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INTERNATIONAL TECHNOLOGY SPILLOVERS FROM TRADE: THE IMPORTANCE OF THE TECHNOLOGICAL GAP

JORGE CRESPO
CARMELA MARTÍN
FRANCISCO J. VELÁZQUEZ
Universidad Complutense de Madrid

This paper analyses two significant and to date open issues regarding the role of trade as a channel for international technology spillovers. The first refers to its relative impact on growth in comparison to that of own R&D spending. The second has to do with the importance of the technological gap to take advantage of foreign technology. For this purpose we estimate a version of the growth model proposed by Benhabib and Spiegel (1994), which includes some modifications to better capture the technology diffusion process. Our results first suggest that domestic R&D and human capital stocks are critical for foreign technology adoption. Secondly, they indicate that richer countries are more successful in taking advantage of international technology spillovers.

Keywords: Technology diffusion, trade, growth.

(*JEL* O0, F4)

1. Introduction

Recent endogenous growth models provide us with new insights into the relationship between trade and growth[1]. In this respect, the improvements in the analysis of the role of trade as a channel for the

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[1] A representative sample of this literature may be found in Grossman and Helpman (1991), Grossman and Helpman (1995) and Temple (1999).

diffusion of technology and its impact on growth deserve a special mention. Despite this, a significant debate about two important and related issues is still open: firstly, the importance of international technology spillovers versus own R&D spending, and secondly, the relative importance of the technological gap in taking advantage of foreign technology. In principle, one may think of two opposing effects. On the one hand, it may be expected that without barriers to technological diffusion, the higher the technological gap of a country, the greater the potential impact on growth of foreign technology spillovers[2]. On the other hand, however, one may also expect that the higher the technological gap, the lower will be the country's absorptive capacity[3], which is defined as the extent to which foreign technology is incorporated into the domestic production system. The latter is of great importance given that it would be contrary to the aggregate convergence hypothesis predicted by development theories that rely on trade as a mechanism of diffusion of technology (see Lucas, 2000).

The goal of this paper is to try to assess the extent to which the degree of development of countries affects their capacity to adopt foreign technologies. In this sense, we have chosen the OECD countries because, contrary to the less developed ones, all of them undertake technological activities. Thus, this is a suitable area to assess the importance of international bilateral spillovers between countries with different domestic R&D intensities[4]. In this respect, note that in the OECD countries both per capita GDP and R&D effort show wide ranges: \$5,800 to \$36,500 and 0.4 to 4.4 in 2001, respectively.

This paper differs from previous studies of technology diffusion in an important way: it explicitly specifies international technology spillovers not only from the most R&D intensive countries to the rest, as is usual in the literature, but also in the other direction[5], trying to asses their possible different impacts on growth. In this respect, and at least in the context of the OECD countries, it is reasonable to expect that the latter is likely to occur.

[2] This is what Gerschenkron (1962) and Kuznets (1973) call the 'advantage of backwardness' and refers to the advantage of being a technological laggard in 'borrowing' new technology from leading edge countries.

[3] See Nelson and Phelps (1966) and Benhabib and Spiegel (2002).

[4] It should be noted the difficulties of testing for spillovers coming from developing countries to develop ones.

[5] Coe and Helpman (1995) allowed for spillovers in both directions, but they didn't assess the specific contribution of each kind of spillover to economic growth.

The remainder of this paper is organized as follows. In the next section, we explain the procedure for testing for the presence of international technology spillovers and the different measures of spillovers. In Section 3, we present the results of our panel estimations for the OECD countries. Finally, in Section 4, we offer a brief summary and some final remarks.

2. Assessing the impact of spillovers on economic growth

A number of different approaches have been employed to study empirically the importance of international technology diffusion. They usually build on R&D driven growth models that allow for the expansion in either the variety or the quality of intermediate inputs[6]. In an open economy framework, one source of growth is technology diffusion, which takes place through the employment of specialized and advanced intermediate products that have been invented abroad. The most frequent method consists of using a production function approach to relate Total Factor Productivity (TFP) to measures of domestic and foreign R&D activities[7]. We start from the specification of TFP proposed by Benhabib and Spiegel (1994),

$$\triangle \log TFP_{it} = \delta + \varphi H_{it} + \mu H_{it} \left(\frac{y \max_t - y_{it}}{y_{it}} \right) + \varepsilon_{it} \qquad [1]$$

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. Thus, human capital and the technological gap are the engines of growth in this model. Human capital would therefore be a determinant both of the technological progress generated endogenously – the second term of the above expression (Romer, 1990) – and of the absorptive capacity of foreign technology – the third term of the above expression (Nelson and Phelps, 1966) –. International technology spillovers are measured as the per capita income differentials with respect to the leading country[8].

[6] See Romer (1990), Grossman and Helpman (1991, chapters 3 and 4) and Aghion and Howitt (1992). A broader perspective on the topic may be found in Aghion and Howitt (1998).

[7] See Mohnen (2001).

[8] In a recent paper Benhabib and Spiegel (2002) specify the diffusion process in a different way, in which diffusion gets weaker as the distance betweeen the follower and the leader increases. Indeed, if human capital stock of a follower is sufficiently low, this kind of process implies that productivity growth in the follower country may never catch up with the leader.

Although this model is of great interest from an empirical point of view because of 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 the absorptive capacity of foreign technology are not only influenced by human capital but also – as shown in Cohen and Levinthal (1989) and Griffith *et al.* (2000) – by domestic R&D capital (RDK). Thus, it would be more reasonable to include both factors in the specification. Another questionable issue in the model of 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 limitation, in this paper we include a direct measure of international technology spillovers (S). So, we employ the following specification

$$\triangle \log TFP_{it} = \delta + \varphi_1 H_{it} + \varphi_2 RDK_{it} + \mu_1 H_{it} S_{it} + \mu_2 RDK_{it} S_{it} + \zeta_{it} \quad [2]$$

This specification would, however, produce problems with multicollinearity as human and R&D capital stocks are highly correlated (correlation coefficient is 0.75). A possible solution to this problem consists of using an alternative specification where both variables are aggregated into a single one[9]. In this sense, we calculate the domestic stock of technological knowledge of each economy (T) as a combination of the human and R&D domestic capital stocks[10].

$$\triangle \log TFP_{it} = \delta + \varphi T_{it} + \mu T_{it} S_{it} + \xi_{it} \quad [3]$$

In order to explore the extent to which the success of foreign technology adoption is influenced by the technological gap, international spillovers are broken down into two parts: one that only includes imports with a higher technological content than the recipient country (S^H), and another one that includes imports with a similar or lower technological content (S^{SL}). The former comes exclusively from more

[9] Note that there is evidence on the complementary nature of human and R&D capital stocks (Lloyd-Ellis and Roberts, 2002). This variable approaches in some way the theoretical concept proposed by Romer (1990).

[10] Note that we are assuming that $T_{it} = [(\varphi_1/\varphi)\, H_{it} + (\varphi_2/\varphi)\, RDK_{it}]$ and $T_{it} = [(\mu_1/\mu)\, H_{it} + (\mu_2/\mu)\, RDK_{it}]$, thus, we introduce the restrictions: $\varphi_1/\varphi = \mu_1/\mu$ and $\varphi_2/\varphi = \mu_2/\mu$. However, this construction imposes the restriction that both types of capital are substitutes. In this sense, we employ a different specification of T_{it} that has the advantage of allowing both factors to be complements or sustitutives (see the Appendix for further details on the construction of this variable).

R&D-intensive countries and are therefore more likely to contribute to technological catch-up. In this sense, we would expect a higher coefficient associated to S^H than to S^{SL}. Consequently, the specification of the model would be,

$$\triangle \log TFP_{it} = \delta + \varphi T_{it} + \mu_1 T_{it} S_{it}^H + \mu_2 T_{it} S_{it}^{SL} + \zeta_{it} \qquad [4]$$

In addition, we may expect spillovers to have a differential impact on growth in the short-run and long-run. Thus, it seems interesting to analyze the dynamic nature of the relationship between TFP and international spillovers. Adopting an autoregressive representation for the variables in equation [4], we obtain,

$$\triangle \log TFP_{it} = \alpha \triangle \log TFP_{it-1} + \delta^{sr} + \varphi^{sr} T_{it} + \mu_1^{sr} T_{it} S_{it}^H + \mu_2^{sr} T_{it} S_{it}^{SL} + e_{it} \qquad [5]$$

We can estimate the long-run coefficients from equation [5] employing the usual formulas: $\varphi^{lr} = \varphi^{sr} / (1-\alpha), \mu_1^{lr} = \mu_1^{sr} / (1-\alpha), \mu_2^{lr} = \mu_2^{sr} / (1-\alpha)$[11]. In this respect, it should be observed that the elasticities associated both with the domestic stock of technological knowledge ($\varepsilon_{TFP,T}$) and the international technological spillovers that are transmitted through imports ($\varepsilon_{TFP,S^M}, \varepsilon_{TFP,S^R}$) may be calculated in an easy way given the functional form used. Specifically, the values of these elasticities in the mean of the variables (variables with bars) would be:

$$\varepsilon^i_{\triangle TFP,T} = \left(\varphi^i + \mu_1^i \bar{S}^H + \mu_2^i \bar{S}^{SL}\right) \bar{T} \qquad with\ i = sr,\ lr \qquad [6]$$

$$\varepsilon^i_{\triangle TFP,S^H} = \mu_1^i \overline{TS}^H \qquad with\ i = sr,\ lr \qquad [7]$$

$$\varepsilon^i_{\triangle TFP,S^{SL}} = \mu_2^i \overline{TS}^{SL} \qquad with\ i = sr,\ lr \qquad [8]$$

International technology spillovers are usually specified as the foreign R&D stock that an economy can benefit from. The typical approach consists of estimating it as a weighted sum of other countries' R&D stocks (Griliches, 1979), where the weights capture the assumed channel of technology diffusion. Following the influential paper by Coe and Helpman (1995), many studies use import shares as weights[12].

[11] As shown by Wickens and Breusch (1988), these expressions result in the same value of the long run coefficients that would have been reached from the instrumental variable estimation of the long run equation with the set of instruments given by all explanatory variables in the original equation.

[12] See Keller (2000), Xu and Wang (1999), Lumenga-Neso *et al.* (2001). Another channel of transmission of technology spillovers, though rather less exploited and

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 to GDP as weights[13],

$$S_{it}^{CH} = \frac{m_{i.t}}{Y_{it}} \log\left(\sum_{j\neq i} \frac{m_{ijt}}{m_{i.t}} RDK_{jt}\right) \qquad [9]$$

where RDK is the R&D capital stock of the technology supplier countries, m_{ijt} the imports into country i from country j, $m_{i.t}$ the total volume of imports of country i, and Y_{it} the GDP of country i. This measure can be interpreted as the R&D capital stock of the average trading partner.

Lichtenberg and Van Pottelsberghe (1998) show that this specification suffers from bias caused by the level of disaggregation of data for trading partners. Thus, they propose an alternative measurement (S) in order to overcome it,

$$S_{it} = \sum_{j\neq i} m_{ijt} \frac{RDK_{jt}}{Y_{jt}} \qquad [10]$$

This indicator measures the technological content of imports. We choose to use the latter indicator as the measure of international technology spillovers[14], expressed - as the stock of technological knowledge - in terms of employment. Nevertheless, as argued previously, we break down spillovers for every country and every year between those with a higher technological content than the recipient country (S^{H}) and those with a lower or similar technological content (S^{SL}). We expect

without conclusive results to date, is foreign direct investment. In Blomström and Kokko (1998) and Saggi (2002) may be found surveys of existing literature on this issue.

[13] This type of weighting scheme is criticized by Keller (1998) who found that regressions based on random shares generated similar results than those obtained by Coe and Helpman (1995). However, Coe and Hoffmaister (1999) noted that Keller's bilateral import shares were not in fact random.

[14] Falvey *et al.* (2002) study the importance of treating knowledge either as a private good – Coe and Helpman (1995) – or a public good in the recipient countries – Lichtenberg and Van Pottelsberghe (1998) –. They conclude that spillovers, if they exist, act as a public good in the recipient countries.

the former would contribute to a greater extent to technological catch-up. So, the spillovers term is as follow,

$$S_{it} = S_{it}^{H} + S_{it}^{SL} = \left[\sum_{\substack{j \neq i \\ j \in M}} m_{ijt} \left(\frac{RDK_{jt}}{Y_{jt}} - \frac{RDK_{it}}{Y_{it}} \right) \right] + \left[\sum_{\substack{j \neq i \\ j \in R}} m_{ijt} \frac{RDK_{jt}}{Y_{jt}} + \frac{RDK_{it}}{Y_{it}} \sum_{\substack{j \neq i \\ j \in M}} m_{ijt} \right] \quad [11]$$

where M is the set of more R&D-intensive countries than country i in year t, and R refers to the remaining set of countries[15]. The first term in square brackets captures the higher technological content of imports coming from more R&D-intensive countries[16]. The second term reflects the rest of the spillovers.

3. Data, econometric estimation and results

Our data consists of 28 OECD countries – with Belgium and Luxembourg being aggregated and the Slovak Republic not included – over the period 1988-1998. Data are from the OECD National Accounts (Vol. 1). R&D expenditure data are obtained from the OECD Main Science and Technology Indicators, and imports from the OECD International Trade by Commodities Statistics[17]. Finally, TFP has been estimated using a parametric approach[18].

The different specifications of the model proposed are estimated using panel data techniques that take into account the existence of individual

[15] The R&D intensity is approached as the ratio between the R&D capital stock and GDP. Thus, for every country i M are those countries with a higher ratio than i and the opposite for R.

[16] The higher technological content of imports is calculated as the difference between the R&D intensity of the trading partner and domestic R&D intensity, multiplied by the volume of imports.

[17] For more details see the Appendix. Data may be obtained through individual request to authors.

[18] Specifically, we have estimated TFP as the Solow residual obtained from a Cobb-Douglas production function log-differenced, using second and third lags of the explanatory variables as instruments in a GMM estimation of the model transformed in orthogonal deviations. The result obtained was: $\triangle \log Y = 0.35 \triangle \log K + 0.63 \triangle \log L$, where both coefficients are individually significant with a confidence level of 5%. Moreover, we can not reject the null hypothesis of constant returns to scale.

effects – specific features of each country such as legislations or cultural aspects – possibly correlated with the explanatory variables[19]. In order to cope with the likely problem of simultaneity between the growth of output and R&D investment and/or human capital, we estimate the model using Instrumental Variables (IV) techniques. Given the difficulty of finding suitable external instruments, we follow the standard solution of using the lags of the explanatory variables as instruments in a GMM estimation of the model transformed in orthogonal deviations[20] (Arellano and Bover, 1995).

The results of estimating dynamically equation [2] are reported in the first column of Table 1. The obtained coefficients are significant and have the expected sign in the case of human capital and spillovers when the R&D capital stock is employed as indicator of the foreign technology absorptive capacity of the economy. However, the coefficient associated to the R&D capital stock has a negative sign and the spillovers are insignificant when the human capital stock is employed as indicator of the foreign technology absorptive capacity of the economy.

This finding is surprising inasmuch as the R&D capital stock should have a positive effect on the TFP growth of the economy. This leads us to suspect that what we are detecting may be a problem stemming from the possible presence of colinearity between human and R&D capital stocks, as indicated in previous section. We have therefore repeated the estimation using each of these variables separately (see columns 2 and 3 in Table 1). The results show a positive and significant impact in both cases. This therefore appears to confirm the existence of a multicollinearity problem[21]. In order to cope with this problem we have followed the solution proposed in Section 2 employ-

[19] 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. 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 tested afterwards.

[20] Unlike first differencing, which introduces a moving average structure in the error term, this transformation preserves a lack of correlation between the transformed errors if the original ones are not autocorrelated and have constant variance.

[21] In this respect, examination of the correlations matrix shows that there is a high correlation between human and R&D capital stocks. Moreover, following Goldberger (1991) we have regressed every explanatory variable against a constant and the remaining explanatory variables. The results seem to confirm the multicollinearity problem given the high R^2 obtained.

TABLE 1
TFP Growth Regressions[1]

Explanatory Variables	(1)	(2)	(3)	(4)	(5)	(6)
TFP_{t-1}	0.0188	0.1330***	0.1627***	0.1381**	0.1411***	0.2051***
	(0.0780)	(0.0455)	(0.0631)	(0.0615)	(0.0449)	(0.0160)
Human capital stock	0.0634**	0.0240**	-	-	-	-
	(0.0274)	(0.0098)				
R&D capital stock	-0.0386***	-	0.0063**	-	-	-
	(0.0098)		(0.0030)			
Knowledge	-	-	-	0.0154***	0.0134***	0.0061**
				(0.0035)	(0.0036)	(0.0030)
Human capital stock x Spillover	-0.0141	0.0030***	-	-	-	-
	(0.0102)	(0.0008)				
R&D capital stock x Spillover	0.0225***	-	0.0035***	-	-	-
	(0.0058)		(0.0007)			
Knowledge x Spillover	-	-	-	0.0011**	0.0027***	-
				(0.0005)	(0.0010)	
Spillover	-	-	-	-	-0.0040	-
					(0.0026)	
Knowledge x Spillovers with higher technological content	-	-	-	-	-	0.0048***
						(0.0016)
Knowledge x Spillovers with similar or lower technological content	-	-	-	-	-	0.0034***
						(0.0010)
Sargan's test (degrees of freedom)	25.85 (20)	21.94 (21)	23.83 (20)	24.51 (20)	24.55 (20)	25.77 (22)
M1	1.23	0.31	0.09	0.39	0.36	-0.46
M2	0.77	0.62	0.69	0.68	0.69	0.88

Note: standard errors in brackets. Confidence level: * 10%, ** 5%, *** 1%. M1 and M2 are tests for the lack of first-order and second-order serial correlation in the residuals.
Instruments used for:
(1) are TFP_{t-3}, Human capital $stock_{t-1}$, Human capital stock x $spillover_t$, R&D capital stock x $spillover_t$.
(2) are TFP_{t-3},TFP_{t-4}, Human capital $stock_{t-1}$, Human capital stock x $spillover_t$.
(3) are TFP_{t-3}, R&D capital $stock_{t-1}$, R&D capital stock x $spillover_t$.
(4) are TFP_{t-3}, $Knowledge_{t-2}$, Knowledge x $spillover_t$.
(5) are TFP_{t-3}, $Knowledge_{t-3}$, Knowledge x $spillover_t$, $Spillover_t$.
(6) are TFP_{t-3}, $Knowledge_{t-3}$, KnowlxSpill with higher technological $content_{t-1}$, KnowlxSpill with similar or lower technological $content_{t-1}$.
[1] Variables expressed in orthogonal deviations.

ing principal components analysis to group human and R&D capital stocks into a single variable called the domestic stock of technological knowledge (see the Appendix for a more detailed explanation about the construction of the this variable).

We have therefore repeated the estimations considering the domestic stock of technological knowledge (column 4 in Table 1). The coefficients show the expected signs. However, in this case there is the imposed restriction that the domestic stock of technological knowledge interacts with spillovers. But it is important to test whether or not spillovers affects TFP growth directly, because if the answer is yes the omission of this variable would yield biased coefficients. Thus, we have included spillovers as an additional regressor (column 5 in Table 1). The results point to an impact of spillovers through the absorptive capacity of the recipient economy.

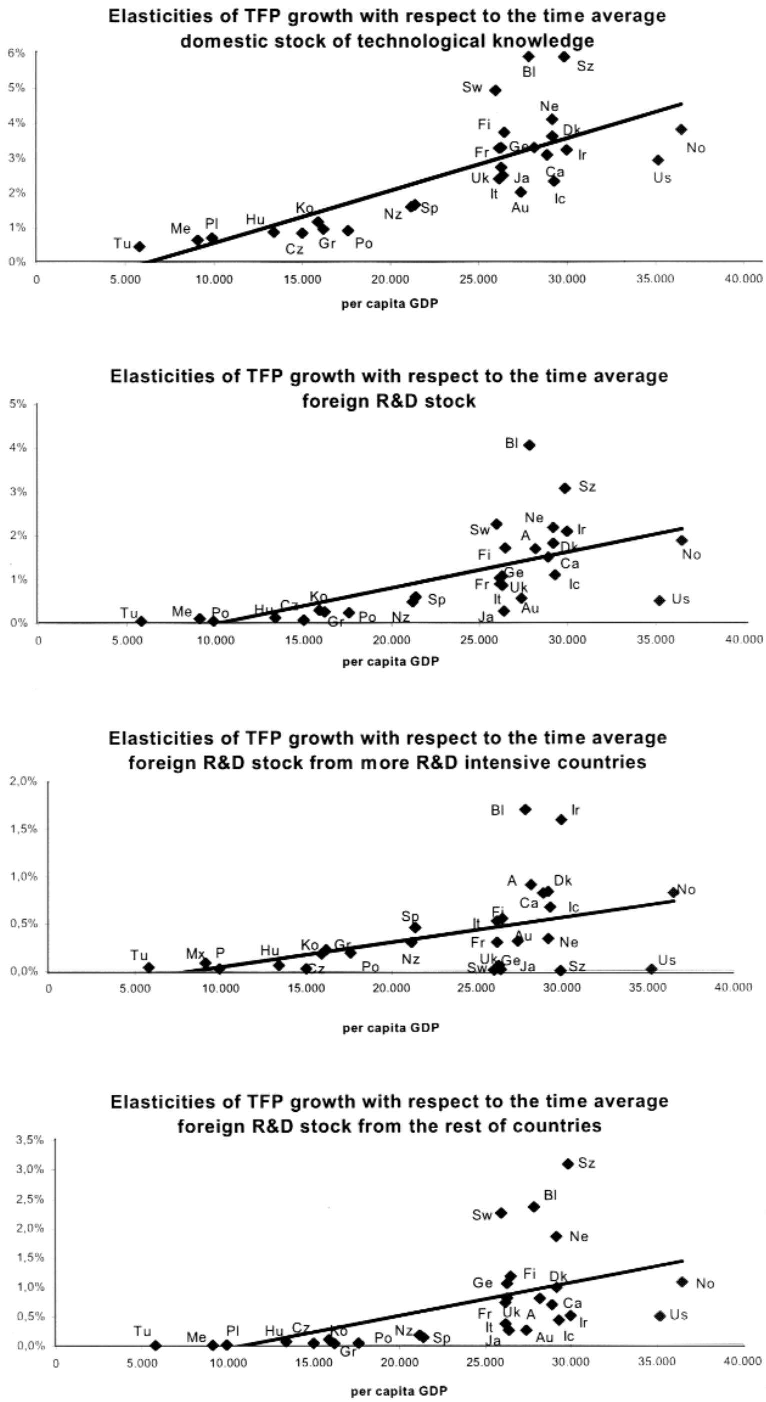
In the last column we report the results corresponding to the breakdown of spillovers into those with a higher technological content (S^H) and those with a similar or lower technological content (S^{SL}). The estimated coefficients are again significant and have the expected sign. It is important to point out that the domestic stock of technological knowledge has a much higher output elasticity than the foreign R&D capital stock (see Table 2). Although this is an expected result given that it is obtained from a sample of developed countries, recent work has shown that the major sources of technical change leading to productivity growth in OECD countries are not domestic[22]. However, the most remarkable and rather unexpected result here is the similarity between the elasticity of the spillovers coming only from countries with a higher R&D intensity and those coming from countries with a similar or lower R&D intensity[23].

TABLE 2
Elasticities of TFP Growth (in %).

	Short-run		Long-run	
Domestic stock of technological knowledge ($\mathcal{E}_T$)	3.25	1.97	3.77	2.48
Foreign R&D capital stock ($\mathcal{E}_S$)	0.22		0.25	
Foreign R&D capital stock with higher technological content ($\mathcal{E}_{S^H}$)		0.34		0.43
Foreign R&D capital stock with similar or lower technological content ($\mathcal{E}_{S^{SL}}$)		0.44		0.55

[22] Coe and Helpman (1995), Park (1995), Eaton and Kortum (1999) and Keller (2002) show that output elasticities of foreign R&D are higher than those of domestic R&D in OECD countries. Keller (2000) however finds the opposite result.
[23] The restriction of equal coefficients associated to spillovers from more R&D intensive countries and those coming from similar or lower R&D intensive countries can not be rejected statistically.

FIGURE 1


Elasticities of TFP growth with respect to the time average domestic stock of technological knowledge
per capita GDP
Elasticities of TFP growth with respect to the time average foreign R&D stock
per capita GDP
Elasticities of TFP growth with respect to the time average foreign R&D stock from more R&D intensive countries
per capita GDP
Elasticities of TFP growth with respect to the time average foreign R&D stock from the rest of countries
per capita GDP

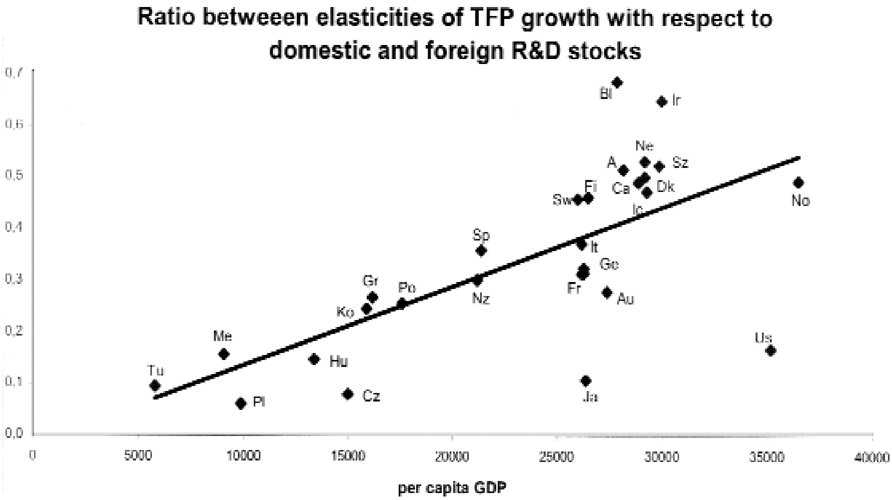
Indeed, as the domestic stock of technological knowledge and foreign R&D capital per employee differ from one country to another -and taking into account that the elasticity of these factors increases with their level (see Section 2)-, calculating each country's elasticity appears to be a matter of interest. For this we have used the expressions [6], [7] and [8] in the time average of the variables for each country. The results are displayed in Figure 1, where it is also included per capita GDP of countries in 2001. The findings are as follows. First, richer countries exhibit higher elasticities of the stock of technological knowledge. Second, although poorer countries have more potential for foreign technology spillovers, our results suggest that they cannot successfully translate them into higher TFP growth rates due to their lower absorptive capacity. Consequently, foreign technology diffusion through imports in the OECD have stronger effects on growth in the relatively rich than in the relatively poor countries.

The relative impact of spillovers with respect to the impact of the domestic stock of technological knowledge is also higher in the relatively rich countries (see Figure 2). Finally, we find that in the poorer countries, as expected, the relative impact of spillovers coming from more R&D-intensive countries is more important. Note that the disclosure of the individual country ratio of elasticities provides a reasonable explanation for the rather unexpected result obtained for the OECD average.

As a whole, our results are fairly consistent with those of previous studies that arrive at significant foreign R&D elasticities in OECD countries (Coe and Helpman, 1995; Nadiri and Kim, 1996; Lichtenberg and Van Pottelsberghe, 1998; Xu and Wang, 1999; Keller, 2000). However, the elasticities obtained are not directly comparable with those estimated in other studies based on modelizations similar to that of Coe and Helpman (1995), as the way the different stocks enter the production function is not as just another productive factor, but as determinant of the increase in aggregate efficiency (see Benhabib and Spiegel, 1994).

Before concluding, it is interesting to carry out a simple exercise of growth accounting in order to assess the specific contributions of both the domestic stock of technological knowledge and the foreign R&D stock channelled through imports to the increase in TFP growth. Moreover, to assess the different contributions of spillovers to the

FIGURE 2


Ratio betweeen elasticities of TFP growth with respect to domestic and foreign R&D stocks
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
0
5000
10000
15000
20000
25000
30000
35000
40000
per capita GDP
Bl
Ir
Ne
A
Sz
Ca
Dk
Fi
Sw
No
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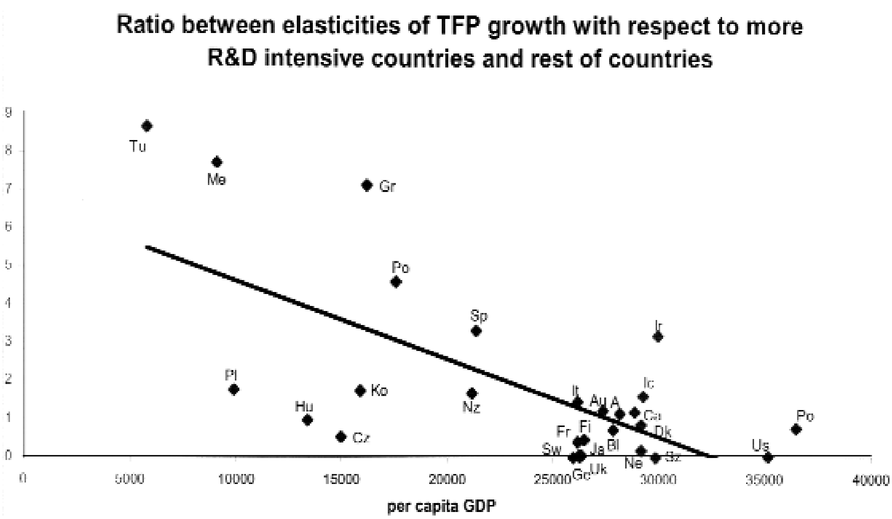
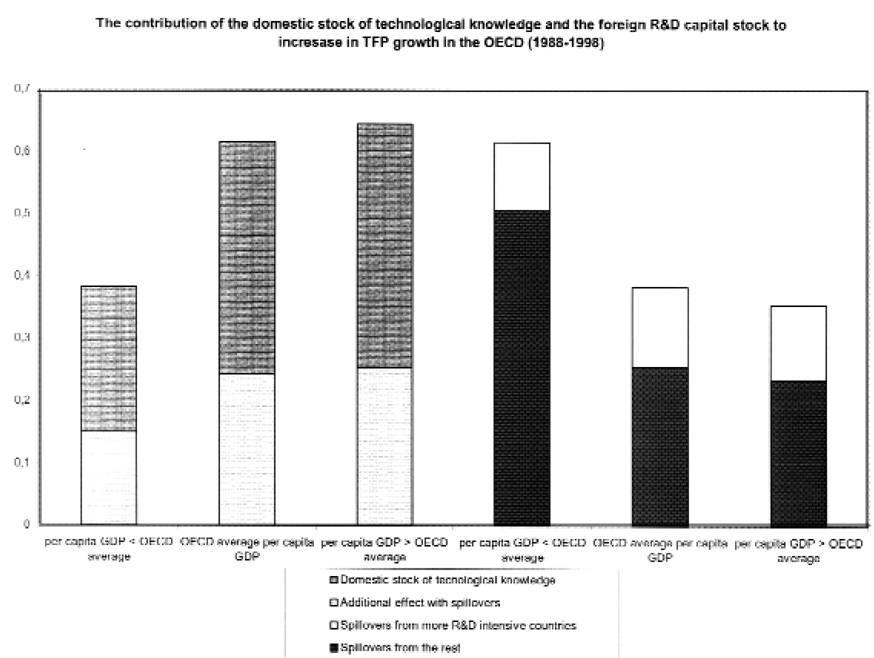

Ratio between elasticities of TFP growth with respect to more R&D intensive countries and rest of countries
9
8
7
6
5
4
3
2
1
0
0
5000
10000
15000
20000
25000
30000
35000
40000
per capita GDP
Tu
Me
Gr
Po
Sp
Ir
Pl
Ko
It
Ic
Hu
Nz
Au
A
Ca
Po
Fr
Fi
Dk
Cz
Sw
Ja
Bl
Us
Ne
Sz
Ge
Uk

growth of countries according to their per capita GDP, we have repeated this exercise dividing the sample into two groups; those countries with a per capita GDP level higher than the OECD average and those with a lower level. The results of this exercise are in Figure 3, where the first three bars represent the contribution of the domestic stock of technological knowledge to TFP growth, whereas the last three bars represent the contribution of foreign technology to TFP growth. 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 61.65% of the increase in TFP growth over the period) the contribution of foreign technology spillovers is also important, especially that coming from the rest of countries, which accounts for about 1/4 of the increase in TFP growth. These results are, however, different in the case of the poorer countries, where spillovers prove to be the major engine of the increase in TFP growth.

FIGURE 3



4. Summary and conclusions

This paper analyses the relevance of two key issues: one refers to the relative importance of international spillovers versus own R&D and human capital formation spending, while the other refers to the importance of the technological gap in obtaining gains from foreign technology. In this sense, if the domestic stock of technological knowledge is sufficiently low, productivity growth in the less advanced countries may never catch up with the advanced ones.

For this purpose we estimate a modified version of the growth model with endogenous technological change used in Benhabib and Spiegel (1994), in order to better capture the technology diffusion process. In particular, our specification takes into account not only the role of the domestic human capital, but also that of the domestic R&D capital stock (stock of technological knowledge) as determinants of the own generation of technology and the absorptive capacity of foreign technology. In addition, we introduce a direct measure of international technology spillovers channelled by trade that is broken down into two parts to capture the likely influence of the technological gap on the success of foreign technology adoption.

Our results show that growth is more influenced by the domestic R&D and human capital stocks than by foreign technology. In this respect, this paper finds that spillovers affect TFP growth not directly, but through the absorptive capacity of the economy. However, the most remarkable and rather unexpected result here is the similarity of the elasticities associated to the spillovers coming from countries with a similar or lower R&D intensity and to those coming from more R&D intensive countries. Finally, our results suggest that richer countries are more successful in taking advantage of international technology spillovers, i.e., although the technological gap provides greater potential for foreign spillovers, it restricts their successful profiting in terms of growth.

Appendix

· *Physical capital stock:* calculated from private productive investment flows based on the perpetual inventory method. The initial stock refers to 1960, it 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).

· *R&D capital stock:* calculated on the basis of accumulated R&D expenditures, using the perpetual inventory method and assuming a depreciation rate of 10%. The initial stock refers to 1973.

· *Human capital stock: calculated according to:*

$$H_t = \sum_{i=1}^{3} GPE_{i,1995} \cdot DUR_{i,t} \cdot PNE_{i,t} \qquad [A.1]$$

where: $GPE_{i,1995}$ is the public and private expenditure per student at educational level i in relation to the average total education cost of a university student 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.

· *Domestic stock of technological knowledge:* calculated as a combination of the stocks of human capital per worker (H) and technological capital per worker (RDK). For this purpose, we have applied the principal components procedure to both variables expressed in logarithms. This specification has the advantage that both factors may be complements or substitutes instead of imposing the restriction of being substitutes as in the case of using a linear combination of the variables expressed in levels. The result is:

$$T_{it} = H_{it}^{0.380} RDK_{it}^{0.925} \qquad [A.2]$$

where: H_{it} is the human capital stock per employee divided by the sample mean. RDK_{it} is the R&D capital stock per employee divided by the sample mean.

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Resumen

Este trabajo analiza dos aspectos fundamentales relacionados con el comercio como canal de difusión de la tecnología. El primero, se refiere a la importancia que tiene la tecnología foránea frente a la desarrollada en el propio país para el crecimiento económico. El segundo, tiene que ver con la relevancia del gap tecnológico para asimilar el conocimiento técnico exterior. Para ello, se emplea una versión modificada del modelo de crecimiento propuesto por Benhabib y Spiegel (1994) que capta de forma explícita el canal de difusión de la tecnología. Nuestros resultados sugieren que los stocks de capital humano y tecnológico son cruciales para asimilar las técnicas foráneas. Además, se pone de manifiesto el mayor éxito en la asimilación de tecnología de los países más avanzados.

Palabras clave: Difusión de tecnología, comercio, crecimiento.

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