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International technology diffusion through imports and its impact on economic growth

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Abstract

This paper provides new evidence on the importance of international technology spillovers channelled by imports and its impact on economic TFP growth of the OECD countries. For this purpose we estimate a version of the growth model with endogenous technological change used in Benhabib and Spiegel (1994), which includes some modifications in order to capture the differences in the degree of success that countries have in benefiting from foreign technology spillovers. Our results suggest that domestic R&D and human capital stocks are critical for successful technology diffusion from abroad.

JEL Classification: O0; F4
Key words: International Technology Spillovers, Foreign Trade, Growth, OECD.

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1. Introduction

Recent growth literature generally acknowledges the essential role of endogenous technical change in explaining both economic growth and cross-country income differences. In most of these studies technology is viewed as technological knowledge, which is basically obtained through investments in R&D, whose returns are partly public in the sense that they have positive externalities or, in other words, technology spillovers.

There is, however, a significant debate about two important and related issues: first, about the extent to which those technology spillovers are national or international and, secondly, about the relative importance of international spillovers versus own R&D spending. Naturally, both issues have major policy implications and are at the heart of a wider debate on income convergence (divergence) across countries. Indeed, it is clear that strong and international spillovers favour convergence while either weak and/or local technology spillovers make divergence more likely.

In principle, one may put forward several reasons for expecting international spillovers to be rather weak. Consider first that technology is likely to be protected by patents, and that, in any event, the inventor has an incentive for keeping the know-how secret. Moreover, given that a part of technological knowledge is tacit, that is to say cannot be codified, its diffusion is rather difficult and costly and usually needs of person-to-person contacts to be successful (Teece, 1977; David, 1992 and von Hippel, 1994, for instance). Consequently, and taking into account that it is costly for people to travel from one place to another, it is reasonable to think that the higher the relative importance of non-codified knowledge is the less important international technology spillovers will tend to be, or, put in another way, that geographical proximity matters for benefiting from technology spillovers. This idea is supported for example in Eaton and Kortum (1999), Branstetter (2001) and Keller (2001).

Finally, one may also argue that the importance of international technology spillovers depends not only upon geographical distance, but also upon what Griliches (1979) called "technological distance" or, in other words, technological gap. Here one may think of two effects of an opposite sign. Thus, on the one hand, it may be expected that the greater the technological gap of a country is, the greater the potential for foreign technology spillovers will be, but, on the other hand, one may also expect that the lesser will be its "absorptive capacity", defined as its degree of success in adopting foreign technology. In this respect, two major determinants have been emphasised: human capital (Nelson and Phelps, 1966; Benhabib and Spiegel, 1994; Eaton and Kortum, 1996; Xu, 2000 and Hanushed and Kimko, 2000) and domestic R&D stock (Cohen and Levinthal, 1989; Griffith, Redding and Van Reenen, 2000 and Kinoshita, 2000)

In this context, this paper is largely focused on the analysis of the last issue, because in our view, enhancing our knowledge on the major determinants of successful adoption of foreign technology spillovers is crucial for not only understanding, but also influencing the observed income differences across countries and, consequently, their patterns of convergence (divergence) over time. More specifically, its purpose is to provide additional evidence on the importance of international spillovers channelled by imports on the economic growth of the OECD countries, putting the emphasis on the analysis of the role played by the differences in the absorptive capacity across countries. In this respect, a new measure taking into account both domestic human capital and R&D capital is considered. Accordingly, the structure of the paper is as follows. First, in the next section, we explain the theoretical growth model. In section 3, we propose a measure of international technology spillovers that tries to overcome some criticism that have received by those used in previous studies. Then, after discussing the data and the econometric method, we present the main results. Lastly, we offer a summary and some final remarks.

2. Theoretical model

We start from a Cobb-Douglas production function, which uses the traditional productive factors, i.e.

$$\Delta \log Y_{it} = \Delta \log A_{it} + \boldsymbol{a} \cdot \Delta \log K_{it} + \boldsymbol{b} \cdot \Delta \log L_{it} + \Delta \log \boldsymbol{x}_{it} \tag{1}$$

where Y is the production level, K the stock of physical capital, L employment, A an index of technical efficiency and the subindices i and t the references to the country and to time, respectively. Where Solow's residual represents technical change that may be initially specified in the way proposed by Benhabib and Spiegel (1994)

$$\Delta \log A_{it} = \boldsymbol{d} + \boldsymbol{j} \cdot H_{it} + \boldsymbol{m} \cdot H_{it} \cdot \left(\frac{y\max_t - y_{it}}{y_{it}} \right) + \boldsymbol{e}_{it} \tag{2}$$

Where H is the stock of human capital, *ymax* the level of per capita income of the leader country, and y the per capita GDP of the country analysed. So, this is an endogenous growth model where human capital and technological gap are the engines of growth. In this sense, human capital would therefore be determinant both of the technological progress generated endogenously –second term of the expression– (Romer, 1990) and of the "absorptive capacity" of foreign technology –third term– (Nelson and Phelps, 1966)[1], approaching the technological gap here on the basis of the per capita income differentials to the leader country.

[1] For evidence on this issue see Eaton and Kortum (1996), Xu (2000), Hanushek and Kimko (2000) and Caseli and Coleman (2001) for recent evidence.

Although this model is of great interest from the empirical point of view for the way in which it expresses technological progress, we believe that there are some aspects that should be reconsidered. In this respect, it is to be expected that both technical efficiency and absorptive capacity of foreign technology are not only influenced by human capital but also – as shown in Cohen and Levinthal (1989), Griffith, Redding and Van Reenen (2000) and Kinoshita (2000) – by domestic R&D capital. Thus, we have used a single variable (T) that somehow measures the domestic stock of technological knowledge of each economy as a linear combination of human and R&D domestic capital stocks (see appendix 1)[2].

Another questionable issue in the model used in Benhabib and Spiegel (1994) is that it refers to the technological convergence process between different economies without alluding to its causes. Therefore, with the aim of trying to overcome this, in this paper we have included a direct measure of international technology spillovers (S) based on the conjunction of two variables: the intensity and geographical structure of the imports and, on the other hand, the R&D stocks of the different countries of origin of these imports[3]. Namely,

$$\Delta \log A_{it} = \mathbf{d} + \mathbf{j} \cdot T_{it} + \mathbf{m} \cdot T_{it} \cdot S_{it} + \mathbf{e}_{it} \qquad (3)$$

In addition, and in order to explore the extent to which the success of foreign technology adoption is influenced by the technological gap, we have broken down international spillovers into two parts: one that only includes imports from more R&D-intensive countries (S^M) and is therefore more likely to contribute to technological catch-

[2] Note, that this variable approaches in some way the theoretical concept proposed by Romer (1990).

[3] In this sense, this paper follows the approach of using actual import shares used in Coe y Helpman (1995) and Coe, Helpman and Hoffmaister (1997) instead of that one of ramdom shares used in Keller (1997, 2000).

up, and another one that includes the rest of spillovers (S^R). Consequently, the final specification of the model to be estimated is,

$$\Delta \log A_{it} = d + j \cdot T_{it} + m_1 \cdot T_{it} \cdot S_{it}^M + m_2 \cdot T_{it} \cdot S_{it}^R + e_{it} \qquad (4)$$

It should be noted that the elasticities associated with the domestic stock of technological knowledge ($e_{Y,T}$), with the term that reflects international technology spillovers that are more conducive to technological catch-up (e_{Y,S^M}) and with the rest of spillovers (e_{Y,S^R}), can be calculated in an easy way because of the functional form used for the production function. Specifically, the values of these in the mean value of the variables would be,

$$e_{Y,T} = \left(j + m_1 \cdot \overline{S}^M + m_2 \cdot \overline{S}^R\right) \cdot \overline{T} \qquad (5)$$

$$e_{Y,S^M} = m_1 \cdot \overline{T} \cdot \overline{S}^M \qquad (6)$$

$$e_{Y,S^R} = m_2 \cdot \overline{T} \cdot \overline{S}^R \qquad (7)$$

Now that we have explained the model that will be estimated, it is time to justify in more detail the proposal that is put forward here to approach international technology spillovers.

3. <u>Measurement of international technology spillovers</u>

As was mentioned earlier, one may argue that in order to be able to assess the ability of a country to converge towards the income levels enjoyed by the most advanced economies, it is important to ascertain the importance of international technology spillovers. In this respect, in the literature on economic growth that has appeared in the last few years, efforts have been made to obtain a proper measurement of such spillovers.

International technology spillovers are usually identified with the foreign R&D stock that an economy can benefit from. The typical approach for the empirical assessment of international technology spillovers is to estimate a production function that includes in the regressors a term capturing the impact of the foreign R&D as a weighted sum of other countries R&D stocks. The choice of the weight depends on the specific channel of diffusion of foreign technology analysed. In this respect, ever the influential paper by Coe and Helpman (1995), many studies have used import shares as weights[4]. Specifically, they define the foreign R&D capital stock (S^{CH}) as the import-share-weighted average of the domestic R&D capital stocks of trade partners, using the share of total imports over the GDP to weight it according to the volume of imports of the country recipient of the spillovers[5]:

$$S_{it}^{CH} = \frac{m_{i.t}}{Y_{it}} \cdot \log\left(\sum_{j \neq i} \frac{m_{ijt}}{m_{i.t}} \cdot RDK_{jt} \right) \qquad (8)$$

where RDK is the R&D capital stock of the supplier countries, m_{ijt} the imports made by country i from country j, $m_{i.t}$ the total volume of imports made by country i, and Y_{it} the GDP of country i.

However, this specification suffers from certain limitations due to the likely bias caused by the level of disaggregation of data referring to trading partners. Thus,

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[4] See Coe, Helpman and Hoffmaister (1997), Keller (1998, 2000), Xu and Wang (1999), Bayoumi, Coe and Helpman (1999), Lumenga-Neso, Olarreaga and Schiff (2001).

[5] This type of measure seems to be better founded on empirical literature than Keller's (1998) counterfactual shares –see Nadiri and Kim (1996), Sjoholm (1996), Xu and Wang (1999), Lumenga-Neso, Olarreaga and Schiff (2001) and Coe and Hoffmaister (1999) as illustration-.

Lichtenberg and Pottelsbergue (1998) propose an alternative measurement (S^{LP}) in order to overcome it,

$$S^{LP}{}_{it} = \sum_{j \neq i} m_{ijt} \cdot \frac{RDK_{jt}}{Y_{jt}} \qquad (9)$$

However, it can be convincingly argued that the measure of international technology spillovers included in expression (9) may be biased, given the different size of the countries in question and the fact that the small countries usually show a higher opening to trade than large ones. In order to avoid this likely bias, we propose to introduce a factor of correction (M^*_{it}) that takes into account the differences between the actual and the "theoretical" value of imports for each country according to its size. So, this measure of spillovers (S^{CMV}) would be,

$$S^{CMV}{}_{it} = M^*_{it} \cdot \sum_{j \neq i} m_{ijt} \cdot \frac{RDK_{jt}}{Y_{jt}} \qquad (10)$$

where M^*_{it} is the ratio between the actual average import penetration rate of the sample ($\bar{g}_t$) and the theoretical value of this ratio for the country i (g^*_{it})[6]. In order to obtain the theoretical value of imports penetration rate of each country we estimate the following equation:

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[6] Note that the final expression proposed for S^{MVC} is:

$$S^{CMV}_{it} = \frac{\bar{g}_t}{g^*_{it}} \cdot \sum_{j \neq i} m_{ijt} \cdot \frac{RDK_{jt}}{Y_{jt}}$$

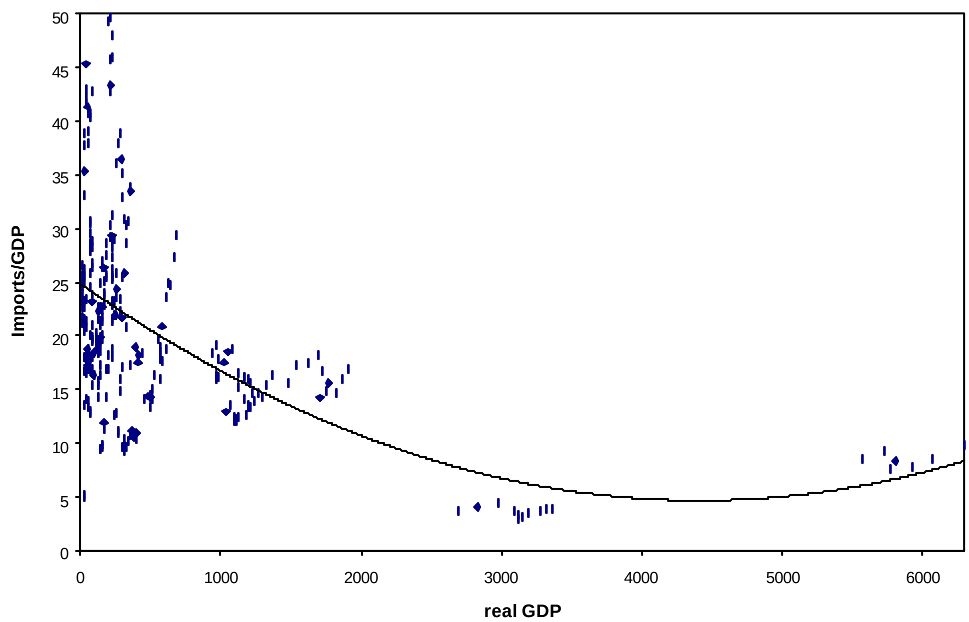
that is equivalent to:

$$S^{CMV}_{it} = \bar{g}_t \cdot Y_{it} \cdot \sum_{j \neq i} \frac{m_{ijt}}{m^*_{i.t}} \cdot \frac{RDK_{jt}}{Y_{jt}}$$

$$g_{it} = l + w_1 y_{it} + w_2 y_{it}^2 + u_{it} \tag{11}$$

where g_{it} is the actual imports penetration rate and y_{it} is real GDP. Thus, we obtain g^*_{it} as the fitted value of (11).

Figure 1. Relationship between openness and size of economies for the period 1988-1998.



The data on import shares over GDP and the size of the countries of the OECD are represented in Figure 1 and the results of the estimation of the equation above for each of the years are shown in Table 1.

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where $m^*_{i.t}$ is the "theoretical" value of imports. Then, the first and second terms ($\bar{g}_t \cdot Y_{it}$) will be the value of imports if country i had the average import penetration rate of the sample of countries, and the ratio $\frac{\sum_{j \neq i} m_{ijt}}{m^*_{i.t}}$ is the relationship between the actual and theoretical value of imports.

Table 1. Relationship between import share over GDP and size of the OECD countries –expression (12)-. OLS estimates

$$g_{it} = l + w_1 y_{it} + w_2 y_{it}^2 + u_{it}$$

Year	Explanatory Variables		
	l	y_1	y^2
1988	23.29 (8.48)	-0.87x10^{-3} (-2.67)	1.06 x10^{-6} (1.84)
1989	24.23 (8.59)	-0.86 x10^{-3} (-2.62)	1.02 x10^{-6} (1.83)
1990	24.37 (9.96)	-0.89 x10^{-3} (-3.39)	1.04 x10^{-6} (2.46)
1991	23.47 (9.85)	-0.84 x10^{-3} (-3.01)	0.97 x10^{-6} (2.12)
1992	23.63 (11.35)	-0.89 x10^{-3} (-3.73)	1.05 x10^{-6} (2.75)
1993	23.20 (12.52)	-0.93 x10^{-3} (-4.77)	1.12 x10^{-6} (3.70)
1994	23.67 (12.12)	-0.89 x10^{-3} (-4.13)	1.06 x10^{-6} (3.18)
1995	24.96 (12.97)	-0.90 x10^{-3} (-4.23)	1.02 x10^{-6} (3.12)
1996	26.13 (13.21)	-1.01 x10^{-3} (-5.58)	1.14 x10^{-6} (4.68)
1997	28.02 (12.71)	-1.10 x10^{-3} (-5.46)	1.20 x10^{-6} (4.67)
1998	29.43 (12.31)	-1.16 x10^{-3} (-5.27)	1.24 x10^{-6} (4.56)
Total	24.85 (36.53)	-0.91 x10^{-3} (-13.80)	1.04 x10^{-6} (11.01)

t-ratio in brackets

Finally, Table 2 shows both the “theoretical” and the observed import shares over GDP values, as well as the ratio between them.

Table 2. Actual vs theoretical penetration import rate.

Countries	GDP/OCDE (%)	Actual imports penetration rate (a)	Theoretical imports penetration rate (b)	(a)/(b)
Iceland	0.03	23.83	24.79	0.96
Czech Republic	0.13	21.52	24.63	0.87
Hungary	0.18	26.07	24.55	1.06
New Zealand	0.25	17.37	24.42	0.71
Ireland	0.30	41.21	24.34	1.69
Poland	0.36	17.29	24.25	0.71
Portugal	0.40	27.99	24.18	1.16
Greece	0.46	18.29	24.06	0.76
Norway	0.70	19.55	23.67	0.83
Finland	0.72	17.38	23.64	0.74
Denmark	0.77	21.87	23.55	0.92
Turkey	0.90	12.53	23.34	0.54
Austria	0.91	25.87	23.33	1.11
Belgium-Lux.	1.17	48.04	22.91	1.17
Switzerland	1.21	27.50	22.83	1.20
Sweden	1.27	21.91	22.75	0.96
Mexico	1.53	18.06	22.33	0.81
Netherlands	1.65	34.21	22.14	1.55
Korea	1.76	21.84	21.96	0.99
Australia	1.84	10.26	21.83	0.47
Spain	2.79	15.30	20.37	0.75
Canada	3.22	22.20	19.72	1.13
United Kingdom	5.50	17.37	16.56	1.05
Italy	6.05	12.82	15.85	0.81
France	6.62	15.09	15.14	1.00
Germany	9.19	16.13	12.23	1.32
Japan	16.61	3.66	6.49	0.56
United States	33.49	9.20	8.49	1.08

In addition, we think that it is interesting to distinguish between foreign R&D spillovers coming from more R&D-intensive countries and the rest of spillovers. In this respect, it can be said that the former may contribute to a greater extent to technological catch-up. Such a breakdown can be made in the following way,

$$S_{it}^{CMV} = S_{it}^{M} + S_{it}^{R} = \frac{1}{M*}\left[\sum_{\substack{j\neq i\\ j\in M}} m_{ijt}\left(\frac{RDK_{jt}}{Y_{jt}} - \frac{RDK_{it}}{Y_{it}}\right)\right] + \frac{1}{M*}\left[\sum_{\substack{j\neq i\\ j\in L}} m_{ijt}\frac{SKT_{jt}}{Y_{jt}} + \frac{SKT_{it}}{Y_{it}}\sum_{\substack{j\neq i\\ j\in M}} m_{ijt}\right] \quad (12)$$

4. Data, econometric estimation and results

The information used to estimate the model was obtained from several international statistical sources, mainly from the OECD and EUROSTAT (see more details in the Appendix 1). The countries that make up the sample are the 28 of the OECD – Belgium and Luxembourg are aggregated and the Slovak Republic is not included – and the reference period is 1988 -1998.

Estimation of the different specifications of the model proposed present some problems that have to be tackled. In the first place, it should be noted that technical efficiency is determined by specific features of each country – legislations, cultural aspects, production structure, etc. – which, if not taken into consideration, would create a problem of omitted variables. However, since we have a panel data set available, it is possible to take them into account in order to obtain consistent estimators.

The key question, however, lies in testing whether these individual effects are correlated or not with the explanatory variables, as, if so, the within estimator should be used. To find out whether this is the case, we have used the test proposed by Arellano and Bover (1990), which – unlike Hausman's test –, is valid even if the errors are heteroscedastic and are autocorrelated[7].

In addition, there may be a problem of simultaneity between the growth of output and R&D investment and/or human capital, then it would be better to estimate the model using the Instrumental Variables (IV) method. Finding suitable external instruments may however prove to be difficult. As we know, a standard solution is to use the Generalised Method of Moments (GMM), for which we estimate the model in orthogonal deviations.

[7] This procedure consists of forming a system of equations combining level equations and first-differences equations, where the equality of the level and first-differences coefficients is contrasted afterwards.

By using the econometric procedure above mentioned we have begun with the estimation of expression (1) in order to estimate the Solow´s residual or, in other terms, the TFP[8]. The results of the regressions by using the within estimator and then the method of Instrumental Variables –used in order to correct the first-order serial correlation observed- are reported in Table 3.

Table 3.- Estimation of the production function: expression (1)[1]

$$\Delta \log Y_{it} = \alpha \cdot \Delta \log K_{it} + \beta \cdot \Delta \log L_{it} + \varepsilon_{it}$$

Explanatory Variables	Within Estimation	Instrumental Variables[2]
D log K_{it}	0.6134 (3.34)	0.3521 (6.26)
D log L_{it}	0.4935 (4.51)	0.6301 (26.21)
Number of countries	28	28
Years	11	11
Number of observations	308	308
Sargan's test (degrees of freedom)		25.85 (22)
M1 [3]	2.64	1.81
M2 [3]	1.56	0.82

t-ratio in brackets.

[1] Variables normalised by the mean value and expressed in orthogonal deviations.
[2] The third and fourth T_{it} lags are used as instruments.
[3] M1 and M2 are tests for the lack of first-order and second-order serial correlation in the residuals.

Then, we have also used the method of Instrumental Variables to estimate the different versions of the TFP regressions discussed earlier. The results are reported in Table 4. The first column shows those corresponding to the specification of foreign spillovers suggested in Lichtenberg and Pottelsberghe (1998). The second column presents

[8] It should be noted that the calculation of TFP using the income share of labour and capital provides similar results.

the results obtained in the estimation of the equation that includes our proposal for avoiding the likely bias that country size differences may imply in the evaluation of the spillovers. In this sense, note that with this specification we obtain higher coefficient for the variable that tries to capture the importance of foreign spillovers. Moreover, in the table of the Appendix 2 one can find information about the importance of the bias. Otherwise, it is important to point out that the domestic stock of technological knowledge exhibits much higher output elasticity than the foreign R&D capital. This is an expected result given that it is obtained from a sample of developed countries.

Finally, in the third column we report the results corresponding to equation 5, namely the one including our proposal for exploring the effect of the technological gap for the successful adoption of foreign R&D. Recall that (as explained in section 2) it consists of breaking down foreign spillovers into two parts: those ones channelled by imports with an origin in more R&D intensive countries (S^M) and the rest of them (S^R). The most remarkable and rather unexpected result here is the higher elasticity of the latter (0.19 % against 0.15%). Note however, that those elasticities are referred to the OECD average. In this respect, it is worth exploring in more detail what the likely underlying across-country differences are.

Table 4.- TFP regressions[1]

Explanatory Variables	Expression (4)	Expression (4) (corrected by size bias)	Expression (5)
Estimation Method	IV	IV	IV
T	0.0102 (3.08)	0.0101 (2.23)	0.0126 (3.89)
$T \cdot S^{LP}$	0.0021 (3.28)	-	-
$T \cdot S^{CMV}$	-	0.0026 (2.57)	-
$T \cdot S^{M}$	-	-	0.0044 (2.80)
$T \cdot S^{R}$	-	-	0.0028 (5.81)
Number of countries	28	28	28
Years	11	11	11
Number of observations	308	308	308
Sargan's test (degrees of freedom)	25.28 (20)	24.92 (20)	25.05 (21)
M1 [2]	1.76	1.77	1.78
M2 [2]	0.64	0.68	0.69
Instruments	GMM(T,0,1) GMM(TS^{LP},0,1)	GMM(T,0,1) GMM(TS^{CMV},0,1)	GMM(T,0,1) DEV(TS^{CMV},0,1) DEV(TS^{M},1)
Calculation of the elasticities associated with the mean domestic stock of technological knowledge and foreign R&D stock per employee (%).			
$e_{Y,T}$	1.23	1.26	1.59
$e_{Y,S^{LP}}$	0.21		
$e_{Y,S^{CMV}}$		0.26	
$e_{Y,S^{M}}$			0.15
$e_{Y,S^{R}}$			0.19

t-ratio in brackets.
[1] Variables normalised by the mean value and expressed in orthogonal deviations.
[2] M1 and M2 are tests for the lack of first-order and second-order serial correlation in the residuals.

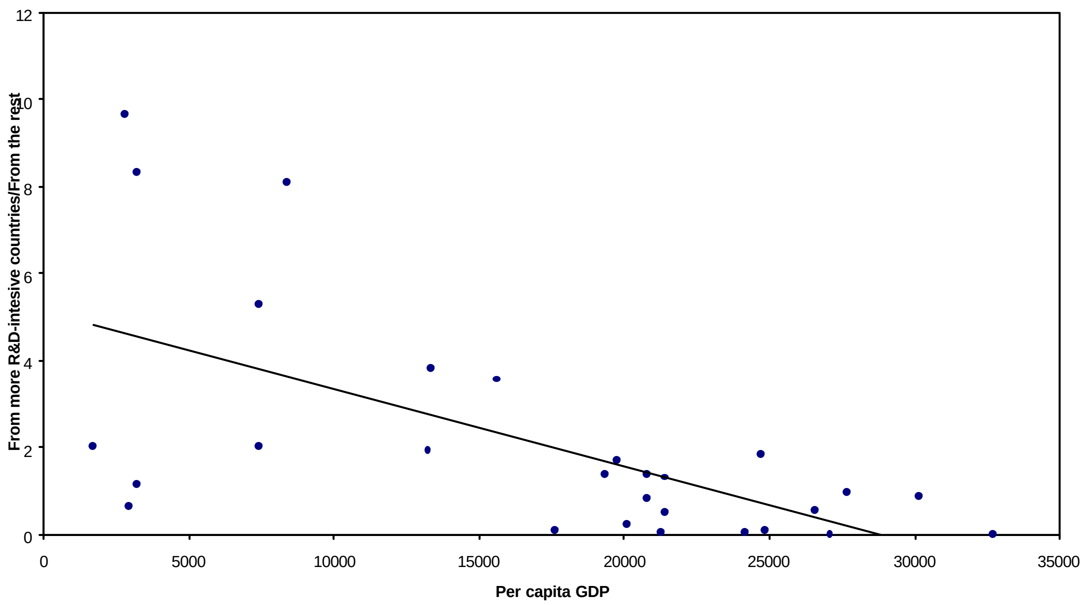
Indeed, as the domestic stock of technological knowledge and foreign R&D capital per employee differ from one country to another -and bearing in mind that we have ascertained that the elasticity of these factors increases with their level (see section 2)-, calculating each country's elasticity appears to be a matter of interest. For this we have used the expressions of the elasticities (5), (6) y (7) in the time average of the variables for each country. The results are set out in Table 5 and for a better interpretation of the set of elasticities obtained for each country we have represented them in Figure 2.

Table 5. Elasticities associated with the means of: domestic stock of technological knowledge ($e_{Y,T}$), foreign R&D stock from more R&D-intensive countries (e_{Y,S^M}) and foreign R&D stock from the rest (e_{Y,S^R}). In percentage

Countries	$e_{Y,T}$	e_{Y,S^M}	e_{Y,S^R}	$e_{Y,S^M} / e_{Y,S^R}$
Germany	2.834	0.020	0.666	0.03
Australia	1.343	0.103	0.074	1.39
Austria	1.890	0.301	0.231	1.30
Belgium–Luxembourg	3.029	0.611	0.748	0.82
Canada	1.862	0.318	0.233	1.36
Korea	0.550	0.043	0.021	2.03
Czech Republic	0.385	0.004	0.007	0.62
Denmark	2.204	0.289	0.297	0.97
Spain	0.846	0.131	0.034	3.80
Finland	2.374	0.198	0.355	0.56
France	2.724	0.179	0.374	0.48
United Kingdom	2.062	0.028	0.354	0.08
Greece	0.333	0.035	0.004	8.10
The Netherlands	2.505	0.124	0.620	0.20
Hungary	0.353	0.011	0.009	1.12
Ireland	1.270	0.396	0.112	3.55
Iceland	1.159	0.181	0.098	1.84
Italy	1.606	0.247	0.148	1.67
Japan	2.460	0.021	0.308	0.07
Mexico	0.184	0.012	0.001	8.32
Norway	2.396	0.285	0.331	0.86
New Zealand	0.870	0.075	0.039	1.91
Poland	0.256	0.004	0.002	2.01
Portugal	0.308	0.029	0.006	5.27
Sweden	3.493	0.007	0.803	0.01
Switzerland	4.077	0.000	1.146	0.00
Turkey	0.094	0.003	0.000	9.65
U.S.A.	2.956	0.012	0.468	0.02
Arithmetic mean	1.658	0.131	0.267	2.00
Standard deviation	1.135	0.152	0.298	2.57

The findings are as follows. There is evidence, first of all, that, as expected, underlying the ratio of elasticities for the OECD average there are different country patterns. Second and importantly, it seems that poorer countries have more potential for foreign technology spillovers, but it also appears that they cannot successfully translate them to growth rates due to their lower absorptive capacity. Consequently, our results suggest that foreign technology diffusion through imports in the OECD have stronger effects on growth in the relatively rich than in the poorer countries. Finally, we find that in the poor countries, as expected, the spillovers coming from more R&D-intensive countries are more important ($e_{Y,S^M} > e_{Y,S^R}$). Note that the disclosure of the individual country ratio of elasticities provides a reasonable explanation to the rather unexpected result obtained for the OECD average.

Figure 2. Relationship between per capita GDP and elasticity ratio between the foreign R&D capital stock from more R&D-intensive countries and from the rest



As a whole, our results are fairly consistent with those of recent previous studies that are also referred to OECD (Coe and Helpman, 1995; Keller, 2000 and Lumenga-Neso, Olarreaga and Schiff, 2001). However, we obtain lightly smaller elasticities for foreign spillovers.

Before concluding, it is interesting to carry out a simple exercise of growth accounting in order to assess the specific contribution of both the domestic stock of technological knowledge and the foreign R&D stock channelled through imports to TFP growth. The results of this exercise are presented in Table 6. As shown, although the domestic stock of technological knowledge proves to be the major engine of TFP growth in the OECD (it is responsible for the 73.14% of total TFP growth over the period) the contribution of foreign technology spillovers is also important.

Table 6. The contribution of domestic stock of technological knowledge and foreign R&D stock to TFP growth in the OECD (1988-1998).

Domestic stock of technological Knowledge	**Without spillovers**	**57.85%**	**73.14%**
	Additional effect with spillovers	**14.29%**	
Foreign R&D stock	**From more R&D intensive countries**	**10.35%**	**26.86%**
	From the rest	**16.52%**	

5. Summary and conclusions

This paper studies the importance of both the domestic stock of technological knowledge (domestic R&D and human capital stocks) and the international technology spillovers channelled through imports on economic growth of the OECD countries over the last few years. For this purpose we estimate a version of the growth model with endogenous technological change used in Benhabib and Spiegel (1994), which includes some modifications in order to better capture the likely differences in the degree of success that countries have in benefiting from foreign technology spillovers. Specifically, it explores the role of the domestic human and R&D capitals as determinants of the absorptive capacity of foreign technology spillovers. In addition, our model includes a measure of international technology spillovers that tries to overcome some of the criticisms of those used in previous studies.

Our results provide new evidence on the positive contribution of foreign technology spillovers channelled by imports on economic growth of the OECD countries. They suggest, however, that growth is more influenced by domestic R&D and human capital stocks. In this respect, this paper finds that those factors have not only a direct, but also an indirect effect on growth, to the extent to which they favour the absorptive capacity of foreign R&D.

In that sense, this paper finds that richer OECD countries are more successful in taking advantage of foreign technology spillovers. Indeed, according to our results it appears that, although technological backwardness provides greater potential for foreign spillovers, it does not permit their successful adoption. This suggests, therefore, that international diffusion of technology channelled by imports is only likely to be conducive to income convergence across OECD countries if the less technologically developed countries make a greater effort to enhance their domestic R&D and human capital stocks. Needless to say, the implications of our results for economic policy in less-developed countries are evident.

APPENDIX 1:

The variables included in this paper and the sources used for their construction are set out below:

- **Real Gross Domestic Product at market prices**: it is calculated on the basis of OECD data: National Accounts. Volume I: Main Aggregates. For this purpose, we have taken 1990 as the base year and it is expressed in dollars.

- **Employment**: it is obtained from the OECD publication: National Accounts. Volume I: Main Aggregates.

- **Physical capital stock**: it is calculated on the basis of the accumulation of investment flows, in accordance with the perpetual inventory method. The initial stock of capital was estimated by means of the Harberger and Wisecarver (1977) procedure, using the gross fixed capital formation deflator as the price index. Lastly, the depreciation rates are taken from EUROSTAT (1997). The Gross Fixed Capital Formation series and their deflators are obtained from the OECD: National Accounts. Volume I. Main Aggregates.

- **R&D capital stock**: it is elaborated on the basis of the accumulation of R&D expenditures, using the perpetual inventory method and assuming a depreciation rate of 10%. The data used is taken from OECD: Research and Development Expenditure in Industry; OECD: Basic Science and Technology Statistics; OECD: Main Science and Technology Indicators.

- **Human capital stock**: it is calculated according to the methodology proposed in Martín, Velázquez and Funck (2001). This procedure is similar to that by Barro and Lee (1993, 2000) but it takes into account the existence of quality differences between educational levels and tries to capture them by using the differences in expenditure per student:

$$H_t = \sum_{i=1}^{3} GPE_{i,1995} \cdot DUR_{i,t} \cdot PNE_{i,t}$$

where: $GPE_{i,1995}$ is the public and private expenditure per student at educational level i in relation to the total education cost of a university student at the average for the OECD in 1995, considering all the educational levels that he/she has had to complete to obtain his/her degree.

$DUR_{i,t}$ is the duration pertaining to educational level i in year t.

$PNE_{i,t}$ is the percentage of population between the age of 25 and 64 that has completed educational level i in year t.

- **<u>Domestic Stock of technological knowledge</u>:** it is calculated by means of the procedure of principal components, so that we necessarily obtain as the result a single component, which gives an adjusted R^2 of 0.92. Specifically, the combination obtained is:

$$T_{it} = 0{,}398 \cdot H_{it} + 0{,}917 \cdot RDK_{it}$$

where: H_{it} is the human capital stock per employee divided by mean.

RDK_{it} is the R&D capital stock per employee divided by mean.

- **<u>Imports</u>:** they are obtained from the OECD publication: Monthly Statistics of Foreign Trade.

APPENDIX 2

Relationship between elasticities associated with the means of the spillovers without size bias correction ($e_{Y,S^{LP}}$) and elasticities of corrected spillovers ($e_{Y,S^{CMV}}$).

Rank of countries according to real GDP	$e_{Y,S^{LP}} / e_{Y,S^{CMV}}$
U.S.A.	0.42
Japan	0.32
Germany	0.60
France	0.75
Italy	0.79
United Kingdom	0.82
Canada	0.98
Spain	1.01
Australia	1.09
Korea	1.09
The Netherlands	1.11
Mexico	1.10
Sweden	1.13
Switzerland	1.14
Belgium-Luxembourg	1.14
Austria	1.17
Turkey	1.15
Denmark	1.18
Finland	1.17
Norway	1.18
Greece	1.21
Portugal	1.21
Poland	1.19
Ireland	1.21
New Zealand	1.22
Hungary	1.21
Czech Republic	1.21
Iceland	1.24

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