COMPLEMENTARITY BETWEEN HUMAN CAPITAL AND TRADE IN REGIONAL TECHNOLOGICAL PROGRESS

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Abstract: *The effect of openness and trade orientation on economic growth remains a highly contentious issue in the literature. Trade facilitates the spread of knowledge and the adoption of more advanced and efficient technologies, which hastens total factor productivity (TFP) growth and, hence, per capita income. New technologies that spread through trade require a sufficiently skilled labour force to adapt them to the domestic productive environment. Thus, openness and human capital accumulation will lead to TFP growth and the greater the complementarity between both variables, the higher the TFP growth. This paper discusses the implications of these assumptions and tests their empirical validity, using a pool of data for manufacturing industry in Spanish regions in a period in which both the stock of human capital and openness experienced a notable increase.*

Keywords: Trade, human capital, technological progress, industry.

1. INTRODUCTION

There is currently wide-ranging agreement in the literature regarding the fact that the accumulation of traditional production factors, capital and labour, is not sufficient to explain economic growth. From Solow's work (1957) onwards, output growth has been explained not in terms of the accumulation of production factors, but rather as a result of total factor productivity (TFP) growth. For this reason, a significant part of the literature on economic growth has concentrated on investigating the determinants of TFP growth. Endogenous growth models have analysed the importance of innovation as a factor stimulating productivity, and hence growth. In particular, the most recent contributions have emphasised the importance of domestic research and development efforts (R&D) and the spread of technology in order to explain productivity growth. For any given effort in R&D, the increased openness of an economy and its integration in its economic surroundings will thus increase its growth rate. The spread of ideas thus takes on an international character, with trade as one of the main channels by which this spread of technology takes place (Grossman and Helpman, 1991; Coe and Helpman, 1995; Coe et al, 1997).

Coe and Helpman (1995) place their empirical model within the framework of innovation-driven growth models. Their objective is to confirm that foreign technological innovation encourages domestic productivity. In particular, they aim to evaluate the indirect effects of the importing of goods and services that embody their trading partners' technology. The authors analyse a sample of OECD countries in such a way that the results obtained establish that both domestic and foreign efforts in R&D have a positive effect on productivity, confirming the existence of a process of international R&D diffusion, in which trade plays a significant role.

Another area of research within the framework of the new theories of endogenous growth focuses on the relationship between openness and commercial liberalisation and growth[1]. The underlying ideas for these models focus on greater openness facilitating an economy's access to new technologies and its adoption of more efficient production

[1] The relationship between openness and economic growth is a controversial area. While the new endogenous growth theories support the existence of a positive link between the two - Romer (1986), and Lucas (1988) - other authors - Krugman (1994) and Rodrik (1995) - remain skeptical about this relationship. Moreover, according to Rodriguez and Rodrik (1999), the empirical evidence does not enable conclusive results to be extracted.

techniques by means of its access to a greater variety of intermediate goods, which increase the productivity of domestic production factors. In this field, Holmes and Schmitz (2001) show that greater openness, stemming from a reduction in commercial tariffs, leads to a redistribution of resources by producers, from non-productive to productive activities, which results in greater total productivity and hence increased growth.

The exchange of goods also encourages the exchange of information and ideas between economic agents, that increases productive efficiency and the development of new technologies and competitive products demanded by clients, because of which it will indirectly affect the productivity level of the economy as a whole. For this reason, although most empirical literature which has analysed the relationship between the spread of technology through trade and productivity has concentrated on the role of imports as an effective channel for this spread, some recent contributions have remarked on the role of exports in this phenomenon. For example, Funk (2001) points out that these are also a way for making the exchange of ideas and technology possible. In particular, he emphasises the role of knowledge acquired from the relationship with clients when introducing innovations in the productive process and encouraging domestic productivity.

Another of the factors that has been considered as fundamental in explaining economic growth is the accumulation of human capital. From a neoclassical point of view, Mankiw et al (1992) extend Solow's model with the inclusion of human capital as a production factor as well as labour and physical capital. From the perspective of endogenous growth models, human capital has played a key role in understanding TFP growth, both in developed and developing economies. Nevertheless, the existing empirical evidence is not conclusive in confirming a positive and outstanding role for human capital in economic development. Problems with measuring this variable, as well as with the limited robustness of the results because of the presence of anomalous observations in some economies have been highlighted and could explain why results contrary to theoretical supposition have been obtained (Temple, 1999, 2001; de la Fuente and Doménech, 2000).

In the context of the subject under discussion here, Engelbrecht (1997) tests the robustness of the results concerning the influence of foreign and domestic R&D, introducing human capital as another determining factor in productivity. In this case, the results suggest that the concept of technological capital stock introduced by Coe and

Helpman (1995) is not broad-based enough to include innovation associated with human capital. This variable includes other types of innovation that are not related to R&D, such as learning by doing or on-the-job learning, which positively affect TFP. In addition, increased human capital will affect firms' ability to learn and absorb new technologies through trade and to use production factors more efficiently, which would have a positive effect on domestic production.

In short, it could be assumed that both commercial openness, which among its other effects encourages the adoption of new technologies, and human capital are factors to be taken into consideration when we try to explain TFP and economic growth. However, the repercussions of the interaction between these factors should be considered as well as the individual role of each. For example, the contribution to the national product by individuals, who ultimately are the owners of human capital, will depend on their motivations and incentives, and these may be influenced by institutional and economic factors. A factor that may determine the contribution of the owners of human capital to the growth of their economy may thus be the degree of openness to the outside world. Pissarides (1996) synthesises the reasons why human capital may be more productive when the economy is exposed to international competition and trade, and looking at the question from the opposite perspective, how the positive effects of greater openness may be related to the level of human capital. Firstly, trade is an activity that requires certain skills, as the goods usually involved in trade are of a higher quality than those produced and consumed domestically, and penetration and maintenance of foreign markets is more complex than for local markets. These circumstances may be even more accentuated in the case of industrial products. An economy with a greater endowment of human capital may take better advantage of the benefits of trade by importing more sophisticated capital goods and use them to produce better quality goods, with which it will be able to compete better with the products of other economies. Finally, the greater the openness of an economy, the better the performance of its human capital. This is because its potential market will be greater and opportunities for the development of new products with potentially greater benefits will increase, and in connection to this, skilled individuals will have more incentives to carry out activities that contribute to the national product to a greater extent.

In the light of the ideas set out in the paragraphs above, the basic objective of this paper is to test the hypothesis that complementarity between trade and human capital reinforces their individual effect on TFP and hence on economic growth. To this end,

the sample of Spanish regions (NUST2 in the EUROSTAT classification) has been used. As been pointed out above, prior empirical analyses do not provide conclusive results concerning the role of these variables as TFP determinants. While Coe and Helpman (1995), Engelbrecht (1997) and Frantzen (2000) find evidence in favour of these hypotheses, Lichtenberg and Van Pottelsberghe de la Potterie (1998), Keller (1998), Kao et al. (1999), Funk (2001) and del Barrio et al. (2002) criticise and qualify these results. This controversy may to some extent be due to the fact that the empirical studies carried out use samples of countries that are heterogeneous to a certain degree. Heterogeneity across countries thus prevents to reach definite conclusions on that regard.

Moving from an international field to an interregional one may be the solution which lessens the effect of the differences in the unobservable determinants of growth between individuals, as regions within a country are supposed to be more homogeneous, especially in those aspects which are difficult to control for in the analysis (such as the cultural and institutional ones). It may thus be expected that the results obtained in our work on the effect of human capital and trade on TFP are less conditioned by the problems that may exist in the samples of countries used in this type of analysis so far.

In this context, the case of the industrial sector in the Spanish regions is especially attractive for two reasons. Firstly, Spain's socio-political circumstances since the 1980s – reforms in the education system, industrial restructuring, integration into the European Union and an opening up to the outside world – make the verification of these hypotheses interesting. Secondly, there are detailed and homogenous official statistics enabling the variables involved in the analysis to be carefully measured. Moreover, restricting the analysis to the industrial sector makes testing the theoretical suppositions more attractive, as the characteristics implicit in their formulation match up to a greater extent to those found in this sector than those found in primary or service industries. As far as we know, this study is the first attempt to test these suppositions, not only using a sample of regions and therefore with more homogenous characteristics, but also based on information coming exclusively from industry.

The results obtained for Spanish regions in the period from 1980 to 1995 confirm the importance of the spread of knowledge through trade, in such a way that greater openness favours TFP and ultimately, growth. This positive effect of openness is complemented by human capital. Although this variable contributes positively to the Spanish regions' productivity, its complementarity with openness increases the effect of

the latter. In the same way, this positive effect of openness and human capital encourages technical progress and the verification of a technological catch-up process. A more detailed analysis confirms the hypotheses on which this work is based in such a way that unlike previous studies, not only imports (especially of intermediate and capital goods) but also trade in goods and services as a whole leads to improvements in the technical progress of the economy involved. Finally, there are indications that the intensity of the effects of trade and human capital depends on the level of each region's economic development.

The rest of the paper is organised as follows. In Section 2, the empirical model used is presented and the variables which may influence the analysis are discussed. Section 3 contains a description of the evolution of the variables relevant to the analysis. The general results are presented in Section 4, while we analyse if it is basically imports of intermediates and capital goods what matters for the diffusion of technology in Section 5. Finally, Section 6 confirms that the effects of human capital and trade depend on the level of regional economic development and Section 7 concludes.

2. THE EMPIRICAL MODEL

According to the ideas above, we will present the empirical model that will enable us to obtain an estimation of the effect of trade and human capital on TFP. To do so, it is necessary to take some additional factors into account. While there is widely accepted agreement in the theoretical literature on the importance of human capital in economic growth, discussion focuses on the way in which it exerts its influence. From the perspective of growth accounting and the expanded neoclassical model, human capital is considered as an additional production factor. Following another line of thought, Miller and Upadhyay (2000) point out that this approximation may be inadequate, as the additional inputs considered may indirectly affect output, influencing the efficiency of traditional production factors. For this reason, they would be directly affecting TFP. In the same terms, Benhabib and Spiegel (1994) specify a model in which TPF growth is determined by the level of human capital, which they believe includes domestic innovation which will be endogenous, and a variable that includes the interaction between human capital and productivity catch-up. This supposes that the latter would capture the international spread of knowledge, an idea adapted from the model of

Nelson and Phelps (1996)[2]. As a consequence, based on these arguments, our exercise will consider that human capital affects TFP.

Following the ideas of the growth models in which trade is one of the main mechanisms for the spread of knowledge, it can be assumed that tradable goods include technological advances. This implies that an economy can benefit from the innovative effort of its trading partners by means of importing products from these economies (Coe and Helpman, 1995). According to Ben-David and Loewy (1998), exports may also be considered as a channel for the spread of knowledge, from which even a leading technological economy can benefit. As Grossman and Helpman (1991) point out, sellers may benefit from their clients' knowledge. For example, the exchange of information regarding competition in the market or potential increases in rivals' productivity may encourage innovation in a firm to attain productivity increases that enable it to continue to be competitive. Moreover, the knowledge acquired to satisfy customer demand in terms of product characteristics and quality will contribute to increasing domestic technology and productivity (Funk, 2001). For this reason, we will suppose that it is not only the import rate, as in Coe and Helpman (1995), and Coe et al (1997), among others, which will determine TFP in Spanish regions' industry, but rather that it will be the region's total volume of trade, which will influence its productivity.

Hence, the ideas set out in the above paragraphs can initially be synthesised in the following expression:

$$TFP_{it} = f(H_{it}, T_{it})$$

where TFP is total factor productivity, H is human capital, including endogenous domestic innovation and capacity for learning and assimilating foreign innovations and technology and T is the level of openness, all referring to region i in the period t.

However, to explicitly include the possibility that both factors are acting interactively, we will consider a more expansive version of the above specification:

$$TFP_{it} = f(H_{it}, T_{it}, H_{it}*T_{it}) \qquad (1)$$

It is thus considered that for the exchange to be productive, a certain capacity to adapt the new technologies incorporated in the tradable goods to the domestic productive system is required of producers. For this reason, while openness and human capital are

[2] Interestingly, in accordance with Abramovitz (1994), economies that differ greatly from the leader in terms of characteristics such as supply of employment, market size, etc. may have difficulties applying the technology developed by the leader.

factors that taken separately may be generating gains in productivity and growth, their effect will be increased in that these factors are complementary. That is to say that the possibility that the effect of human capital accumulation depends on the level of the economy's openness, and similarly, that the impact of commercial openness is related to the available stock of human capital, will be considered. In addition, this specification may include the fact that economies with the same level of openness and the same supply of human capital present different levels of TFP owing to the differences in the adaptation of their human capital to the technological knowledge spread by trade.

As a stage prior to estimating the effects of trade and human capital on the TFP of industry in the Spanish regions, a measure of the latter variable is needed. The TFP measure used is based on Solow's residual, i.e. it will be the return obtained from the production factors, once the quantities used and their prices, established in their respective markets, are considered. Hence, if it is considered that technological capital, or other forms of intangible capital that contribute to increases in production, are accumulated in the same way as physical capital is accumulated, this capital will not be directly observable, but can be approximated using TFP. In this respect, it can be assumed that this variable provides an approximation of an economy's technology level.

Starting from the simplest hypotheses, we can suppose that based on a Cobb–Douglas production function, the industrial output of the economy in region i, Y_i, is obtained by the combination of labour, L_i, and capital, K_i. Given that there is no overwhelming evidence against the supposition of constant returns to scale for Spanish industry (see Goerlich and Orts, 1996), this production technology can be assumed, in such a way that the relationship can be expressed as

$$Y_i = A\, L_i^{\alpha_i}\, K_i^{1-\alpha_i}, \qquad \alpha_i < 1$$

Having reached this point, the definition of α_i depends on the hypotheses regarding the level of competition in the market. Hence, if there is a situation of perfect competition, payment for the labour factor matches the marginal productivity of this factor, and α_i is therefore defined as the share of wage payments to labour in total income. In the case of imperfect competition, given the existence of a mark-up, the coefficient α_i is defined as the share of labour in total cost of production (cost of labour and capital). Goerlich and Orts (1996), as well as concluding that constant returns to scale may be a reasonable supposition for the Spanish economy, point out that perfect competition may be a reasonable approximation to the real conditions of Spanish

industry. Moreover, the period covered by the study (1980-95) is a period in which Spanish industry faced growing competition, both from within Spain and abroad. For this reason, it seems appropriate to suppose perfect competition[3] and in this case the less restrictive method of TFP calculation, where it is considered that the cycle may be affecting each period's results, i.e. enabling α_i to vary every year. Then, TFP for each region and period is computed as:

$$A_{it} = TFP_{it} = \frac{Y_{it}}{L_{it}^{\alpha_{it}} K_{it}^{1-\alpha_{it}}}$$

3. THE DATA

The aim of this Section is to briefly summarise the evolution of the variables involved in the analysis. Details of statistical sources and the construction of these variables can be found in the Appendix. However, as a prior step to descriptive analysis, some aspects of the information referring to human capital and the level of openness need to be explained.

In most of the empirical literature which analyses the effect of human capital on economic development, two alternative measures of this variable are used – the average number of years of schooling of the population aged over 25 or the total of those employed with a given level of studies completed. The statistical information available plays a key role in choosing one or the other measure. In the case of the Spanish regions, the available statistics enable calculation of the total of those employed with secondary or higher education in the industrial sector, a measure which has been taken into consideration in this study.

In the same way, and given the ideas set out in the previous Section, it has been considered that both imports and exports have to do with the effect of trade on productivity. For this reason it has been decided to consider them as a whole, using the rate of openness of an economy as defined in its broadest sense, i.e. as the sum of imports plus exports of goods over regional gross added value. However, the consideration of imports and exports at a regional level involves the possibility that on occasions, the region of the origin of exports, and destination of imports, and that

[3] The calculations were also made supposing imperfect competition, following the method suggested by Hall (1998). Although the estimation of TFP in this case slightly differs from that obtained by considering perfect competition, the main conclusions of the study remain unaltered.

attributed to them in the official data are not the same. For example, there could be a case of a frm with its headquarters in a given region having productive plants in other regions, with trade being attributed to the first one. For the purposes of our analysis, this is not of crucial importance as according to the hypotheses mentioned on the spread of knowledge by trade. What is important is the region where there are suitable technological conditions for absorbing this knowledge that spreads through commercial exchanges. It is reasonable to assume that those conditions may mainly be focused on the R&D departments located at the headquarters of these companies.

We will shortly describe the main characteristics of TFP. As can be seen in Figure 1, its average annual growth is positive in all the regions, with the single exception of Asturias. However, this growing trend is not uniform across all the regions or over time. Cantabria and La Rioja show the highest levels of TFP growth, 43% between 1980 and 1995, followed by the Balearic Islands with 40% and Aragon with 35%. Nevertheless, the decrease in Asturias is around 5%.

As well as these regional disparities in the rates of industrial TFP growth, appreciable differences can be seen in the levels of technology at the beginning of the sample. There is nevertheless a confirmed negative relationship between growth rates and the initial TFP level. Figure 1 thus suggests the existence of a process of convergence in manufacturing technology between regions. However, despite this evidence in favour of a process of homogenisation in the technology of the industrial sector, appreciable differentials persisted in the levels of industrial TFP in the Spanish regions at the end of the period under consideration.

Figure 2 shows the relationship between average annual growth of human capital in the industrial sector and its level at the beginning of the period under consideration, for seventeen Spanish regions. Between 1980 and 1995, there was a very significant increase in the level of human capital in the Spanish regions. Regions with low levels of human capital in 1980, such as Extremadura, Galicia, Andalucia and the Balearic Islands (in ascending order) experienced the greatest increases in this variable.

On the other hand, regions that in 1980 presented the highest proportion of employed with secondary schooling or higher educational levels, such as Madrid, Navarre, Asturias and the Basque Country (in descending order) presented lower levels of increases. This suggests a homogenisation of the level of human capital between the Spanish regions as well as showing a growing effort in improving the skills of the labour force. This process of convergence in the skills of the labour force of the

industrial sector between Spanish regions is shown graphically in Figure 2. There is a strong negative lineal relationship between growth and the initial level of this variable.

The growth in the level of openness in the Spanish regions compared to their 1980 levels is shown in Figure 3. The disparities in the growth of this variable are more pronounced than in the previous two cases. Thus, there is an average annual growth rate of 17% in the Balearic Islands, 13% in Castilla–La Mancha and 12% in Castilla–León, compared with 2% in La Rioja and 4% in Murcia. Such disparate figures reflect the fact that regions with industries traditionally open to the outside world experienced less striking increases in their level of openness than regions whose industrial opening occurred in the second half of the 1980s, with Spain's entry into what was then the European Economic Community. Changes in this variable throughout the period analysed reflect a change of trend indicating a significant increase in the level of openness for all the regions from the second half of the 1980s onwards. For this reason, despite the disparities in the growth of regional openness that persisted in the 1990s, it is indeed possible to speak of a process of homogenisation in the openness of the Spanish regions. As Figure 3 makes clear, those regions with lower levels of openness at the beginning of the sample, such as the Balearic Islands, Castilla–La Mancha and Castilla–León, experienced a much greater average growth than those like Valencia or Murcia, which presented higher levels of openness in 1980.

In summary, Spain and its regions experienced very significant increases in terms of both their human capital and their level of openness to the rest of the world throughout the period under study. These are factors which make the analysis performed in this study especially interesting. Of particular note is the fact that these increases took place above all in those regions that presented relatively low levels of human capital and openness in 1980, meaning that a process of regional convergence can be observed in both variables. However, despite this homogenisation process, there are still significant differences between the regions, both from the point for view of endowments of skilled labour force in the industrial sector as well as in their level of openness.

Thus, considering the ideas set out above on the role of human capital and openness in the spread of knowledge and its effect on industrial TFP, we may suppose that the disparities observed in these two variables may explain, at least partially, the development and differences seen in industrial TFP in Spanish regions.

4. ESTIMATION RESULTS

Using on the empirical specification suggested in Section 2, in this section we will describe the main results obtained by estimating the effects of human capital and openness, with explicit consideration of their interaction, on the TFP of the industrial sector of Spanish regions. Assuming a logarithmic relationship between the variables, the equation susceptible to be estimated based on expression (1) will be[4]:

$$\ln TFP_{it} = \sum_{i=1}^{17} \delta_i + \sum_{\tau=1}^{16} \delta_\tau + \phi^H \ln H_{it} + \phi^T \ln T_{it} + \phi^{TH} \ln T_{it} \ln H_{it} + \varepsilon_{it} \qquad (2)$$

where δ_i and δ_τ are regional and time dummies respectively, and ε a is well-behaved perturbance. The regional dummies account for an individual effect for each of the 17 Spanish regions. This is due to the characteristics of the sample, which contains time series and cross-section data, making consideration necessary of the specific aspects of each individual in the sample, which are not measurable or observable and which will be constant over time. Moreover, given that the business cycle may be affecting all the regions at each point in time, the time effects common to all regions are included. The Hausman test selected the fixed effects over the alternative of a random effects model, for all the specifications considered in our analysis.

The results of the estimation of equation (2) are shown in Table 1. The first two columns show the results of two simple models that include human capital and openness respectively as explanatory variables. In both cases, the estimated parameters present the expected positive signs as well as being statistically significant. The outstanding point is the lesser effect of openness on productivity. When both variables are included in the regression, column (iii), the estimated coefficients do not significantly alter. Finally, the interaction of both variables has been included in the last column. In this case, the results also show the expected signs with all the variables being statistically significant. This specification is also preferable to any of the previous ones based on the lowest value for the AIC statistic in this case. The relevant feature is that the inclusion of the interaction between human capital and openness reveals that there is indeed a positive and significant complementarity that increases the effect of these variables on TFP.

[4] The proposed specification may be seen as a trans-log function where the coefficients associated to the quadratic terms are restricted to equal zero. In fact, when these restrictions were tested in our model, they were not rejected.

The consideration of the time dimension in the analysis above may lead to the appearance of a problem of spurious correlations, owing to the possible non-stationarity of the variables included in the regression. If indeed these variables are not stationary, the results of the estimation of the model in levels, shown in Table 1, will only be consistent if there is cointegration among the variables. In this analysis, neither unit root tests on the variables nor cointegration tests on the relations estimated in Table 1 are explicitly carried out. This is because the time dimension of the variables is relatively short (16 years) while it has been shown that panel data based unit roots and cointegration tests require a longer time dimension to have good performance (Im et al 1997, Kao 1999, Pedroni, 1995 and 1999). Alternatively, the problem of a spurious relationship in the previous results can be solved using the estimation of the model in first differences, that is estimating the following specification:

$$\Delta \ln TFP_{it} = \sum_{\tau=1}^{16} \delta_\tau + \phi^H \Delta \ln H_{it} + \phi^T \Delta \ln T_{it} + \phi^{TH} \Delta(\ln T_{it} \ln H_{it}) + v_{it}$$

where fixed regional effects disappear as a result of differentiation.

This procedure, similar to that used by Engelbrecht (1997) and Coe et al. (1997) has another advantage. The existing literature usually approximates a region's technology level with that of its TFP, and we have just seen how the results of the previous estimations suggest that both human capital and openness are determinant factors in this technology level. On the other hand, the specification in first differences of equation (2) enables us to analyse to what extent the accumulation of these variables may affect technical progress in the industry of a representative Spanish region. Additionally, and bearing in mind the literature focusing on the process of technological catch-up (Abramovitz, 1986; Dowren and Nguyen, 1989), adapted to the environment of diffusion of technology by trade as in Coe and Helpman (1995) and Engelbrecht (1997), the initial (log) TFP level is included as a regressor:

$$\Delta \ln TFP_{it} = \sum_{i=1}^{17} \delta_i + \sum_{\tau=1}^{16} \delta_\tau + \beta \ln PTF_{i(t-1)} + \phi^H \Delta \ln H_{it} + \phi^T \Delta \ln T_{it} + \\ + \alpha^{TH} \Delta(\ln T_{it} \ln H_{it}) + v_{it} \qquad (3)$$

However, $\beta<0$ does not automatically means the existence of a process of convergence in technological levels, indicating that the less technologically advanced regions would have experienced greater technical progress. Note that (3) again includes fixed regional effects to allow for differences in TFP equilibrium levels. Thus, the above-mentioned condition for β should be read as a sort of conditional catch-up, that is

to say, each region converging to their own technological steady state (see Durlauf and Quah, 1999 for a further discussion on the rate of convergence estimates in panel data).

The results of the estimation in differences with and without the inclusion of the catch-up term are shown in Table 2. In view of these results, the first point to mention is that in isolation, human capital growth is not significant and the increase in openness has a negative effect on technological progress. This result would be in accordance with the irrelevance of human capital that has been observed in the literature when the analysis is performed on *flows* and on the variety of results regarding the effect of trade upon growth, both of which have been discussed in previous sections. However, the inclusion of the interaction between both variables radically changes these results. An increase in human capital or openness, given the other variables, thus has a positive effect on technical progress, which is encouraged by the increase in complementarity between both variables.

In the estimations included in columns (v) and (vi), the parameter associated with the initial TFP level presents the expected negative sign, which confirms the existence of a conditional catch-up in the industry of Spanish regions. As is also usual in the literature, the technological convergence level is much higher in the estimation that enables convergence to different steady states by the inclusion of fixed effects (vi) than in that which does not include such effects (v).[5]

In short, our hypothesis regarding interaction between the effect of openness of an economy and the stock of human capital within it seems to be confirmed by the industrial sector in Spain. This implies that human capital return in each region may differ depending on its trade orientation, and that there may be significant asymmetries in the benefits of openness to the outside, which may be at least partly related to the stock of human capital available to make the most of the advantages offered by trade. The following section deals with discerning to what extent these effects correspond to imports and exports and whether they basically take place through trade in intermediate and capital goods.

[5] It should be noted that (3) is a dynamic fixed effects model. Thus, OLS will provide assymptotically biased estimates. Following the suggestion in Islam (1995) and, particularly, in Caselli et al (1996) we estimated (3) by the GMM method proposed in Arellano and Bond (1991), using the lagged values of the TFP as instruments. However, those results were in accordance with the OLS ones reported in the paper, particularly with those regarding the effects of human capital and openness.

5. DO IMPORTS OF INTERMEDIATE AND CAPITAL GOODS CONTRIBUTE TO A GREATER EXTENT TO TECHNICAL PROGRESS?

Theoretical contributions (see Grossman and Helpman, 1991) have described two ways in which trade favours an economy's productivity. Firstly, the importance of foreign R&D embodied in imported products has been emphasised. Secondly, the mechanisms by which commercial openness and liberalisation may stimulate domestic productivity and growth have been analysed. Thus in the first instance, the use of foreign products that include ideas, developments and knowledge makes access to information possible that would otherwise be difficult, and of course, more expensive, to acquire. This therefore suggests that the greater an economy's exposure to trade in intermediate and capital goods, the greater its TFP will be. Likewise, it would seem reasonable to suppose that the first of these will basically occur by means of the import of intermediate and capital goods, with exports playing a less significant role in this sense.

From another point of view, both imports and exports may contribute to making the second channel feasible. Through various mechanisms, imports and exports provide means of communication that encourage the learning of new forms of production, product design, and market conditions, etc. Despite this, as has been pointed out in previous sections, the empirical literature has almost exclusively considered imports as a channel for spreading knowledge. Even Coe et al (1997), who only use trade in intermediate and capital goods instead of goods as a whole, argue for imports to be considered alone, because "it is more consistent with the theory and empirically they do a better job" (page 140).

Against this opinion, the results presented in the previous section are based on a measure of openness that includes both imports and exports, and also of all types of goods. This was due to the fact that our hypothesis sustains that even while the most important channel for the spread of technology may be the incorporation of foreign goods that are directly involved in the productive process, an economy may also experience advances in its TFP ultimately caused by trade (imports and exports) in other types of goods. Obviously our argument is backed by the second of the above channels.

By including both imports and exports and all types of goods, the results obtained in the previous section do not allow for discrimination of to what extent our procedure has been appropriate, or whether the positive effect of trade on technical progress that we obtained previously is entirely attributable to imports of intermediate and capital

goods. In order to test our hypotheses more clearly, in this section we briefly present the results obtained by using imports and exports of intermediate and capital goods as an approximation to trade. If the diffusion of ideas and knowledge were limited to trade in this type of goods, one would expect that the coefficients associated with the trade variable in this case (the response of TFP to trade) were at least of the same dimension as those presented previously when exchanges of all types of goods were considered. Given the results of the previous section, we are going to limit ourselves in this section to presenting those of the specification in first differences, i.e. with the analysis framed in terms of industrial technical progress[6]. The estimation corresponding to equation (3) is shown in column (i) of Table 3. A significant decrease can be seen in the estimated coefficients for the trade variable when they are compared with those obtained when trade in all types of goods is included – Table 2 (vi). The reduction takes place both in the direct effect and especially, through interaction with human capital. However, the coefficient associated with human capital increases its value, which may be a reflection of the fact that this variable now includes part of the effect attributable to trade in other types of goods. A loss in the model's explanatory capacity is noted when these goods are excluded.

The following columns show the results when the effects of imports and exports are considered separately. When the coefficients associated with the specification that only includes imports of intermediate and capital goods (ii) are compared with the one that only includes exports of these goods (iii), a slightly greater effect in the former can be seen. In fact, when both imports and exports are included in the specification (iv) the high degree of similarity in the coefficients estimated by both can be seen. Hence, the hypothesis of equality of the direct and indirect coefficients for imports and exports is not rejected when it is tested. In addition, the sum of the coefficients of both practically coincide with that obtained in (i) when they were considered as a whole in the measure of openness, for both the direct effect and for interaction of human capital.

In short, the results above confirm that trade in all types of goods leads to improvements in the technical progress of the economy involved, as against the predominant trend in the literature, which suggests goods that include foreign innovations most quickly are the main players in such a phenomenon. In addition, evidence that rule out these effects taking place mostly as a result of imports can be seen

[6] The result from specification in levels are available to interested readers.

in the results. On the other hand, it can be seen that in Spanish industry, increases in exports of capital goods and intermediates would have led to associated improvements in technical progress. This would possibly be as a result of the need to be more competitive in foreign markets and because of the learning process involved in access to these markets. However, these questions should be dealt with in more depth in further studies.

6. REGIONAL HOMOGENEITY IN THE EFFECTS OF TRADE AND HUMAN CAPITAL

The empirical literature has suggested the existence of threshold effects in the factors determining economic growth (Azariadis and Darden, 1990). In short, the return of productive factors may depend on the quantity of them already accumulated. This non-linearity in the return means that the effect of these factors on growth may differ between different economies. Those economies that have attained certain levels of the factor present a greater output than those where its threshold level has not been reached. In particular, Durlauf and Johnson (1995) obtain evidence regarding the existence of threshold effects on human capital, supporting the theoretical hypothesis formulated by Azariadis and Drazen (1990). Rodriguez and Rodrik (1999) raise doubts regarding the homogenous nature of the effect of trade on growth in a sample of economies at different levels of development. Using techniques enabling endogenous selection of subsamples of economies, Hansen (2000) confirms a threshold effect for human capital, although only in a sample of countries that have reached high enough levels of development. However, it should be remembered that the application of these techniques to panel data requires a high cross-section dimension, as the asymptotic results are obtained for the number of individuals tending to infinity with a fixed number of periods (Hansen, 1999). These has made it impossible to apply to our sample, and therefore it has been divided *a priori* into groups of individuals with similar development levels, as in other works in the related literature (Mankiw et el, 1992, Miller and Russek, 1997).

As a consequence, the sample of Spanish regions has been divided according to TFP level at start of the time period under consideration. Hence, if a region's TFP level in 1980 was lower than the national average level, it was considered to belong to the group of less developed regions. A group of 11 less developed and 6 more developed

region was obtained in this manner[7]. The average human capital in the first group was 86.7% of the Spanish average in the first year, while the average in the second group was 103.2% of the Spanish total. The level of openness in the less advanced regions was 78.2% of the average, with this percentage rising to 127.7% in the more developed regions.

Our hypothesis supposes that the benefits of openness and human capital will be greater in those regions in which a certain degree of development has already been attained, as there will be suitable incentives and determining factors so that these instruments can more fully exploit their opportunities. To test this supposition, the estimation of the effects of human capital and trade has been obtained, both in the specification in levels (equation 2) and in differences (equation 3) for both groups of economies. The results shown in Table 4 seem to support this hypothesis. In terms of the estimation of the model in levels (columns i and ii) it can be seen that human capital has a positive and significant effect on the more developed regions, while its effect is negative in the less developed ones. As far as openness is concerned, this has a positive and significant effect in both groups, although notably less so in the case of the less developed regions. But perhaps what is most interesting is that the coefficient associated with interaction is only significant in the case of the more advanced regions. In general terms, the conclusions that can be drawn from the results obtained by analysing the effects on technical progress (columns iii and iv) coincide with the above. The direct effect of accumulation of human capital and the increase in openness is much greater in the case of the more developed Spanish regions, and this phenomenon is in turn reinforced when the interaction between both variables is considered.

7. CONCLUSIONS

Recent developments in theories on innovation and growth have emphasised the importance of the spread of technological knowledge as an explanation for productivity growth, with trade as one of the main channels for spreading this knowledge. The importance of the existing complementarity between investment in human capital and innovation, which enables the acquisition of a sufficient skill level in the workforce to

[7] The regions considered to be less developed are AN, AR, BL, CB, CL, CM, CN, CV, EX, GA and MC, and the most advanced are AS, CT, MT, NA, PV and RI.

be able to absorb and efficiently use the new and more advanced technologies, has also been highlighted.

In the analysis carried out for the industrial sector in Spanish regions there is evidence to support these ideas. This analysis is of special interest for two reasons. Firstly, it is the first contribution in this type of literature to test theoretical suppositions in a sample of regions, and is consequently more homogenous in the determinants of production technology, in preferences and in the socio-economic environment than the samples of countries usually used. Secondly, there is the fact that social, economic and political circumstances in Spain in the period studied led to increases in commercial relations with other countries, which in the case of the existence of a positive effect between openness and growth must have resulted in a clear improvement in Spanish industry's productivity. At the same time, the Spanish economy experienced substantial increases in its supply of skilled labour. Together with the immediate effect that such a phenomenon may have involved, its role in the use of potential benefits of trade has been considered.

The results of this study show that both human capital and commercial openness have a positive and significant influence on Spanish regions' TFP. Likewise, a greater adaptation of the labour force's skill level and the knowledge flowing through trade will be a key factor in the process of technical progress. When considering both imports and exports of all types of goods, it has been shown how the beneficial effects of trade do not seem limited to imports of intermediate and capital goods. Exports of these goods seems to have the same scale of influence, and benefits have been noted in the trade of other types of goods, which calls into question some of the most deep-rooted opinions in the literature on the subject.

Finally, it should be remembered that the exercise carried out suffers from the limitation of not having considered other international sources of knowledge, particularly those arising from direct foreign investment. Consideration of this factor and the crossed effect that it may present with human capital merit further study. Likewise, because of the limitations of the statistical information, we were unable to use variables that provide an approximation of the innovative efforts of regional economies and the incorporation of foreign innovation. Although human capital and trade may be incorporating its effects, as has been argued, there is no doubt that its explicit consideration would provide greater knowledge of the underlying reasons behind the evolution of technical progress in Spanish industry and the differences in this field

between the Spanish regions. In any case, we consider that the work set out here provides the initial basis for subsequent developments.

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DATA APPENDIX

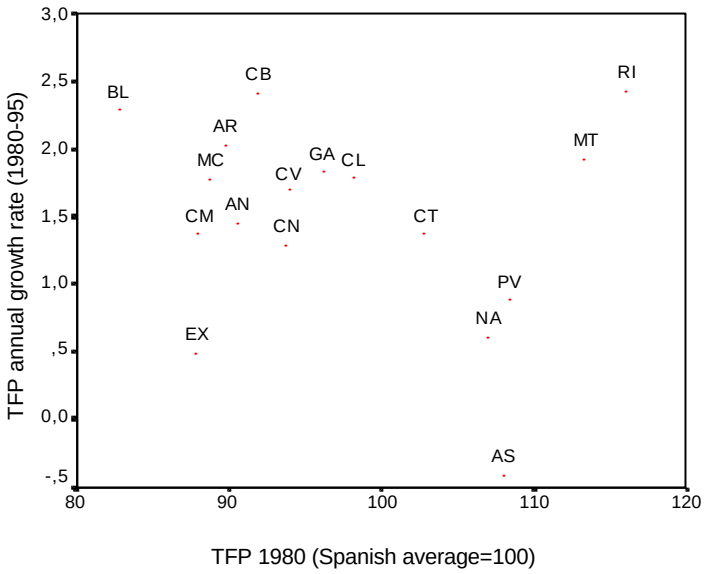
For each region in the sample, total factor productivity is defined as $TFP_{it} = (Y/L)_{it} / (K/L)_{it}^{\alpha_{it}}$ where Y is the Gross Added Value (GAV) at market prices, K is the stock of physical capital, both at constant 1986 prices, and L is the number of workers, in the industrial sector. α is the share of remuneration of workers in GAV in the industrial sector in constant prices. The sectoral GAV at 1986 constant prices (growth accountancy perspective) is obtained by deflating the current sectoral information provided by the CRE (Regional Accounts produced by the Spanish Statistical Office –INE, http://www.ine.es-) with the correspondent sectoral deflator provided by the INE's National Accounts. The information on employment in industry comes from the Labour Force Survey, produced by the INE following the EUROSTAT criteria. The data regarding the stock of regional physical capital at constant 1986 prices for the industry is obtained from Dabán, et al. (1997).

The CRE provides information on sectoral remuneration of wage-earning employment, as well as wage-earning employment, in current pesetas for each Spanish region. This information allows to compute the labour cost of employment in constant prices by using the cost price index as deflator. Remuneration of workers at constant 1986 prices is obtained for each industry in each region by multiplying the unitary labour cost by the number of workers in the corresponding industry.

From data published in *Información Estadística sobre comercio exterior e intracomunitario. Agencia Estatal de Administración Tributaria. Dpto. de impuestos especiales*, (Statistical Information on Foreign and Inter-community Trade. Spanish Tax Office, Special Taxes Dept.) and the information supplied by the INE's National Accounts we obtain regional imports and exports for capital and intermediate goods, and for total goods in constant 1986 prices.

The data regarding workers with secondary or higher schooling in industry were obtained from Pérez and Serrano (1998) –http://www.ivie.es.

Figure 1. TFP growth in the Spanish regions.



Note: Andalucia (AN), Aragon (AR), Asturias (AS), Balearic Islands (BL), Cantabria (CB), Castilla-León (CL), Castilla-La Mancha (CM), Canary Islands (CN), Catalonia (CT), Valencia Region (CV), Extremadura (EX), Galicia (GA), Murcia (MC), Madrid (MT), Navarre (NA), the Basque Country (PV) and La Rioja (RI).

Figure 2: Human capital accumulation in the Spanish regions.

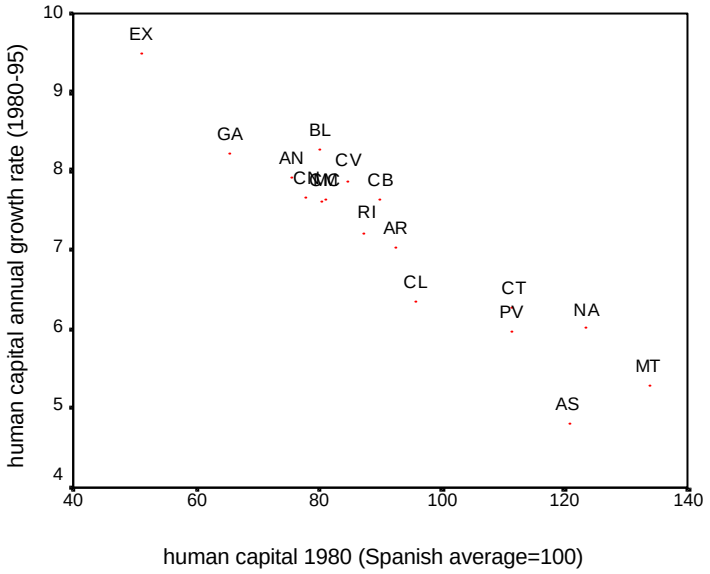


Figure 3: Change in openness in the Spanish regions.

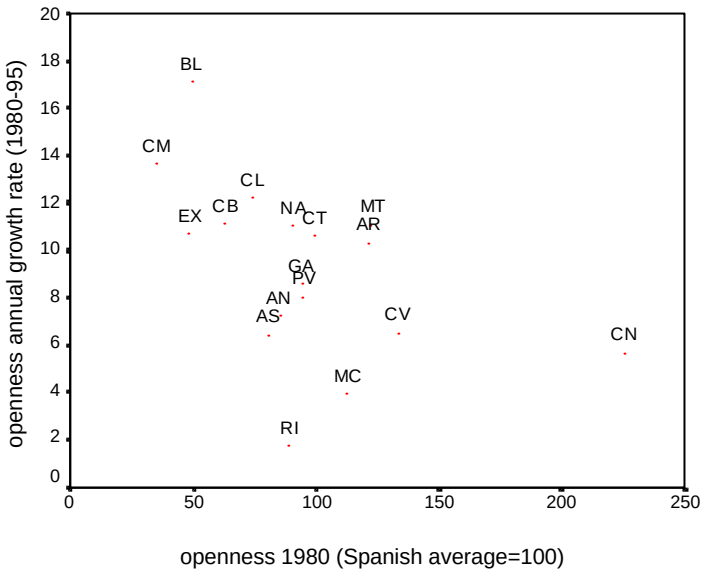


Table 1. Estimation of the effect of H and T in industrial TFP.

	(i)	(ii)	(iii)	(iv)
Ln H	0.121		0.113	0.188
	(3.11)		(2.97)	(4.30)
Ln T		0.044	0.041	0.096
		(3.34)	(3.21)	(4.59)
Ln H Ln T				0.056
				(3.28)
R^2 adj.	0.889	0.890	0.893	0.897
e'e	0.5004	0.4975	0.4797	0.4588
AIC	-6.059	-6.065	-6.094	-6.131

Note: All regressions include fixed regional and time effects, the estimated coefficients of which are not shown on the table.

Table 2. Estimation of the effect of H and T in industrial technical progress

	(i)	(ii)	(iii)	(iv)	(v)	(vi)
Δ ln H	0.034		0.046	0.124	0.112	0.091
	(0.73)		(1.01)	(2.68)	(2.44)	(2.10)
Δ ln T		-0.072	-0.07	0.105	0.123	0.166
		(-4.36)	(-4.41)	(2.69)	(3.15)	(4.03)
Δ (ln H ln T)				0.162	0.181	0.214
				(5.00)	(5.5)	(6.17)
$\ln TFP_{i\,(t-1)}$					-0.046	-0.286
					(-2.69)	(-6.36)
Regional dummies	No	No	No	No	No	Yes
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
R^2 adj.	0.221	0.277	0.277	0.344	0.360	0.453
e'e	0.2979	0.2766	0.2754	0.2491	0.2417	0.1927
AIC	-6.630	-6.704	-6.701	-6.794	-6.816	-6.917

Table 3. Estimation of the effect of imports and exports of capital goods and intermediates on industrial technical progress.

	(i)	(ii)	(iii)	(iv)
Δ ln H	0.139 (2.54)	0.167 (2.62)	0.168 (2.67)	0.261 (3.64)
Δ ln T	0.100 (2.92)			
Δ ln M		0.070 (2.43)		0.051 (1.84)
Δ ln X			0.061 (2.62)	0.047 (2.03)
Δ (ln H ln T)	0.126 (4.17)			
Δ (ln H ln M)		0.094 (3.58)		0.069 (2.67)
Δ (ln H ln X)			0.085 (3.99)	0.068 (3.20)
ln $TFP_{i\,(t-1)}$	-0.280 (-5.84)	-0.293 (-6.03)	-0.274 (-5.77)	-0.272 (-5.83)
Regional dummies Time dummies	Yes Yes	Yes Yes	Yes Yes	Yes Yes
R^2 adj.	0.375	0.359	0.388	0.410
e'e	0.220	0.226	0.215	0.206
AIC	-6.784	-6.758	-6.804	-6.835

Note: M refers to the ratio between imports and gross added value, while X refers to the same ratio for exports.

Table 4. Estimation of the effect of H and T on industrial technical progress according to level of development.

Dependent var. Ln TFP_{it}			Dependent var. Δ Ln TFP_{it}		
	$TFP_{i0} \rangle TFP_{N0}$	$TFP_{i0} \langle TFP_{N0}$		$TFP_{i0} \rangle TFP_{N0}$	$TFP_{i0} \langle TFP_{N0}$
	(i)	(ii)		(iii)	(iv)
ln H	0.540 (5.04)	-0.103 (-1.92)	Δ ln H	0.177 (1.95)	0.066 (1.29)
ln T	0.171 (5.06)	0.062 (2.46)	Δ ln T	0.206 (2.56)	0.112 (2.22)
ln H ln T	0.208 (4.19)	0.026 (1.52)	Δ (ln H ln T)	0.268 (3.77)	0.157 (3.8)
			ln $TFP_{i\,(t-1)}$	-0.156 (-2.27)	-0.45 (-6.84)
Regional dumm. Time dummies	Yes Yes	Yes Yes	Regional dumm. Time dummies	Yes Yes	Yes Yes
R^2 adj.	0.836	0.894	R^2 adj.	0.434	0.510
e'e	0.1506	0.1978	e'e	0.0529	0.1133
AIC	-5.967	-6.467	AIC	-6.915	-6.937