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THE ROLE OF INTERNATIONAL TECHNOLOGICAL SPILLOVERS IN THE ECONOMIC GROWTH OF THE OECD COUNTRIES[(*)]

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Abstract

This paper explores the role of imports as a mechanism of transmission of international technological spillovers and the significance of these for the growth and economic convergence of the OECD countries. For this purpose a growth model is estimated that includes amongst its determinants a measure of the stock of technological knowledge. The results reveal first that international technological spillovers transmitted through imports have had a favourable influence on the economic growth of the OECD countries, Secondly, they suggest that the capacity of countries to take advantage of those spillovers depend on their own human and R&D capital endowments.

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Key words: International Technological Spillovers, Foreign Trade, Growth, OECD.

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1. Introduction

The wealth of literature that has appeared on economic growth since the mid-eighties has brought with it renewed interest in numerous related issues[1]. Amongst these we single out the one that deals with the influence of trade on the growth of the countries and, therefore, on the possibility that convergence processes may take place in their per capita incomes. In this respect, the models that recognise that technology differs between countries and has an endogenous nature are the ones in particular that have emphasised the importance of trade for growth through underlining their potential role as a channel of transmission of international technological spillovers[2].

Thus, it may be argued that trade facilitates imitation and adoption of the technical knowledge possessed by trading partners. In spite of the recent increase in the empirical work[3] on the issue, our knowledge of the scope of technological spillovers and the nature of the channels of transmission is still quite meagre. Thus, evidence on the extent to which technological spillovers are transmitted through imports is rather inconclusive. In this respect we do not know either, as would be desirable, the extent to which such technological spillovers contribute to the growth and convergence of the income of countries.

[1] A representative sample of this literature may be found in Barro and Sala-i-Martin (1995), Aghion and Howitt (1998) and Temple (1999).

[2] With this, reference is made to the positive externalities of international scope that appear to take place in technical knowledge and by which, therefore, the technical advances that occur in some countries may be propagated to others.

[3] See Coe and Helpman (1995); Coe, Helpman and Hoffmaister (1997); Engelbrecht (1997a,b); Keller (1998); Lichtenberg and van Pottelsberghe de la Potterie (1998) and Funk (2001) and references there in.

In this sense, this research is planned with the aim of enlarging the evidence on these matters. Specifically, its prime objective is to explore the possible contribution of the international technological spillovers which are transmitted through imports to the growth of the developed countries (the members of the OECD). To achieve this objective, the paper is structured in the following way. In section 2 we discuss the model of economic growth which is going to be estimated to assess the effect of spillovers. For this purpose we start off from the model used in Benhabib and Spiegel (1994), in which we introduce some modifications in order to better specify the nature of international knowledge diffusion. In section 3 we explain the way in which the international technological spillovers are going to be measured and we substantiate the advantages of the measure proposed compared with others used in previous studies. In section 4 we go on to estimate econometrically the model for a panel data set referring to the OECD countries and the period 1988-1998 and we comment on the results obtained. Finally, in section 5 we give a brief summary of the paper and its main conclusions, including some considerations about the implications for economic policy.

2. Theoretical model

In this paper we start off from a Cobb-Douglas production function, which uses the traditional productive factors, i.e.

$$\Delta \log Y_{it} = \Delta \log A_{it} + \alpha \cdot \Delta \log K_{it} + \beta \cdot \Delta \log L_{it} + \varepsilon_{it} \qquad (1)$$

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. In addition, technical progress is specified initially in the way proposed by Benhabib and Spiegel (1994):

$$\Delta \log A_{it} = \delta + \varphi \cdot H_{it} + \mu \cdot H_{it} \cdot \left(\frac{ymax_t - y_{it}}{y_{it}} \right) \quad (2)$$

where H is the stock of human capital per employee, *ymax* the level of per capita income of the leader country, and y the per capita GDP of the country analysed. The human capital would therefore be the determinant both of the technical progress generated endogenously (Romer, 1990) and of the capacity for assimilation of external technology (Nelson and Phelps, 1966)[4], approaching the technological gap here on the basis of the per capita income differentials.

In this way, substituting (2) at (1), the model would be:

$$\Delta \log Y_{it} = \delta + \varphi \cdot H_{it} + \mu \cdot H_{it} \cdot \left(\frac{ymax_t - y_{it}}{y_{it}} \right) + \alpha \cdot \Delta \log K_{it} + \beta \cdot \Delta \log L_{it} + \varepsilon_{it} \quad (3)$$

Although this model is of great interest from the empirical point of view for the way in which it expresses technological progress, it suffers from certain limitations that it is necessary to overcome. In this respect, it is to be expected that it is not only human capital that determines technical efficiency and, by extension, economic growth, but that this is also directly influenced by R&D capital. In this respect, we should note that, however, there is evidence of their complementary nature (Martín and Velázquez, 2001, Frantzen, 2000 or Lloyd-Ellis and Roberts, 2000). It therefore seems advisable to consolidate them in a single variable which somehow measures the stock of technological knowledge of each economy and which approaches the theoretical concept proposed by Romer (1986). In this way, the model would adopt the following expression:

$$\Delta \log Y_{it} = \delta + \varphi \cdot T_{it} + \mu \cdot T_{it} \cdot \left(\frac{ymax_t - y_{it}}{y_{it}} \right) + \alpha \cdot \Delta \log K_{it} + \beta \cdot \Delta \log L_{it} + \varepsilon_{it} \quad (4)$$

where the new variable T is the stock of technical knowledge per employee constructed as a linear combination of the human and R&D capital stocks.

A second limitation of the Benhabib and Spiegel (1994) model – especially with a view to the aims of this research – is that it refers to the technological convergence process between different economies without alluding to their causes. Indeed, the authors consider that per capita income is indicative of the level of technological development of a country, so that the per capita income gap in respect of the leader country addresses the extent to which a nation may take advantage of the existing technological advances by means of imitation – *catch-up* effect –[5]. The Benhabib and Spiegel (1994) model, however, does not explain the source of the international technological spillovers that lead to the catch-up processes between the per capita income levels of the countries.

Therefore, with a view to overcoming this second limitation, in this paper we have included a measure of international technological spillovers (*S*) based on the conjunction of two variables: the intensity and geographical structure of the imports and the technological capacity of the different countries of origin of these imports.

Accordingly, the model would finally be as follows:

$$\Delta \log Y_{it} = \delta + \varphi \cdot T_{it} + \mu \cdot T_{it} \cdot S_{it} + \alpha \cdot \Delta \log K_{it} + \beta \cdot \Delta \log L_{it} + \varepsilon_{it} \qquad (5)$$

It should be noted that given the functional form used – Cobb-Douglas – the elasticities associated with physical capital (α) and employment (β) are obtained directly. However, elasticities can also be calculated from the stock of national technological

[4] We should not forget, however, the importance of what Abramovitz (1994) called 'technological congruence' which basically indicates that countries that differ to a large extent from the leader as regards such features as offer of employment, market size, etc. may encounter difficulties in applying technology developed by the leader.
[5] Note that this approach means implicitly that the country with the highest level of per capita income - traditionally the U.S.A. – cannot benefit from the advances that may take place in other countries or, in other terms, that the economic leader is also the technological leader in all activities. An hypothesis that does not seen very plausible.

knowledge ($e_{Y,T}$) as well as from the term that reflects international technological spillovers ($e_{Y,S}$). Specifically, the values of these would be:

$$e_{Y,T} = \left(j + m \cdot S \right) \cdot T \tag{6}$$

$$e_{Y,S} = m \cdot T \cdot S \tag{7}$$

Consequently, the model assumes that elasticities vary directly in accordance with the stock of technological knowledge – human and R&D capital stocks – and with the magnitude of the spillover, which reflects the existence of rising performances in these two factors, so that growth is not exhausted. This is therefore the model that will be estimated, but before this we should explain and justify the proposal that is put forward here to approach international technological spillovers.

3. Measurement of international technological spillovers

As already mentioned in the introduction to the paper, one of the crucial matters in order to be able to assess the capabilities of countries to converge towards the income levels enjoyed by the most advanced economies is to ascertain the nature and channels of transmission of international technological spillovers. In this respect, in a good deal of the literature on economic growth that has appeared in the last few years efforts have been made to try and obtain a proper measurement of such spillovers. Unfortunately, we still do not have a satisfactory measure. When making a brief review of the measures used we have to begin by pointing out that spillovers may be of two types, intranational or international, depending on the geographical context considered[6]. The discussion below naturally focuses on the modelling of the latter type.

Now, international technological spillovers are usually identified with the foreign R&D that an economy can utilise. Thus, this is the sense of the term that has been used in some papers that have studied the effects of the existence of bilateral spillovers on growth, i.e. the elasticities of the output of a country in respect of the R&D capital stock of another[7]. Calculation of the foreign R&D capital, however, is not so immediate when, as in our case, we are considering a larger number of countries. In fact, the specification of some sort of weighting of the R&D capital stock of the other countries becomes unavoidable. In this respect, Griliches (1979) suggests using some measure of what he calls 'distance' as a weighting factor.

One way of implementing the proposal made by Griliches (1979) is that suggested initially by Jaffe (1986), and followed by Park (1995) and Branstetter (2001). The idea that these authors maintain is that spillovers depend on the 'technological proximity' presented by the companies, sectors or countries analysed. Thus, they use as an indicator of this proximity a vector where the different technological fields are represented, which is used afterwards as weighting for calculating the stock of foreign R&D capital. This methodology, however, suffers from the limitation of not explaining the channel of transmission of technology.

An alternative application of Griliches' (1979) proposal that does not suffer from the afore-mentioned limitation is that used in Coe and Helpman's (1995) influential paper, who

[6] Similarly, a distinction could be made between intrasectoral and intersectoral spillovers, depending on whether they occur between companies in the same sector or in different sectors. However, since the important thing in this paper is to assess the aggregate role played by international spillovers in growth such a distinction is unnecessary.

[7] See, for instance, Bernstein and Mohnen's (1998) paper for the case of the bilateral spillovers between the U.S.A. and Japan.

contend that the channel of transmission of spillovers is trade[8]. Accordingly, they define the foreign R&D capital stock (S) as the sum of the R&D capital stock of the supplier countries, weighted by their share on total imports:

$$S_{it} = \sum_{j \neq i} \frac{m_{ijt}}{m_{i.t}} \cdot SKT_{jt} \tag{6}$$

where SKT is the stock domestic R&D capital stock, m_{ijt} the imports made by country i from country j, $m_{i.t}$ the total volume of imports made by country i.

Nevertheless, in order to overcome some criticism foreign R&D capital stock obtained in the above way has been relativized by the weight of total imports over the GDP. With this they can capture the influence not only of the structure of imports, but also of their volume[9]. Therefore, the final proposal they put forward is, in logarithmic terms:

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

We should bear in mind, however, that this specification does not allow us to address another very important aspect: the technological intensity of the trading partner[10].

Furthermore, construction of the foreign R&D capital stock in this way has other drawbacks that have to be considered. In this respect, Jacobs, Nahuis and Tang (1999) point out a problem in the type of weighting used. Thus, they warn that a sudden change in

[8] Another channel of transmission of technological spillovers, though rather less exploited and without conclusive results to date, is direct international investment. To get an idea of the current state of research into the second channel, the survey conducted by Blomström and Kokko (1998) and the paper by Branstetter (2000) may be consulted.

[9] Similar measurements may be found in other papers, such as those by Engelbrecht (1997), Braconier and Sjöholm (1998) or Keller (1999).

[10] To appreciate this criticism, the following example may be useful: let us suppose that country A trades with country B or country C only, the R&D capital stock of B being twice that of C, while the GDP of B is three times that of C – as a result C is technologically more intensive than B –. However, if A made the same volume of imports from B and from C, by applying the measure put forward by Coe and Helpman (1995), the result obtained would be that the spillover received from trading with B only is higher than that received from trading with C only. However, in fact, the spillover received from C is higher through having a greater degree of technological intensity even though the same amount is imported in both cases.

the structure of imports could generate a significant alteration in the foreign R&D capital. This would be because this foreign stock is not calculated by capitalizing investments of the country in question, i.e. by considering the past, but by weighting what other countries possess at present. It should be borne in mind, however, that this criticism does not bear great importance when, as happens in this case, aggregate data are used of countries in which there is significant stability in the geographical pattern of imports.

A further problem in the measurement of foreign R&D capital proposed by Coe and Helpman (1995) is, as pointed out by Lichtenberg and Pottelsberghe (1998), that this measurement may be biased depending on the degree of disaggregation with which this information is available. These authors therefore put forward an alternative formula to minimise this bias in which the technological intensity of the exporting country is considered, i.e.:

$$S_{it} = \sum_{j \neq i} m_{ijt} \cdot \frac{SKT_{jt}}{Y_{jt}} \qquad (7)$$

where SKT_{jt} is the R&D capital stock of the country j, while Y_{jt} is the GDP of the country j.

Accordingly, in this paper we have opted for using the latter indicator as the measure of international technological spillovers, expressed - just as the stock of technological knowledge - in terms of employment.

4. Data, econometric estimation and results

The information used to estimate the model was obtained from the FUNCAS European Studies Programme Sectoral Data Base[11]. This data base combines several international statistical sources, mainly those from the OECD and EUROSTAT. The countries that make up the sample are the 28 of the OECD – Belgium and Luxembourg are aggregated – and the reference period is that running from 1988 to 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 the technical efficiency ratio is determined by specific features of each country – legislations, cultural aspects, 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 – as indicated by Arellano and Bond (1990) – in checking 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 contrast proposed by Arellano and Bond (1990), which – unlike Hausman's test –, is valid even if the errors are heteroscedastic and are auto-correlated[12].

In addition, there may be a problem of simultaneity between the growth of output and R&D investment – as is pointed out amongst other places in Griliches (1995) or Crespo and Velázquez (1999) – and/or human capital – as shown by Turrión and Velázquez (2000)–. To the extent that endogeneity biases appear in the explanatory variables it would be better to estimate the model using the instrumental variables method.

[11] The Appendix offers a detailed explanation of the original sources employed to construct the variables used in this study.

Finding suitable external instruments may however prove to be difficult. A standard solution, however, consists of using the lags of the explanatory variables as instruments for which it is necessary to estimate the model in orthogonal deviations, i.e. subtract the weighted value of its future mean from each variable.

Therefore, taking all these issues into account, we have proceeded first to check the validity of the model estimated by Benhabib and Spiegel (1994) for a set of countries – the 28 forming the OECD – with smaller differences between their factorial endowments than those arising in the sample of 78 countries that they use. The equation (3) is estimated accordingly. Since the Arellano and Bond (1990) contrast rejects the null hypothesis of absence of correlation between the explanatory variables and the individual effects, we have used the within estimator. As in the case of Benhabib and Spiegel (1994), the results obtained show a positive influence of human capital stock on economic growth, despite the fact that the term that proxies the catch-up effect is not significant. However, as may be appreciated, the error term is not white noise, as there is first order serial correlation, possibly caused by the afore-mentioned problem of simultaneity.

The use of instrumental variables enables us to overcome the above-mentioned problem, while Sargan's test validates the instruments employed. We thereby obtain – corroborating the results of Benhabib and Spiegel (1994) – that per capita income differential in respect of the leader has had a direct influence on the growth of the OECD countries.

[12] This contrast consists of forming a system of equations combining level equations and first-differences equations, while the equality of the level and first-differences coefficients is contrasted afterwards.

Table 1.- Estimation of the base model[1]

$$\Delta \log Y_{it} = d + j \cdot H_{it} + m \cdot H_{it} \cdot \left(\frac{Ymax_t - Y_{it}}{Y_{it}} \right) + a \cdot \Delta \log K_{it} + b \cdot \Delta \log L_{it} + e_{it}$$

Explanatory Variables	Within Estimation	Instrumental Variables[2]
H_{it}	0.0013 (3.33)	0.0006 (6.42)
H_{it}*catch-up	0.000005 (0.03)	0.0002 (2.14)
Δ log K_{it}	0.6934 (3.68)	0.4873 (8.06)
Δ log L_{it}	0.4759 (4.39)	0.6974 (19.09)
Number of countries	28	28
Years	11	11
Number of observations	308	308
Sargan's test (degrees of freedom)		23.51 (21)
M1	2.14	1.44
M2	1.35	0.53

t-ratio in brackets.
[1] Variables expressed in orthogonal deviations.
[2] The second log L_{it} lag and the third and fourth H_{it} lags are used as instruments.

In any case, and in order to improve the explanation, we have proceeded to estimate a new specification, which, instead of human capital, includes the technological knowledge stock as a linear combination – calculated by principal components – between human and R&D capital[13]. As happened in the previous case, we confirm the existence of individual effects correlated with the explanatory variables, so we have again used the within estimator.

The results of the estimation are set out in table 2. These show the positive and significant influence of the technological knowledge stock for economic growth. Again, however, we obtain a non-significant coefficient for the term that reflects catch-up, caused by

[13] Remember that the explanation referring to the construction of the variables used in the estimation is set out in the appendix.

the presence of first order serial correlation, which suggest the convenience of using the instrumental variables method to correct it.

As may be seen in the second column of table 2 the use of instruments, validated by Sargan's test, enables us, on the one hand, to correct the serial correlation and, on the other, to obtain a significant coefficient for catch-up.

Table 2.- Estimation of a version incorporating the stock of tecnological knowledge[1]

$$\Delta \log Y_{it} = \delta + \varphi \cdot T_{it} + \mu \cdot T_{it} \cdot \left(\frac{Ymax_t - Y_{it}}{Y_{it}} \right) + \alpha \cdot \Delta \log K_{it} + \beta \cdot \Delta \log L_{it} + \varepsilon_{it}$$

Explanatory Variables	Within Estimation	Instrumental Variables[2]
T_{it}	0.0012 (3.37)	0.0005 (5.63)
T_{it}*catch-up	0.00004 (0.22)	0.0002 (2.55)
Δ log K_{it}	0.7027 (3.61)	0.5017 (7.69)
Δ log L_{it}	0.4751 (4.38)	0.6863 (20.15)
Number of countries	28	28
Years	11	11
Number of observations	308	308
Sargan's test (degrees of freedom)		23.38 (21)
M1	2.13	1.45
M2	1.29	0.55

t-ratio in brackets.
[1] Variables expressed in orthogonal deviations.
[2] The second log L_{it} lag and the third and fourth T_{it} lags are used as instruments.

The final step has consisted of incorporating the stock of technological knowledge along with the importance of international spillovers indicator. The results of the estimation by instrumental variables – which may be seen in table 3 – indicate the importance that both factors have had in the economic growth experienced by the OECD countries during the period analysed. It is worthwhile drawing attention to the interest in this modelling, as it better reflects, both the nature of international technological spillovers and the channel by which they appear to be transmitted.

However, as the model estimated does not offer a direct measure of the elasticity of output associated with stocks of technological knowledge and with spillovers, we have proceeded to calculate it as described above. The results of this estimation are set out in table 3 and they underline a fact of great interest and significance for economic policy: the impact of the own stock of technological knowledge, with an elasticity of 3.46%, is much greater than that of international technological spillovers, with an elasticity of 0.33%[14].

[14] These results are in line with those obtained by Coe and Helpman (1995), Fagerberg and Verspagen (1999) or Jacobs, Nahuis and Tang (1999), who conclude that the impact of the stock of own technological capital is greater than that stemming from abroad. The elasticities obtained in this paper, however, are relatively lower, which may be explained by differences in the definition of certain variables, in the spectrum of countries considered and in the time period.

Table 3.- Estimation of the version using the stock of tecnological knowledge and the foreign R&D capital stock[1]

$$\Delta \log Y_{it} = \boldsymbol{d} + \boldsymbol{j} \cdot T_{it} + \boldsymbol{m} \cdot T_{it} \cdot S_{it} + \boldsymbol{a} \cdot \Delta \log K_{it} + \boldsymbol{b} \cdot \Delta \log L_{it} + \boldsymbol{e}_{it}$$

Explanatory Variables	Within Estimation	Instrumental Variables[2]
T_{it}	0,0012 (3,40)	0.0005 (2.08)
$T_{it}*S_{it}$	0,0000001 (0,04)	0.00004 (2.07)
Δ log K_{it}	0,6998 (3,60)	0.3197 (4.63)
Δ log L_{it}	0,4748 (4,37)	0.8225 (17.05)
Number of countries	28	28
Years	11	11
Number of observations	308	308
Sargan's test (degrees of freedom)		27.39 (21)
M1	2.14	1.23
M2	1.31	0.24
Calculation of the elasticities associated with the mean domestic stock of technological knowledge and foreign R&D capital per employee (%).		
$\boldsymbol{e}_{Y,T}$		3.46
$\boldsymbol{e}_{Y,S}$		0.33

t-ratio in brackets.
[1] Variables expressed in orthogonal deviations.
[2] The second log L_{it} lag and the second and third T_{it} lags are used as instruments.

The results obtained refer to the OECD as a whole. However, as the 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, calculating each country's elasticity appears to be a matter of interest. For this we have used the expressions of the elasticities defined in section 2 in the time mean of the variables for each country. The results are set out in table 4.

The values obtained corroborate the existence of increasing returns in the stock of technological knowledge - technological and human capitals stocks-. In fact, the countries with the lowest endowment of this type of capital -Turkey, Mexico, Portugal, Poland and Greece - show elasticities that do not exceed 1.6%, whereas the most advanced countries - U.S.A., Belgium-Luxembourg, Norway or Denmark, to mention a few - triple these values.

In addition, we obtain a very high correlation between import shares and the effect of technological spillovers on growth[15]. This result therefore provided new evidence as to the positive influence of imports on growth, suggesting, moreover, that the higher the technological capacity of the trading partners, the greater this influence will be.

[15] Specifically, the correlation coefficient between the relative amount of imports of each economy -Imports over GDP - and the elasticity of the technological spillovers is 0.86.

Table 4.- Elasticities associated with mean domestic stock of technological knowledge ($e_{Y,T}$) and foreign R&D capital per employee ($e_{Y,S}$) for the OECD countries (%)

Countries	$e_{Y,T}$	$e_{Y,S}$
Germany	4. 454	0.446
Australia	3.912	0.263
Austria	5.217	0.921
Belgium–Luxembourg	5.951	1.896
Canada	4.767	0.717
Korea	1.981	0.104
Denmark	5.390	0.904
USA.	6.176	0.270
Spain	2.957	0.228
Finland	3.666	0.478
France	4.473	0.485
Greece	1.596	0.075
The Netherlands	4.199	0.859
Hungary	1.620	0.032
Ireland	3.285	0.803
Iceland	2.686	0.397
Italy	3.702	0.319
Japan	4.041	0.134
Mexico	0.892	0.020
Norway	5.478	0.859
New Zealand	3.182	0.241
Poland	1.571	0.037
Portugal	1.449	0.078
United Kingdom	3.671	0.329
Czech Republic	1.866	0.028
Sweden	4.720	0.692
Switzerland	5.102	1.062
Turkey	0.452	0.003
Mean	3.516	0.453
Standard deviation	1.603	0.434

5. Summary and conclusions

The purpose of this paper is to advance in the knowledge of two questions of undoubted interest with evident implications for economic policy. The former of these refers to the importance and mechanisms of transmission of international technological spillovers for the economic growth of the developed countries (those making up the OECD). The latter, connected with the former, is the importance of such spillovers for economic convergence between them.

For this purpose, we have set out from the modelling initially proposed by Benhabib and Spiegel (1994), which is modified by means of introducing two fundamental changes. Thus, first of all, we have included the stock of technological knowledge – constructed as a linear combination of the R&D and human capital stocks – as a factor capable of influencing growth, both directly and indirectly: improving the capacity of absorption of foreign technology. Secondly, we have included an explicit measure of international technological spillovers which combines the technological capacity of the rest of the countries and the weight of the imports that are made from each one of them. The different specifications of the model are estimated by means of the panel data method for the 28 countries of the OECD – Belgium and Luxembourg are aggregated – and the period is that running between 1988 and 1998.

The results achieved reveal, first, the existence of international technological spillovers which have had a favourable impact on the economic growth of the OECD countries, albeit to a much lesser extent than the stock of own technological knowledge capital. Secondly, the paper provides additional evidence that support the role of imports as a channel of transmission of such spillovers. Finally, the most significant contribution of this study is perhaps that of showing that the capacity of countries to take advantage of the spillovers associated with the technical advances made by its trading partners largely depends on its own human and R&D capital endowments.

From the results obtained we may therefore draw certain implications for economic policy. Two seem to be more significant. The former is that the advisability of policies that encourage the opening-up of trade is endorsed. The latter is that support is given to the importance of educational and R&D policies for achieving potential improvements in productivity and growth entailed in international technological spillovers.

APPENDIX:

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 perpetuary 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 Beutel et al. (1992), Velázquez (1995) and 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 constructed on the basis of the accumulation of R&D expenses, using the perpetuary inventory method and assuming a depreciation rate of 10%. The use of R&D expenses as an indicator of the degree of technological development versus the number of patents used in other papers is due to the reasons set out in Crespo and Velázquez (1999). The data used are 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 (2000). It is an indicator that takes into account the existence of quality differences between educational levels using 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 European Union 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>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 0.87. Specifically, the combination obtained is:

$$T_{it} = 0{,}932 \cdot H_{it} + 0{,}932 \cdot S_{it}$$

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

S_{it} is the R&D capital stock per employee.

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

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