2005. International trade, economic growth and intellectual property rights: A panel data study of developed and developing countries. *Journal of Development Economics* 78 (2): 529-47.

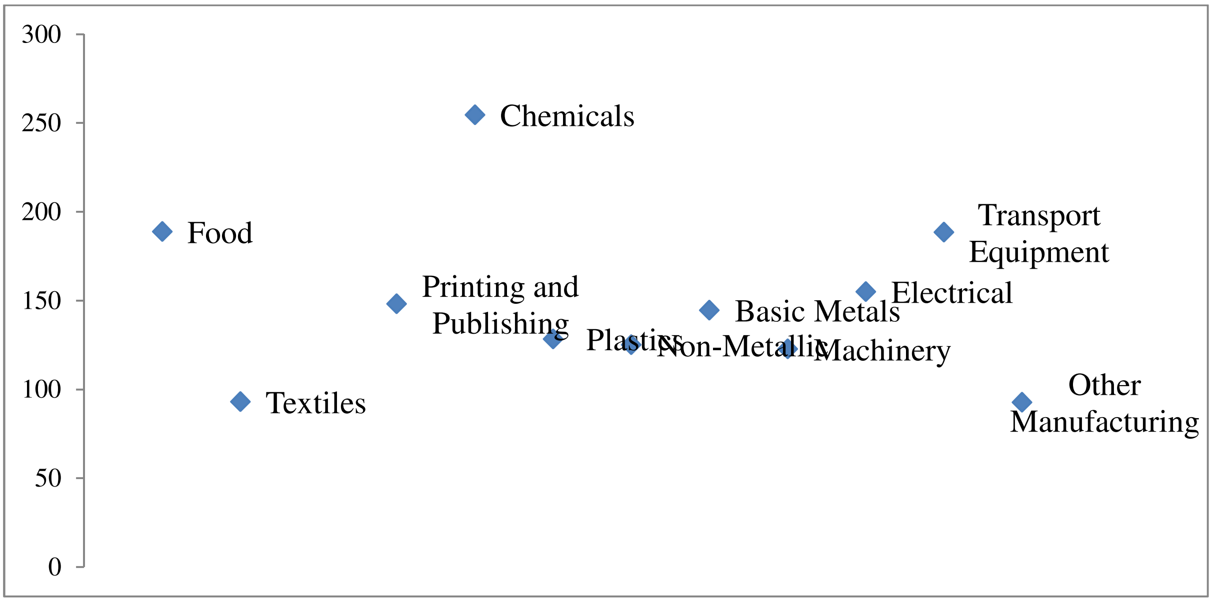
Syverson, Chad. 2011. What determines productivity? *Journal of Economic Literature* 49 (2): 326-65.

Van Ark, Bart, Dirk Pilat, Dale Jorgenson, and Frank R. Lichtenberg. 1993. Productivity levels in germany, japan, and the united states: Differences and causes. *Brookings Papers on Economic Activity.Microeconomics*: 1-69.

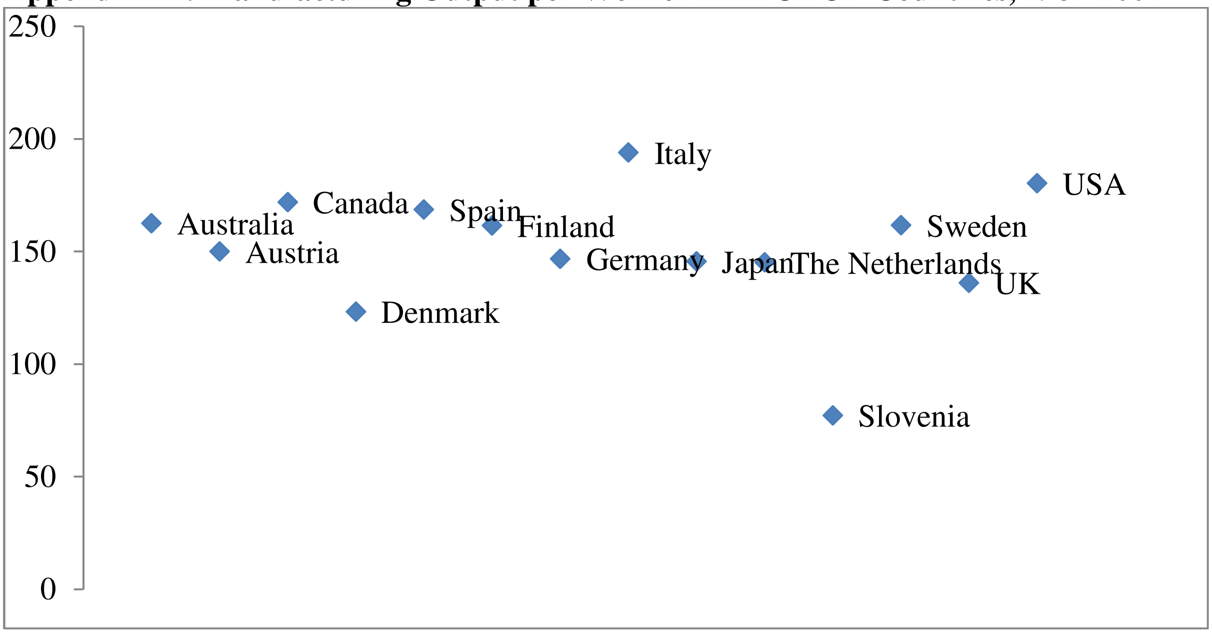
Wolff, Edward N., and M. Ishaq Nadiri. 1993. Spillover effects, linkage structure, and research and development. *Structural Change and Economic Dynamics* 4 (2): 315-31.

APPENDICES

Appendix A1: Output per Worker in 12 Manufacturing Industries of OECD-14, 1987-2007



Appendix A2: Manufacturing Output per Worker in 14 OECD Countries, 1987-2007



Appendix A3: Summary Statistics

Variable	Mean	SD	Min	Max
q	5.06	0.65	2.46	8.53
k	0.58	0.44	-0.71	3.34
m	3.19	0.90	1.35	8.24
h	4.04	9.38	-47.65	77.21
r	0.65	1.11	-3.94	1.92
DSP	6.04	2.46	-2.13	12.21
ISP1	22.99	1.93	14.77	28.26
ISP2	22.91	2.42	13.79	29.34
ISP3	2.75	1.66	-3.68	6.44
ISP4	2.59	2.15	-4.66	6.78
HFDI	5.84	1.88	0.80	11.34
VFDI	0.25	1.26	0.00	20.53
Rights	3.55	0.93	1.84	4.88

Appendix A4: Correlation Matrix of Knowledge Spillover Indices

	ISP1	ISP2	ISP3	ISP4
ISP1	1.00			
ISP2	0.92	1.00		
ISP3	0.56	0.56	1.00	
ISP4	0.56	0.73	0.89	1.00

Appendix B1: Baseline Pooled OLS (POLS) Results from (4)

	1	2	3	4
k	0.609***	0.611***	0.611***	0.612***
	(0.02)	(0.02)	(0.02)	(0.02)
m	0.620***	0.619***	0.622***	0.622***
	(0.01)	(0.01)	(0.01)	(0.01)
h	0.151***	0.153***	0.160***	0.159***
	(0.01)	(0.01)	(0.01)	(0.01)
r	0.22**	0.31***	0.12*	0.08*
	(0.00)	(0.00)	(0.00)	(0.00)
DSP	0.001	0.002	-0.001	0.000
	(0.00)	(0.00)	(0.00)	(0.00)
ISP1	0.008***			
	(0.00)			
ISP2		0.006***		
		(0.00)		
ISP3			0.003	
			(0.00)	
ISP4				0.003
				(0.00)
N	2753	2753	2753	2753
R^2	0.926	0.926	0.926	0.926
F/ p-value	824.97/0.00	797.87	781.77	783.46
		0.000	0.000	0.000
AB(1)/p-value	4.55/0.00	4.61/0.00	2.30/0.02	2.33/0.02
AB(2)/p-value	1.10/0.27	1.12/0.23	1.07/0.28	1.09/0.27
AB(3)/p-value	0.41/0.67	0.43/0.67	0.37/0.71	0.38/0.70

Standard errors in parentheses consistent for arbitrary heteroscedasticity with * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.The dependent variable q is the log of gross output per hour worked. All regressions include an intercept, country, industry and year fixed effects. AB refers to Arellano and Bond (1991) test for serial correlation and reported up to 3 lags.

Appendix B2

The Common Correlated Effects estimator (CCEE) of Pesaran (2006) is written as:

$$y_{i,t} = \alpha_0 + \mathbf{b}'\mathbf{X}_{i,t} + \sum_{j=2}^{N} d_j D_j + \sum_{t=2}^{T}\sum_{j=1}^{N} \psi_1(\bar{y}_t D_j) + \sum_{k=1}^{m}\sum_{t=2}^{T}\sum_{j=1}^{N} \boldsymbol{\psi}_{2i}(\bar{\mathbf{X}}_{\mathbf{t}} D_j) + u_{i,t}$$

The first three terms represent a standard fixed effects estimator. Terms four and five in the summations are interaction terms between cross-section averages and N cross-section specific dummies. This estimator is the Common Correlated Effects Pooled Estimator (CCEP). The CCEMG used in the paper can be seen if interaction terms in the second and third summation are replaced by cross-section averages of y and $\mathbf{X}$.

Appendix C: Industry Regressions from CCEMG

	k	m	h	r	DSP	ISP1
Food	0.639	0.370	0.011	0.269	-0.097	0.012
Textiles	0.609	0.446	0.046	0.192	-0.675	0.058
Printing	0.207	0.413	0.090	0.316	-0.496	0.040
Coke	0.169	0.227	0.113	0.450	0.002	-0.028
Chemicals	0.407	0.506	0.060	0.17	0.593	0.124
Rub & Pl.	0.368	0.353	-0.030	0.345	0.000	0.118
Non-Metallic Miner.	0.311	0.487	-0.003	0.230	0.376	-0.101
Basic Metals	0.361	0.349	0.276	0.336	0.652	0.169
Machinery	0.313	0.341	-0.006	-0.115	0.419	-0.149
Elec. Equipment	0.681	0.446	-0.333	-0.157	-0.326	0.094
Transport Equip	0.585	0.522	0.197	0.135	-0.375	-0.096
Oth.Manufacturing	0.145	0.444	-0.023	0.256	0.001	-0.101

CCMEG (2006) allows for cross-section parameter heterogeneity both in the observables and the unobservables. The results shown in Table 4 refer to cross-industry averages reported in this Table.

Appendix D: Institutional Factors

	Protection of Intellectual Property Rights Index (*Rights*)		Ease of Doing Business
Country	**1987**	**2004**	
Australia	2.962	4.167	High
Austria	3.583	4.333	Low
Canada	3.233	4.667	High
Denmark	3.783	4.667	High
Spain	3.258	4.333	Low
Finland	3.308	4.642	Medium
Germany	3.917	4.500	Medium
Italy	3.878	4.667	Low
Japan	3.700	4.667	Medium
Netherlands	4.037	4.667	Medium
Sweden	3.723	4.542	Medium
UK	4.158	4.542	High
USA	4.675	4.875	High
Mean	3.793	4.559	