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International research and development spillovers through foreign direct investment and productivity growth

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Philip Bodman and Thanh Le*

Abstract

This study further examines the role of research and development (R&D), both domestic and foreign, in the development of national productivity. A key focus is on the role played by foreign direct investment (FDI) in facilitating technological transfer. The research empirically investigates the significance of FDI as an effective channel of R&D spillovers within a group of 15 OECD countries. It also examines whether the technology transfer through FDI is bi-directional: from an investing country to a host country and vice versa. In addition, the impact of human capital accumulation on a country's capacity to learn from a foreign technology base is also examined empirically. The paper considers the possible effects of FDI on human capital accumulation process, in particular, whether FDI helps channel more resources towards the promotion of education activities. Empirical results obtained all lend strong supports to these hypotheses.

Keywords: R&D, productivity, FDI, trade, human capital, international spillovers

JEL classification: O15, O32, O47

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1- Introduction

Modern theories of economic growth starting with Romer (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992, 1998) emphasize that the accumulation of knowledge through scientific research and its application to production of goods and services is the engine of long-run growth. In the globalization process, as countries become more open to international trade, foreign direct investment, and international technological diffusion, domestic production and productivity growth can also depend on R&D activities of other countries. A great deal of the growth literature has tried to capture empirically the effects of own R&D capital formation and international technological spillovers on a country's production structure and productivity. Researchers all reach the same conclusion - that domestic R&D expenditure is important for output and productivity growth and there exists a channel through which R&D capital formation in one country affects the production pattern and productivity in another.

There are several channels through which the transmission of ideas and technologies take place: (i) international trade: imports of high technology products (e.g see Coe and Helpman (1995), Coe *et al.* (1997), Kwark and Shyn (2006)); (ii) foreign technology payment: direct adoption of foreign technology, (e.g. see Soete and Patel (1985)); and (iii) acquisition of human capital, (e.g. see Park (2004), Le (2006)). Besides these channels, FDI is considered to be a significant conduit of technology diffusion across borders since the inflow of FDI contains knowledge about new technologies and materials, production methods, or organizational management skills.

Most of the existing research in the area focuses on studying the role of FDI on the host countries' economic growth, e.g. Borensztein *et al*. (1998), Xu (2000). However, very little has been done to characterize the impact of technology embodied in FDI on the total factor productivity (TFP) of FDI receiving countries. A paper by van Pottelsberghe and Lichtenberg (2001) appears to be the only study to date that looks into this issue through the quantification of the stocks of domestic and foreign knowledge and their impact on productivity of both FDI recipients and donor countries. The research in our paper extends the work of van Pottelsberghe and Lichtenberg in two directions. First, it takes into account physical distances between countries, which, as emphasized by Keller (2002), can act as a barrier to countries' economic transactions and technological transfer. Second, the role of human capital is considered both in terms of its contribution to the enhancement of TFP (a direct effect) and to the ability to learn from a foreign technological base – the *absorptive capacity* (an indirect effect). In addition, the analysis empirically investigates the hypothesis that FDI is accompanied by knowledge that may enhance the stock of human capital of the host countries.[1]

The theoretical framework that underlies the research presented here is based on recent work on endogenous technical change such as Romer (1990), Aghion and Howitt (1992, 1998). In these models, R&D expenditures create new technology in the form of product designs/patents for new or better quality intermediate goods. Although the development cost of an intermediate good produced based on a particular design is incurred by only one investor, its embodied knowledge can benefit many other domestic firms as well as international firms abroad. In that sense, the knowledge about the design is non-rival. This captures the aspect of knowledge spillovers in this framework. Countries benefit from the

[1] FDI helps improve the quality of labour force in host country in the aspect that skilled workers trained by multinational corporations (MNCs), when move to local firms or set up their own business, often bring with tem technological and managerial knowledge that they have acquired.

pool of knowledge to the extent that they get access to the information generated by different sources of R&D activity. In addition, benefits will be higher if countries have a better educated labour force because higher quality labour allows countries to absorb the knowledge more quickly.

The empirical analysis in the paper investigates whether R&D activity affects productivity via FDI. Covering 15 industrialized countries from 1983 to 2003, the dataset spans a substantial portion of the world's output and innovative activity during this period. This study distinguishes different sources of technological transmission and their vehicles of transmission: the domestic R&D and the R&D conducted in foreign countries (the knowledge diffusion takes place either through trade or FDI). The results in this paper shed new light on where the sources of R&D spillovers lie. The work in this paper also contributes to the important question of whether more FDI leads to a better-trained labour force.

The results derived from the analysis have several key policy implications. We observe that countries that have embraced a relatively more open international investment regime have usually grown significantly faster than others who have not. The fact that FDI transmits technological knowledge, as well as contributing to the physical capital stock, suggests that openness to direct physical investment, as well as to trade and financial flows, provides an important driver of economic growth. Second, human capital is not only necessary for the general enhancement of technological level itself, but is also essential for the ability to learn from foreign technological sources. This has important implications for the ability of education enhancement policies to raise living standards through multiple channels.

The rest of this paper is structured as follows. Section 2 briefly discusses the theoretical and implied empirical framework that underpin the econometric estimates of the impact that foreign R&D embodied in imports and FDI have on national productivity growth. A brief description of the data is given in Section 3. The main empirical findings and their economic interpretation are reported in Section 4. Section 5 concludes the paper with some closing comments and suggestions for further research.

2- Theoretical considerations and empirical framework

In general, a particular country consists of a large number of final goods producers. However, for simplicity, assume that all final goods producers, on aggregate, produce a homogenous consumption good according to the following production function:

$$Y_t = AK_t^{\beta} D_t^{\alpha} L_t^{1-\alpha-\beta}, \quad A > 0, \quad 0 < \alpha, \beta, \alpha + \beta < 1$$

where Y_t is the output level at time t, K_t is the existing stock of physical capital, L_t is the labour employment, and D_t is a composite input of differentiated goods which is defined as follows:

$$D_t = \left[\int_0^{N_t} \left(q_{mkt} X_{kt} \right)^{\alpha} dk \right]^{\frac{1}{\alpha}}$$

Here, the variable N_t denotes the range of intermediate inputs used for production of final goods in the country (it might be different from the range of intermediate inputs produced in that country). X_{kt} is the physical amount of capital product k employed, and q_{mkt} is its attached quality grade which reflects the productivity of capital good in the production process. Capital goods are produced by specialized intermediate firms. Each firm produces only one kind of capital good at production cost, which is normalized to 1 for simplicity, and rent it out to final goods producers at a rental rate P_{kt}. Standard optimality conditions dictate that the rental rate of a capital good is equal to its marginal product:

$$\frac{\partial Y_t}{\partial X_{kt}} = AK_t^{\beta} L_t^{1-\alpha-\beta} \alpha q_{mkt}^{\alpha} X_{kt}^{\alpha-1} = P_{kt}$$

This gives the demand function for capital good k:

$$X_{kt} = \left(\frac{AK_t^{\beta} L_t^{1-\alpha-\beta} \alpha q_{mkt}^{\alpha}}{P_{kt}} \right)^{\frac{1}{1-\alpha}}$$

With the assumption that each capital good producer facing a fixed set up cost μ, the lifetime profit from producing a capital good is:

$$\Pi_{kt} = -\mu + \int_t^{\infty} \left(P_{kt} - 1 \right) X_{kt} e^{-r(s-t)} ds$$

In this formula, $\left(P_{kt} - 1 \right) X_{kt}$ is the instantaneous profit flow at a point of time. The goal of intermediate firms is to set the price P_{kt} at each date to maximize this profit flow:

$$Max_{P_{kt}} \quad \left(P_{kt} - 1 \right). \left(\frac{AK_t^{\beta} L_t^{1-\alpha-\beta} \alpha q_{mkt}^{\alpha}}{P_{kt}} \right)^{\frac{1}{1-\alpha}}$$

This delivers the monopoly price that intermediate firms will charge:

$$P_{kt} = \frac{1}{\alpha}, \quad \forall k, \ t, \ m$$

as the monopoly price as a mark-up over the marginal cost. Plugging the result into the demand function determines the total demand for capital variety k in equilibrium:

$$X_{kt} = \left(AK_t^{\beta} L_t^{1-\alpha-\beta} \alpha^2 q_{mkt}^{\alpha} \right)^{\frac{1}{1-\alpha}}$$

Demand is the same for all capital varieties of the same quality. For those of higher quality, demand is also higher. Substituting the result into the final goods production function yields:

$$Y_t = \tilde{A} Q_t K_t^{\gamma} L_t^{1-\gamma}$$

where $\tilde{A} = A^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}}$, $\gamma = \dfrac{\beta}{1-\alpha}$, and $Q_t = \int_0^{N_t} q_{mkt}^{\frac{\alpha}{1-\alpha}} dk$ representing the aggregate technology index. The development of this index includes both the introduction of new capital goods (increases in N_t) and quality enhancement (increases in q_{mt}). If TFP is defined as $F_t = \dfrac{Y_t}{K_t^{\gamma} L_t^{1-\gamma}}$, it means that:

$$\log F_t = \log \tilde{A} + \log Q_t$$

This implies that productivity is positively related to the range and quality of the employed product variety. With international trade and investment, both domestic and foreign intermediate goods can be employed for country i's production. If domestic intermediate goods (Q_{it}^d) can be separated from their foreign counterparts (Q_{it}^f) then:

$$\log F_{it} = \log \tilde{A}_i + \alpha_1 \log Q_{it}^d + \alpha_2 \log Q_{it}^f$$

Because R&D investment leads to the expansion of product varieties so by an appropriate choice of unit normalization, Q_{it}^d is identical to the cumulative stock of R&D expenditure SD_{it}, and Q_{it}^f is captured by the foreign knowledge stock variable SF_{it}. This means that TFP in country i may grow either as a result of domestic innovation or international technological spillovers from foreign countries.

To test the above-mentioned hypothesis, three measures of the foreign R&D capital stock variable, SF, are constructed. The first, the import-embodied foreign R&D capital stock is generated as follows:

$$SF_{it}^m = \sum_{j \neq i} \frac{m_{ijt}}{y_{jt}} . SD_{jt} \cdot \frac{1}{d_{ij}}$$

where m_{ijt} is the value of imports of goods and services of country i from country j, y_{jt} is country j's GDP at time t, and d_{ij} is the bilateral geographic distance between country i and country j. The purpose of adding the geographic distance term to this formulation is to capture the possibility that the benefits from spillovers decline with distance between any two countries, as found in Keller (2002). The fact that the analysis takes into account the possibility that physical distances can act as a barrier to economic and technological relations among countries is a key, novel aspect of this study.

The second variant on the measure of the variable foreign R&D capital stock, SF, is the foreign R&D capital stock embodied in *inward FDI*. This measure is constructed as follows:

$$SF_{it}^{g} = \sum_{j \neq i} \frac{g_{ijt}}{k_{jt}} . SD_{jt} \cdot \frac{1}{d_{ij}}$$

where g_{ijt} is the stock of capital flowing from country j to country i and k_{jt} is country j's gross capital formation at time t.[2] Similarly, the *outward FDI* embodied foreign R&D capital stock is also created as:

$$SF_{it}^{l} = \sum_{j \neq i} \frac{l_{ijt}}{k_{jt}} . SD_{jt} \cdot \frac{1}{d_{ij}}$$

where l_{ijt} is total capital flow of country i towards country j. The reason why this paper uses stocks of FDI rather than flows of FDI in calculating different measures of foreign R&D capital stocks is that stocks are less volatile than flows and foreign capital contributes to the economic performance of the target countries in many years later. The above weighting scheme is similar to that of van Pottelsberghe and Lichtenberg (2001) except for the physical

[2] This paper also tries to use GDP instead of capital formation as an alternative specification. Qualitatively, the results obtained are very similar.

distance term. An advantage of these specifications is that they more realistically, and intuitively capture the idea of the distance factor being a barrier to technological transfer.[3]

These constructed measures of foreign R&D capital stocks are expected to capture international spillover effects. Allowing different intermediate inputs from different sources to have different productivity effects, a formulation for TFP analogous to the above is:

$$\log F_{it} = \alpha_i + \alpha_d \log SD_{it-1} + \alpha_f \log SF_{it-1} + \varepsilon_{it}$$

where $i =$ 1, 2, …, N is a country index, $t =$ 1, 2, …., T is a time index. Because the diffusion of technology takes time, a lag structure is introduced into this equation.

Besides looking at technological spillovers through FDI, the original framework is also extended to investigate the effect of the change in the quality of labour force or human capital on productivity:[4]

$$\log F_{it} = \alpha_i + \alpha_d \log SD_{it-1} + \alpha_f \log SF_{it-1} + \alpha_h \log H_{it-1} + \varepsilon_{it}$$

where H is the stock of human capital. The effect of the foreign R&D capital stock on productivity, when the domestic labour force becomes more educated (the higher 'absorptive capacity'), is then examined.[5] For this purpose, foreign R&D capital stocks are allowed to interact with stock of human capital generating new variables in the regression equations.

[3] Kwark and Shyn (2006) conjecture a new method of calculating foreign R&D capital stocks (through trade) which potentially can be applied to our calculation here. However, as noted by those authors, a likely shortcoming of this method is that the measure would depend on the size of the (trade) recipient country (for more details, see Kwark and Shyn (2006)). As a result, the application of this method will be in our future research agenda.

[4] According to Bils and Klenow (2000), if workers need human capital to use advanced technology then growth in human capital can help to improve technology.

[5] The 'absorptive capacity' is pointed out by Benhabib and Spiegel (1994) and Bils and Klenow (2000). In TFP growth literature, Coe *et al.* (1997), and more recently Kwark and Shyn (2006), test this effect by using the secondary school enrolment rate as a proxy for human capital. By contrast, our paper uses the average years of schooling as the proxy for stock of human capital since we believe that the latter better captures the stock while the former tends to reflect more the flow of human capital.

The above specification differs from that used in van Pottelsberghe and Lichtenberg (2001) in three aspects. The first is that here we include a proxy for human capital, which is an important for technological enhancement in industrialized countries in the last decades. The second is that the measures of foreign R&D capital stocks also take into account the impact of physical distances as a barrier to technological transfer. Finally, the data used in the analysis are more up to date (up to 2003) and of larger size (with 15 countries).

Based on these regressions, the long-run relationship between TFP and the domestic and foreign R&D capital stocks is estimated. FDI is considered as a conduit of technological transmission. To this end, and because of the trending nature of the data, the regressions are estimated in levels based on the panel cointegration method suggested by Pedroni (1999), and Im *et al.* (2003). When estimating relationships between trending variables in levels, the cointegration methods have the advantage of uncovering long-run relationships between level variables that are often discarded using differenced specifications of the data (the first differencing method only represents short-run relationships). The methodology used allows for the conduct of formal econometric tests on the above-mentioned hypotheses. In addition, it is also possible to extend the investigation to the role of human capital that is often viewed as an essential input in the research process. The results obtained shed some light on the existence of the complementarity between R&D spillovers and investment in human capital: in particular, does an increase in the level of human capital actually improve the technological absorptive capacity of a country in an open economy context?

Finally, according to Borenstein *et al.* (1998), in order for FDI to be more productive than domestic investment, it requires a minimum threshold stock of human capital. In addition, MNCs often employ highly skilled labour in the host country. They also train local workers to make them match with their technical requirements. This suggests that FDI may have some role in driving human capital accumulation. This is investigated by testing the impact of FDI on the change in the stock of human capital:

$$\log H_{it} = \beta_i + \beta_f \log FDI_{it-1} + \beta_x X_{it-1} + \varsigma_{it}$$

Here, X_{it} is a set of other variables that affect human capital accumulation. This paper adopts real GDP per capita as a typical candidate for these control variables.

3- Data description

Details about data sources and the construction of variables are provided in Appendix 1. This section only reports some key features of the data. The data on value added, capital stock, and employment come from OECD STAN Database (2005). The OECD STAN Databases (2002, 2006) are used for business R&D expenditure data. The data on FDI by country of origin originate from OECD International Direct Investment Database (2006) while the bilateral distance data between countries are obtained from Robertson (1998). Bilateral import values are taken from OECD International Trade Database (2007). The data on average years of schooling of total population aged 25 and over used as a proxy for stocks of human capital are from Barro and Lee (2000). Missing values of bilateral FDI and years of schooling are estimated based on available data using linear interpolation and extrapolation calculations. Descriptive statistics on key variables across countries between 1982 and 2003 are given in Table 1.

The TFP levels for all 15 country time series are normalized to 1 in the year 1985. Among those countries, TFP growth was relatively high in the UK (4.51 percent per year), Italy (4.47

percent), Norway (4.38 percent), and Finland (4.38 percent), whereas it was lowest in Denmark, with 1.57 percent per year.

Table 1- *Summary statistics: average annual growth rates over period 1982-2003 (in %)*

	ΔF	ΔSD	ΔSF^{m}	ΔSF^{g}	ΔSF^{l}	ΔFDI	ΔH	$\Delta GDPPC$
Australia	3.40	6.00	2.69	9.17	15.23	10.65	3.02	1.18
Canada	2.23	6.42	3.78	4.82	8.41	6.86	5.33	1.26
Denmark	1.57	6.71	4.06	13.10	14.04	13.10	0.45	3.24
Finland	4.38	8.17	4.49	24.11	20.82	17.11	1.06	2.46
France	2.97	3.31	2.49	14.47	13.83	14.48	0.96	2.30
Germany	1.91	3.49	2.33	13.56	12.98	13.10	0.60	2.78
Ireland	3.79	9.90	2.40	13.92	17.40	14.36	0.78	6.06
Italy	4.47	3.54	3.74	11.58	14.74	11.61	1.25	3.36
Japan	2.46	5.45	3.54	12.87	11.47	15.25	0.77	3.48
Netherlands	2.05	2.65	2.68	13.91	12.27	14.36	0.67	2.78
Norway	4.38	5.02	3.32	14.42	14.84	10.13	1.62	2.94
Spain	3.68	7.03	8.19	13.79	17.31	14.28	1.73	4.09
Sweden	3.99	5.39	3.89	16.80	15.76	15.65	0.91	2.09
UK	4.51	1.87	4.14	11.39	13.33	11.46	0.65	3.31
US	3.09	3.21	7.84	10.09	8.67	10.76	0.17	2.12
Maximum	4.51	9.90	8.19	24.11	20.82	17.11	5.33	6.06
Minimum	1.57	1.87	2.33	4.82	8.41	6.86	0.17	1.18
Mean	3.26	5.21	3.97	13.20	14.08	12.88	0.83	2.90
Standard Deviation	1.02	2.23	1.78	4.13	3.22	2.63	0.44	1.19

Notes: ΔX is the logarithmic rate of growth of X (in percent). F is total factor productivity, SD is domestic R&D capital stock; SF^{m} is foreign R&D capital stock embodied in imports; SF^{g} is foreign R&D capital stock embodied in inward FDI; SF^{l} is foreign R&D capital stock embodied in outward FDI; FDI is the aggregate stock of FDI; $GDPPC$ is the GDP per capita; and H is the average number of years of education.

The measure of technological investment is based on data for business enterprise R&D expenditure. As Table 1 shows, Ireland had the highest growth rate of R&D expenditure (9.9 percent per year), followed by Finland (8.17 percent) and Spain (7.03 percent). At the lower end, R&D expenditure in the UK and the Netherlands grows at the rate of 1.87 percent and 2.65 percent per year respectively.

Table 1 also contains several measures of technological transfer. The import embodied foreign R&D capital stock is presented in the third column of the table. There is considerable variation across countries: Spain had the highest rate of growth (8.19 percent per year), whereas Germany enjoyed the lowest one (2.33 percent). The structure of the inward and outward FDI embodied foreign R&D capital stocks are given in the fourth and fifth column of Table 1 respectively. The entry in the fourth column shows that the growth rate of foreign R&D capital stock embodied in inward FDI reached its highest levels in Finland (24.11 percent per year) and Sweden (16.8 percent), and reached its lowest levels in Canada (4.82 percent) and Australia (9.17 percent). At the same time, the rate of growth of foreign R&D capital stock embodied in outward FDI is strikingly high in Finland (10.82 percent per year) and Ireland (17.4 percent) as compared to the lower rate of Canada (8.41 percent) and the US (8.67 percent).

Table 1 also summarizes the variation of FDI, stocks of human capital, and GDP per capita. The FDI growth rate in Finland is the largest (17.11 percent per year), whilst that of Canada is the lowest (6.86 percent) over the same period of time. This partly explains why Finland also had the highest rate of growth of inward FDI foreign R&D capital stock and Canada had the lowest one as mentioned above. In terms of the changes in the stock of human capital, Canada stood at the upper end of the range with 5.33 percent per year, whereas its behemoth neighbour country, the US, stood at the other end of the range with only 0.17 percent of change each year. The growth of GDP per capita is fastest in Ireland (6.06 percent per year) and slowest in Australia (1.18 percent).

Given these obtained data, to find out which of the patterns of R&D spillovers described above – import embodied, inward FDI embodied, and outward FDI embodied foreign R&D capital stock – appears to be more successful in capturing the transmission of technology between countries, this paper now turns to the formal empirical analysis.

4- Empirical findings

The purpose of the empirical investigation in this paper is to estimate the effects of R&D spillovers on TFP and to examine whether FDI is an effective channel of technological transfer. In addition, as discussed in Section 2, the analysis investigates whether foreign R&D capital stocks when interacting with the stock of human capital can affect the overall level of technology. testa test is also provided of whether the level of FDI has an impact on a country's human capital. Due to the lack of suitable and direct measures of human capital, we use data on average years of schooling as proxies for human capital.

Similar to many other studies on total factor productivity, this paper seeks to estimate a long-run relationship between TFP and other trending variables. First, we check if our data exhibit a clear trend. To this end, the unit root tests derived by Im *et al.* (2003) were implemented for all data series to see if they are nonstationary. The results are represented in Table 2 below.

Results in Table 2 indicate that all of our data series exhibit a clear trend. Our next step is to estimate equations that have cointegrating relationship among these trending variables. As noted by Coe and Helpman (1995), a cointegrating equation exists if its error terms are stationary. If they are not, the estimating equation may be spurious. Our regression results are given in Table 3 along with two cointegration tests developed by Pedroni (1999) and Engle and Grange (1987).

Table 2 - *Group mean panel unit root tests (annual data 1982-2003 for 15 countries – Im et al. 2003)*

Variable	$\bar{t}_{N,T}$ (a)	$\bar{p}$ (b)	Adjusted Mean (c)	Adjusted Variance (d)	Group Mean Statistic (e)	Decision (f)
$\log F$	-1.3429	1.2667	-1.4804	0.9286	0.5525	$I(1)$
$\log SD$	-1.5263	2.4000	-1.4413	0.9932	-0.3306	$I(1)$
$\log H$	-0.8600	4.3333	-1.3691	1.0265	1.9460	$I(1)$
$\log SF^m$	-0.9089	1.4000	-1.4683	0.8803	2.3091	$I(1)$
$\log SF^g$	-0.0238	2.1333	-1.4409	0.9167	5.7323	$I(1)$
$\log SF^l$	-0.4425	1.8667	-1.4522	0.9031	4.1149	$I(1)$
$\log H * \log SF^m$	-0.7426	0.9333	-1.4877	0.8565	3.1182	$I(1)$
$\log H * \log SF^g$	0.2665	2.6667	-1.3355	0.9439	6.3862	$I(1)$
$\log H * \log SF^l$	-0.2609	1.7333	-1.4573	0.8967	4.8934	$I(1)$
$\log FDI$	0.2870	2.8667	-1.4149	0.9525	6.7537	$I(1)$
$\log GDPPC$	-1.6485	0.9333	-1.4875	0.8553	-0.6740	$I(1)$

Notes: $\log X$ is logarithm of X. F is total factor productivity, SD is domestic R&D capital stock; SF^m is foreign R&D capital stock embodied in imports; SF^g is foreign R&D capital stock embodied in inward foreign direct investment; SF^l is foreign R&D capital stock embodied in outward foreign direct investment; H is the average number of years of education; FDI is the aggregate stock of FDI; and $GDPPC$ is the GDP per capita.

(a) Cross sectional average of individual Dickey-Fuller $\bar{t}_{N,T}$ statistics

(b) Cross sectional average of individual number of lagged differenced terms in $ADF(p_i)$ regression

(c) Cross sectional average of $E\left[t_{i,T}\left(p_i,\theta_i\right)\right]$

(d) Cross sectional average of $Var\left[t_{i,T}\left(p_i,\theta_i\right)\right]$

(e) The test statistic $W_{\bar{t}}$ which has standard normal distribution

(f) Test of the null hypothesis of common unit autoregressive root at 5% level (the critical value is -1.96)

There are twelve pooled cointegrating regressions reported based on specification made up in Section 2. All of the equations include unreported country-specific constants. To allow for the possible difference between the seven largest economies and the rest eight countries, we interact the domestic R&D capital stock with a dummy variable, $G7$, which takes the value of 1 for the seven largest economies and zero otherwise. Almost all of the estimated coefficients reported are of the expected sign and the magnitudes of the estimated elasticities are plausible and relatively stable across different specifications. Because the coefficient of the interaction term between $G7$ and domestic R&D capital stock are positive and significantly different from zero across all equations, domestic R&D capital stock has much larger impact on TFP in large economies as compared to small economies. Cointegration tests at the end of each equation suggest that all equations exhibit cointegrating relationships.

Equation (1) is the basic specification that looks at the impact of two main factors – domestic R&D and human capital – on TFP. All the coefficients are positive and strongly significant, confirming the important roles of domestic R&D and human capital on productivity.[6] Regressions (2) to (4) show the estimated elasticities of TFP with respect to alternative foreign R&D capital stocks in addition to domestic R&D and human capital. In equation (2), the coefficient of foreign R&D capital stock through imports is positive but insignificant. This suggests that there are no significant international R&D spillovers through imports. This result is quite surprising as it is in contrast to that of Coe and Helpman (1995).

With regards to the impact of outside R&D embodied in both inward and outward FDI, regressions (3) and (4) indicate that international R&D spillovers exist and are significant. This suggests that FDI does induce substantial technology transfers from the home country to

[6] The result that human capital both directly and indirectly affects productivity is also found in Engelbrecht (1997).

the host country and vice versa. These results are different from what reported in van Pottelsberghe and Lichtenberg (2001) where the authors do not find any significant evidence of technical spillovers from international firms to host countries' domestic firms. Our results imply that multinational corporations act in both ways: diffuse their own technological advantages to the host country and absorb new technological knowledge available in the host country to their homeland.

Regressions (5) to (7) include the foreign R&D capital stocks interacting with human capital. Except for the coefficient of the interaction term between import-embodied R&D capital stock and human capital, all coefficients are positive and highly significant. This implies the complementarities between human capital and foreign R&D capital stock embodied in FDI: the effect of foreign R&D capital stock embodied in FDI on productivity is larger if the domestic labour force is more educated, and the effect of education on productivity is larger when there is more foreign R&D capital stock through FDI. This result is consistent with the idea that the flow of technology brought along by FDI can be more easily absorbed to increase the growth rate of the host country if that country's absorptive capacity is higher.

Regressions (8) to (10) include the inward FDI foreign R&D capital stock together with the outward FDI foreign R&D capital stock or different interaction terms of alternative measures of foreign R&D with human capital. In regression (8), the inclusion of both kinds of FDI embodied foreign R&D capital stocks make the coefficient of outward FDI foreign R&D capital stock insignificant. This shows that inward FDI has a stronger impact on productivity than outward FDI. In regression (9), both coefficients of inward FDI foreign R&D capital stock and its interaction with human capital are insignificant. This may be due to the multicollinearity problem caused by the possibility that these two variables are highly correlated. The estimated coefficient on the interaction of the outward FDI foreign R&D capital and human capital is not significantly different from zero in equation (10). This confirms that the impact on productivity of inward FDI R&D capital outweighs that of its outward counterpart.

Similarly, equation (11) and (12) incorporate outward foreign R&D capital stock and different interaction terms between foreign R&D capital stocks and human capital alternatively. Once again, results suggest that inward FDI is more relevant to productivity increment than outward FDI as per equation (11). In equation (12), while the coefficient of the interaction term is positive and statistically significant, that of the outward FDI foreign R&D capital stock turns out to be negative (incorrect sign) and insignificant. A possible explanation for this result is the high correlation between these two terms which causes the multicollinearity problem.

The specifications discussed above focus on FDI as the vehicle through which R&D spillovers are transmitted, which is consistent with the theoretical considerations in Section 2. As it has been noted, FDI is also likely to exert an indirect effect on productivity through its pulling of resources to promote the human capital accumulation process. This hypothesis is tested when the level of GDP per capita is controlled for. The obtained regression results are as follows:

$$\log(H_{it}) = \underset{(0.002)}{0.054} * \log(FDI_{it-1}) + \underset{(0.011)}{0.045} * \log(GDPPC_{it-1})$$

$$RSS = 0.041,\ R^2 = 0.955,\ \text{Adjusted } R^2 = 0.953$$

In this regression, country-specific constants are not reported and White heteroskedasticity-consistent standard errors are in parentheses. The t-statistic on the lagged residual in the

ECM and the Pedroni's panel ADF statistic are -4.462 and -166.174 respectively confirming that the equation is cointegrating or there exists a long-run relationship between the dependent variable and the explanatory variables. The coefficient of FDI in this specification is positive and statistically significant. This confirms that FDI has an indirect effect of on productivity growth since it boosts up the level of human capital in the economy.

5- Some concluding remarks

Recent theoretical models of economic growth highlight the importance of FDI as a channel of technological spillovers that allow countries to benefit from innovative activities of their economic partner countries. There have also been many empirical, cross-country studies of economic growth. For the most part, however, these studies do not assign an important role to FDI embodied technology in explaining productivity of both FDI recipients and donor countries. This paper, by contrast, has presented empirical evidence that total factor productivity in both FDI sending and host countries is positively and significantly related to R&D activities in their economic partners and to their stock of human capital.

Our estimates suggest that the R&D spillovers through FDI – as measured by the elasticity of total factor productivity with respect to foreign R&D capital stock – are substantial. Knowledge diffuses across borders in both directions: from FDI donor country to FDI recipient country and vice versa. Contrary to frequent conjectures, import embodied R&D does not seem to contribute to the improvement of the technological base of the host economies.

We also found that the quality of the labour force significantly contributes to the increase in the domestic technological level. Human capital exerts both direct and indirect impacts on TFP through the improvement of workers' skills (as a factor of production) and the ability to learn from foreign technological base. Finally, our estimates confirm the hypothesis that FDI helps improve human capital as it pulls in resources devoted to education.

Finally, we argue that the results emerging from our research, as presented here, does provide valuable new insights into the issue of economic development. Future workextending the analysis might also estimate the structure of technology flows at the industry level to see if a given industry can benefit from R&D investment of other (both domestic and foreign) industries. This will help to enrich our research agenda in the fields of growth and international economics.

Table 3 - *Total factor productivity estimation results (pooled data 1982-2003 for 15 countries, 315 observations – **in level**)*

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
$\log SD$	0.218***	0.210***	0.097***	0.066**	0.199***	0.100***	0.064**	0.064**	0.097***	0.065***	0.063**	0.067**
	(0.014)	(0.021)	(0.014)	(0.028)	(0.021)	(0.014)	(0.025)	(0.025)	(0.014)	(0.023)	(0.025)	(0.028)
$G7.\log SD$	0.114***	0.107***	0.103***	0.093***	0.094***	0.100***	0.084***	0.097***	0.103***	0.093***	0.094***	0.082***
	(0.012)	(0.022)	(0.011)	(0.015)	(0.026)	(0.011)	(0.015)	(0.015)	(0.010)	(0.016)	(0.014)	(0.013)
$\log H$	1.569***	1.558***	1.221***	1.253***	1.530***	1.196***	1.240***	1.177***	1.217***	1.180***	1.154***	1.244***
	(0.086)	(0.087)	(0.092)	(0.113)	(0.095)	(0.096)	(0.110)	(0.097)	(0.114)	(0.098)	(0.097)	(0.107)
$\log SF^{m}$ (import)		0.017										
		(0.039)										
$\log SF^{g}$ (inward)			0.085***					0.064***	0.073	0.059***		
			(0.007)					(0.018)	(0.084)	(0.022)		
$\log SF^{l}$ (outward)				0.090***				0.038			0.040	-0.028
				(0.020)				(0.034)			(0.033)	(0.061)
$\log H.\log SF^{m}$					0.018							
					(0.018)							
$\log H.\log SF^{g}$						0.036***			0.005		0.027***	
						(0.003)			(0.037)		(0.008)	
$\log H.\log SF^{l}$							0.040***			0.018		0.052**
							(0.008)			(0.015)		(0.022)
RSS	0.091	0.092	0.085	0.086	0.091	0.085	0.086	0.084	0.085	0.084	0.084	0.086
R^2	0.861	0.861	0.881	0.876	0.861	0.881	0.878	0.882	0.881	0.882	0.882	0.878
Adjusted R^2	0.853	0.852	0.874	0.869	0.853	0.873	0.871	0.875	0.873	0.875	0.875	0.870
Cointegration tests												
t-stat on the lagged residual in the ECM (a)	-4.226	-3.549	-5.161	-5.081	-4.342	-5.196	-5.256	-5.349	-5.279	-5.399	-5.391	-5.293
Panel *ADF* statistic (b)	-35.518	-15.423	-30.681	-21.114	-25.790	-30.335	-22.960	-15.724	-20.154	-16.171	-15.018	-13.387
Decision (c)	*CI*	*CI*	*CI*	*CI*	*CI*	*CI*	*CI*	*CI*	*CI*	*CI*	*CI*	*CI*

Notes: The dependent variable is $\log F$ (log of total factor productivity, indexed as 1985 = 1). All equations include unreported country-specific constants. White heteroskedasticity-consistent standard errors are given in parentheses. SD is domestic R&D capital stock; SF^m is foreign R&D capital stock embodied in imports; SF^g is foreign R&D capital stock embodied in inward FDI; SF^l is foreign R&D capital stock embodied in outward FDI; $G7$ is dummy variable equal to 1 for the seven major countries and equal to 0 for the other twelve countries. ***, **, and * indicate that parameters are statistically significant at the 1%, 5% , and 10% probability level respectively.

(a) Error correction model is the first difference of each equation augmented to include the lagged residual from the equations reported (up to three lag periods were included; statistically non-significant terms were then eliminated, starting from the least significant)
(b) Pedroni (1999)'s Panel ADF statistic allows dynamics and cointegrating vector to vary across individuals
(c) Test of the null hypothesis of no cointegration at 5% significant level (the critical value is -1.96)

Appendix 1- Data sources and definitions

The total factor productivity F is defined as:

$$F = \frac{Y}{K^{\gamma} L^{1-\gamma}}$$

where Y is value added in the business sector, K is the stock of business sector capital, and L is employment (full-time equivalent) in the business sector. All variables are constructed as indices with 1985 = 1. The coefficient γ is the average share of capital income from 1987 to 1989 reported in Coe and Helpman (1995). Y, K, and L are from OECD STAN Database (2005).

We used the method described by Coe and Helpman (1995, p.878) to estimate domestic business sector R&D capital stocks (lagged by one year) based on R&D expenditures data for total business enterprises from OECD STAN Databases (2002, 2006). First, we computed real R&D expenditure by deflating nominal expenditures by an R&D price index, PR, which is defined as:

$$PR = 0.5P + 0.5W$$

where P is the implicit deflator for business sector output, and W is an index of average business sector wages (both of them come from OECD Economic Outlook Database, 2006). According to Coe and Helpman (1995), this definition of PR reflects that half of R&D expenditures are labour costs, which is consistent with available data on the composition of R&D expenditures. We then calculated domestic R&D capital stocks, SD, the beginning of period stocks, based on the above obtained data on real R&D expenditures, R, and the perpetual inventory model:

$$SD_t = (1-\delta)SD_{t-1} + R_{t-1}$$

where δ is the depreciation rate, which was assumed to be 5 percent. The benchmark for SD was calculated as follows:

$$SD_0 = \frac{R_0}{g + \delta}$$

where R_0 is the R&D expenditure of the first year for which the data were available, SD_0 is the benchmark for the beginning of that year, and g is the average annual logarithmic growth of R&D expenditures over the period for which R&D data were available. The domestic R&D capital stocks were expressed in 1985 PPP million US dollars.

Three measures of the foreign R&D capital stocks were computed for each country. The first is the sum of the domestic R&D capital stocks of 14 trading partners weighted by bilateral imports as share of GDP deflated by bilateral distance. The bilateral imports as share of GDP were calculated for each year from 1983 to 2003 based on data from OECD International Trade Database (2007). The bilateral distance data which show the numbers of kilometres between capital cities of the countries as the crow flies are from Robertson (1998). The second and the third estimate of the foreign R&D capital stocks are those embodied in inward and outward FDI deflated by bilateral distance. The formulas are presented in the text. The data on FDI by country of origin used for the calculation of these stocks come from OECD International Direct Investment Database (2006). Because the time series of bilateral stocks and flows of FDI among OECD countries are not complete over the period 1983-2003 are not complete, missing values were estimated by a linear interpolation computation.

To characterize stocks of human capital, data on average years of schooling of total population aged 25 and over, which come from Barro and Lee (2000), were used. As data from that database were presented as 5-year average and only available up to the year 2000, linear interpolation and extrapolation calculations were employed to predict values for the missing years.

Appendix 2 - Im, Pesaran and Shin (2003)'s unit root test in heterogeneous panel with serially correlated errors

This is a standardized t-bar test statistic based on the (augmented) Dickey-Fuller statistics averaged across the groups. Consider a panel of data of N cross sections observed over T time periods. Suppose that variable y_{it} is generated according to a finite-order $AR(p_i+1)$ process which can be equivalently expressed as the following $ADF(p_i)$ regression:

$$\Delta y_{it} = \rho_i y_{it-1} + \sum_{j=1}^{p_i} \theta_{ij} \Delta y_{it-j} + \alpha_i + \varepsilon_{it} \text{ with } t = 1,.....,T \text{ for each } i \in N$$

The lag truncation order for each individual, p_i, is determined by the data to eliminate autocorrelation from ε_{it}. The null hypothesis of unit roots is $H_0 : \rho_i = 0$, $\forall i$ against the alternative $H_1 : \rho_i < 0$.

From the regression, we obtain the following statistic:

$$\overline{t}_{NT} = \frac{1}{N} \sum_{i=1}^{N} t_{iT}\left(p_i, \theta_i\right)$$

where $t_{iT}\left(p_i, \theta_i\right)$ is the individual t-statistic for testing $\rho_i = 0$, $\forall i$. As soon as $T \to \infty$, followed by $N \to \infty$ while $\frac{N}{T} \to k$ (a finite non-negative constant), the standardized t-bar statistic:

$$W_{\overline{t}} = \frac{\sqrt{N}\left[\overline{t}_{NT} - \frac{1}{N}\sum_{i=1}^{N} E\left(t_{iT}\left(p_i, 0\right) \middle| \rho_i = 0\right)\right]}{\sqrt{\frac{1}{N}\sum_{i=1}^{N} Var\left(t_{iT}\left(p_i, 0\right) \middle| \rho_i = 0\right)}} \to N\left(0,1\right)$$

where $E\left(t_{iT}\left(p_i,0\right)\middle|\rho_i=0\right)$ and $Var\left(t_{iT}\left(p_i,0\right)\middle|\rho_i=0\right)$ are tabulated in their paper.

Appendix 3 - Pedroni (1999)'s cointegration tests in heterogeneous panel with multiple regressors

1- Estimate the appropriate level regression and collect the residuals $\widehat{e}_{it}$ for each i:

$$y_{it}=\alpha_i+\beta_{1i}x_{1it}+\beta_{2i}x_{2it}+....+\beta_{Mi}x_{Mit}+e_{it}$$

2- Difference the original series and estimate the differenced regression:

$$\Delta y_{it}=b_{1i}\Delta x_{1it}+b_{2i}\Delta x_{2it}+...+b_{Mi}\Delta x_{Mit}+\eta_{it}$$

3- Calculate $\widehat{L}_{11i}^2$ as the long-run variance of $\widehat{\eta}_{it}$ using an appropriate Kernel estimator, such as the Newey-West estimator.

4- Using $\widehat{e}_{it}$, estimate the appropriate autocorrelation (for parametric statistics):

$$\Delta\widehat{e}_{it}=\gamma_i\widehat{e}_{it-1}+\sum_{k=1}^{K_i}\gamma_{ik}\Delta\widehat{e}_{it-k}+u_{it}$$

The null hypothesis of the test is $H_0:\gamma_i=0$, $\forall i$ against the alternative $H_1:\gamma_i<0$. From this regression, we compute simple variance of $\widehat{u}_{it}$, denoted $\widehat{s}_i^2$.

5- Calculate Panel t-statistic:

$$Z_{t,NT}=\left(\tilde{S}_{NT}^2\sum_{i=1}^{N}\sum_{t=1}^{T}\widehat{L}_{11i}^{-2}\widehat{e}_{it-1}^2\right)^{-1/2}\sum_{i=1}^{N}\sum_{t=1}^{T}\widehat{L}_{11i}^{-2}\widehat{e}_{it-1}\Delta\widehat{e}_{it}$$

where $\tilde{S}_{NT}^2=\frac{1}{N}\sum_{i=1}^{N}\widehat{s}_i^2$. It is shown that:

$$Z_{t,NT}-\Theta_2\left[\Theta_1\left(1+\Theta_3\right)\right]^{-1/2}\sqrt{N}\rightarrow N\left(0,\phi_{(3)}^{'}\Psi_{(3)}\phi_{(3)}\right)$$

In this notation Θ_j, $j=1,2,3$ are elements of the mean vector Θ of Brownian motion functions; $\phi'_{(3)} = \left(\left(\Theta_1 \left(1+\Theta_3\right)\right)^{-1/2}, -\frac{1}{2}\Theta_2\Theta_1^{-3/2}\left(1+\Theta_3\right)^{-1/2}, -\frac{1}{2}\Theta_2\Theta_1^{-1/2}\left(1+\Theta_3\right)^{-3/2} \right)$; and $\Psi_{(3)}$ is the upper sub-matrix of the Brownian motion covariance matrix Ψ.

Compute the panel cointegration test statistic

$$\frac{\chi_{N,T} - \mu\sqrt{N}}{\sqrt{v}} \rightarrow N(0,1)$$

where $\chi_{N,T}$ is the appropriate standardized form, μ and v are mean and variance adjustment terms respectively and are tabulated in Pedroni's paper.

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