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ESTUDOS DO GEMF
N.º 2 2007

PUBLICAÇÃO CO-FINANCIADA PELA
FUNDAÇÃO PARA A CIÊNCIA E TECNOLOGIA

Impresso na Secção de Textos da FEUC
COIMBRA 2007

Levels of education, growth and policy complementarities

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Abstract

Human capital acquired in the formal education sector is essential for knowledge creation and dissemination but the theoretical and empirical growth literature identifies other major determinants of innovation and imitation activities (R&D, international trade and FDI). This paper is an empirical investigation in a panel data framework of the effects of education and its sub-categories on economic growth emphasizing its complementarity with the other major determinants of technological change and growth. For this purpose we focus on a sample of OECD countries during the last decades of the twentieth century and use an extended and augmented version of the Benhabib and Spiegel (1994) growth specification that considers the role of education in innovation and imitation activities and that interacts education with the other major determinants of technological change. The results reveal the importance of education for growth through technology diffusion and domestic innovation activities. To fully exploit the benefits from R&D expenses in terms of growth the average OECD country needs a sufficient level of secondary and tertiary education and to benefit from the technology incorporated in imports of machinery countries need a sufficient level of overall education.

JEL Classification: O33, O38, O47, C33

Keywords: education, innovation, technological diffusion, panel data

1. INTRODUCTION

According to both the theoretical and empirical growth literature technological change is the main source of growth and differences in the rate of technological change are the principal cause of income differences across countries (see e.g., Klenow and Rodriguez-Clare (1997), Hall and Jones (1999), Easterly and Levine (2001)). For technological change to occur countries need to engage in innovation and/or imitation activities that use primarily human capital as an input (see e.g., Nelson and Phelps (1966), Romer (1990a), Romer (1990b), Abramovitz (1986)). Since formal education is an important source of human capital, the study of the relationship between education, technological change and growth can provide important insights on the causes of income differences across countries.

Endogenous growth theory also shows that different levels of education determine the depth of knowledge creation and dissemination (see e.g., Bailey and Eicher (1994), Storesletten and Zilibotti (2000), Sianesi and van Reenen (2003), Papageorgiou (2003)). Additionally, a better understanding of this relationship taking into account the interaction effects between education and other major determinants of technological change can help policy makers when defining educational policies since simultaneous reforms will have a greater impact on economic growth, i.e., countries will benefit more by coordinating reforms in education and other technological change determinants than by focusing on each policy individually.

This paper is an empirical investigation in a panel data framework of the effects of education and its sub-categories on economic growth, emphasizing its complementarity with the other major determinants of technological change and growth. For this purpose we focus on a sample of OECD countries during the last decades of the twentieth century and use an extended and augmented version of the Benhabib and Spiegel (1994) growth specification. Our main contribution to the literature comes from the fact that we carry out a systematic search of the productivity growth specification by considering the role of the different schooling levels and of additional technological change determinants, R&D, international trade and FDI, and its interaction with education.

The comparability of previous attempts to assess empirically the impact of education on growth is hindered by four aspects. First, the diversity of growth regression specifications estimated, with most analyses focusing on only one particular channel of influence. Second, the different education measures used which can be problematic due to the measurement error problem associated with human capital proxies. Third, the derivation of implications for OECD countries as to the preferential channel through which the influence of education is felt is not easy as many studies use evidence for both developed and developing countries together. And, finally, the use of different econometric approaches and estimation procedures. It is our opinion that there is room for a more systematic approach to the study of the importance of education for growth in OECD countries that addresses this comparability issues while emphasizing the need to assess empirically the importance of the different schooling levels.

The results achieved reveal, first, the importance of education for productivity growth through technology diffusion as a determinant of absorptive capacity in our sample of OECD countries, a result contrary to that of Benhabib and Spiegel (1994) that only confirm a role for education through innovation activities, but in line with the results of Engelbrecht (2003). Second, there is no evidence of a positive direct role of education in domestic innovation activities. Third, these results are robust to the introduction of the additional technological change determinants, R&D efforts, international trade and FDI.

Finally, the importance of education for TFP growth is not exhausted in the absorption of disembodied technology diffusion. Education at the secondary and tertiary levels is crucial to benefit from the investments in R&D in terms of productivity growth in OECD countries. Additionally, all schooling levels are equally important to benefit from technology incorporated in imports of machinery. Technology incorporated in FDI seems to exert no influence in productivity growth, neither directly nor interacted with education.

From the results obtained the more significant implications for economic policy that we can draw are the advisability of policies that encourage investments in education. The composition of human capital acquired in the formal education sector is also important to exploit the growth benefits of the different technological change determinants. Moreover, the positive influence of the interaction effects between schooling levels and other determinants of technological change endorses the importance of simultaneous education, R&D and trade policy reforms as opposed to reforms that focus on each policy individually.

In what follows we present the empirical model that we use to assess the importance of education for productivity growth. Section 3 provides an overview of the data used. Section 4 presents the main empirical results. The last section concludes.

2. EMPIRICAL MODEL

Our main objective is to examine how human capital acquired in the formal education sector affects growth and whether this effect depends on other technological change determinants. For this purpose, we begin by setting up a simple, empirically tractable model that allows us to examine the importance of education for technological change and growth through innovation and technological diffusion, considering additionally its complementarity with other technological change determinants suggested by theoretical and empirical growth studies, R&D, international trade and FDI.

The strategy followed to derive the empirical model is similar to that of Benhabib and Spiegel (1994) that adapt the Nelson and Phelps (1966) model to study the effect of human capital on growth. A higher level of human capital allows a country not only to expand the technological frontier by developing new ideas domestically, but also to close the gap between the current level of productivity and that of the leading technology country faster. We then extend this baseline specification in order to investigate further the different channels of technology creation and diffusion and their complementarity with education.

Consider a standard neoclassical production function, which uses the traditional productive factors,

$$Y_{it} = A_{it} F(K_{it}, L_{it}) \tag{1}$$

where Y is real output, A is an index of technical efficiency, L is a measure of labour input, and denoting as usual countries by the subscript i and time by subscript t.

Our main purpose is to understand how education influences technological change and thus growth, so we want to find a suitable specification for the growth of A, the index of technological efficiency.

As originally proposed by Benhabib and Spiegel (1994), the specification for $\Delta \log A_{it}$, the rate of technological change, as can be seen in equation (2) is:

$$\Delta \log A_{it} = c + gH_{it-1} + mH_{it-1} \log\left(\frac{A_{\max t-1}}{A_{it-1}}\right) \qquad (2)$$

where H is the stock of human capital, $A_{\max t-1}$ is the level of technological efficiency of the leader country, and A_{it-1} is the level of technological efficiency of the country under analysis. In this model, human capital and the technological gap or disembodied technology diffusion, proxied by $\log\left(\frac{A_{\max t-1}}{A_{it-1}}\right)$ the distance to the leader country in terms of technological efficiency, are the engines of growth.

Human capital plays a dual role in the model: it determines both the endogenous capacity to generate new knowledge, represented by the term gH_{it-1} and technology absorption, represented by the term $mH_{it-1} \log\left(\frac{A_{\max t-1}}{A_{it-1}}\right)$. This last aspect means that for foreign technology to have an impact on productive efficiency conditions for its absorption also have to prevail, which are identified in the model with the level of human capital.

This specification however ignores other determinants of technological change that have been widely emphasized by the theoretical and empirical growth literature. It is possible that human capital stocks data are not precise enough as proxies for domestic innovation but they might proxy for other "learning" so that human capital should be included alongside separate R&D variables (see e.g., Engelbrecht (1997), Frantzen (2000), Wolff (2000), Crespo et al. (2004)). The innovation component of $\Delta \log A$ should therefore also include R&D efforts as a possible technological change determinant, bearing also in mind that R&D efforts need human capital to produce results, an issue that translates into the consideration of an interaction term between R&D and human capital in the growth regressions.

The Benhabib and Spiegel (1994) specification also does not refer to the specific way in which technology is transmitted, i.e. the authors only allow for disembodied technology diffusion, when a number of studies show that FDI and imports of capital goods are important channels of technological diffusion (see e.g., Xu and Wang (2000), Lee (2001), Mayer (2001), Crespo, Martín and

Velázquez (2004), Borensztein et al. (1998), Li and Liu (2005)). Besides disembodied technological diffusion and its interaction with education, the growth regression should thus also include specific channels of technology diffusion such as FDI and imports of capital goods, and their interaction with education.

From what has been said we can think of the following specification for the growth rate technology, $\Delta \log A(H)_{it}$:

$$\Delta \log A_{it} = c_i + c_t + gH_{it} + mH_{it} \log\left(\frac{A_{\max t-1}}{A_{it-1}}\right) + nOD_{it} + \omega(HxOD)_{it} + \varepsilon_{it} \tag{3}$$

where c_i is a country-specific component that represents changes in the efficiency with which inputs are used associated with the country characteristics that remain constant over time (e.g., climate, geography, language); c_t is a time-specific component, common to all countries (e.g., common macroeconomic shocks); OD represents one of the additional technological change determinants, R&D, international trade or FDI; and ε_{it} is an i.i.d. error term.

According to equation (3), the growth rate of technology in each country *i* at time *t* depends not only on human capital but also on an additional technological change determinant, both directly and through its interaction with education, representing the fact that the growth benefits from this other technological change determinant might require a certain amount of human capital to be fully exploited.

3. DATA[1]

Our sample consists of a balanced panel dataset that comprises 23 OECD countries from 1960 to 2000, in the widest sample, with observations grouped in 5-year periods. Data availability for some variables forced us to shorten the time period in the analysis in some of the regressions and drop some countries from the sample. In the appendix we provide the full list of countries in the sample.

We use Total Factor Productivity (TFP) growth as our empirical proxy for technological change or productivity growth and measure it as the difference between aggregate GDP growth and the rates of growth of physical capital and labour weighed by their shares in country GDP using a translog specification for the aggregate production function that allows us to consider that factor shares

[1] See the appendix for details.

vary across countries and time[2]. TFP growth refers to the average growth rate for each 5-year period between 1960 and 2000. Relative TFP measures the distance to the technological leader at the beginning of each 5-year period.

The education variable used is average years of schooling of the population measured at the beginning of each 5-year period. We use data on average years of schooling of the population aged 15 and over, total and for secondary and tertiary education from Barro and Lee (2001)[3].

R&D data concerns R&D expenditures as a percentage of GDP from the OECD Main Science and Technology Indicators. Imports data concerns imports of machinery as a percentage of GDP taken from the OECD International Trade by Commodity Statistics database. Finally, FDI data concerns FDI inflows as a percentage of GDP from the OECD International Direct Investment Statistics database. In the appendix we present some basic descriptive statistics for the data used in the regressions.

4. EMPIRICAL FINDINGS

We start by presenting the results from the estimation of our baseline growth specification (equation (2)) and then extend it to account for the influence of the other major determinants of technological change (equation (3)). We consider the influence of these variables one at a time in order to simplify the interpretation of the results and not to overextend the parameter requirements on the data. Nevertheless, we present the estimation results from what we call a joint growth specification where we consider only the statistically significant influences from the separate growth regressions in order to get an overall picture of the mechanisms through which education influences output growth.

We work with pooled cross-country and time series data in order to control for unobserved country-specific factors and endogeneity, two of the problems that can bias the results of empirical growth studies. We estimate our productivity growth regressions using the within groups (WG) estimator to

[2] We also tested the robustness of the results to the use of a Cobb-Douglas specification in the computation of TFP growth and levels but this did not significantly change the results.

[3] Since measurement error in the construction of the education data can influence the results on the impact of education on productivity growth we also tested the robustness of the results to the use of an alternative education dataset, De la Fuente and Doménech (2002) but this did not significantly change the results.

account for omitted country characteristics, while maintaining the exogeneity assumption concerning all the regressors in the analysis. To correct for heteroscedasticity in the data we use the Huber-White sandwich estimator of variance (see e.g., Huber (1967), White (1980), White (1982)). We also conduct a sensitivity analysis of the results to the possible endogeneity of the regressors using the first differenced GMM (Diff-GMM) estimator that considers lagged values of the endogenous variables as instruments (see Arellano and Bond (1991), Caselli et al (1996), Bond et al (2001) and the notes on each table for details).

[insert Table 1 here]

Table 1 presents the results of estimating this basic specification[4]. Romer (1990b) argues that technological advance requires more than the basic skills provided by the earlier stages of education, so *H*, human capital allocated to the R&D sector would correspond to tertiary education, and not aggregate education. We do not want to adopt such a definite distinction for the roles of the different schooling levels in the sense that, for instance, if innovation activities do require "scientific talent" which is only possible to acquire in higher education, the adoption of technologies originally developed in another country might only require skills at the secondary level.

We thus compare the results of estimating the basic specification with an aggregate education variable, *TYR*, with the ones from considering the influence over innovation and imitation activities of different education sub-categories, secondary, *SYR*, and tertiary education, *HYR*. Our main purpose is to select the relevant schooling level for each activity, before testing the robustness of the education results to the introduction of alternative technological change determinants.

Columns (1) to (10) present the results of estimating the Benhabib and Spiegel (1994) specification with the different education variables using within groups. We first introduce the direct impact alone of each education variable on TFP growth through the rate of innovation (columns (1), (3), (5), and (7)). The

[4] When presenting the results of the estimation of the different regressions in the respective tables we substitute the notation for the theoretical concept of technological efficiency, *A*, used when describing the equations for the notation corresponding to the proxy used, *TFP*. Following the same reasoning, the distance to the leader is represented by *RTFP* in the tables and $log(A_{max}/A_i)$ in the equations.

estimated coefficients are positive but only statistically significant at conventional levels when we consider higher schooling levels, *SHYR* and *HYR*.

When we additionally consider a role for each education variable through the rate of technology diffusion (columns (2), (4), (6), and (8)), the former estimated coefficients are no longer statistically significant but the estimated coefficients on the interaction terms between the education variables and relative TFP are positive and statistically significant as expected, confirming the role of education as a determinant of the absorptive capacity of OECD countries.

In column (9) we test a specification where *SHYR* influences productivity growth through the rate of innovation, since for the specifications that consider the direct influence of education alone it presents the highest R-squared, and where *TYR* influences productivity growth through technology diffusion since for the specifications that consider both influences of education it presents the highest R-squared. However, the results only support the influence of education through technology diffusion: the estimated coefficient on *SHYR* is positive as expected but not statistically significant.

Our preferred specification is (10) where we consider the only statistically significant influence, *TYRxRTFP*. The estimated coefficient is again positive and statistically significant. This result is contrary to that of Benhabib and Spiegel (1994) that find that, for their rich-countries sample, education matters for growth only as a determinant of the domestic rate of innovation[5].

For our sample of OECD countries education is important for productivity growth since it allows to fully exploit the benefits from technological spillovers. Additionally, it is overall educational attainment that has the highest explanatory power. The results presented above do not support any direct role for education as a determinant of domestic innovation activities. It can be the case nevertheless that education matters for the production of new knowledge through its interaction with R&D efforts.

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[5] Notice however that our OECD sample is not the same as Benhabib and Spiegel (1994) wealthiest-third sample. On the one hand they do not consider OECD countries like Austria, Belgium, Iceland, the Netherlands, Finland, or Switzerland, and on the other hand they include countries like Argentina, Chile, Iraq, or Venezuela in the "rich" countries sample, determined by the initial GDP per capita levels. For instance, Engelbrecht (2003) reports cross-section results for the 19 OECD countries in the Benhabib and Spiegel (1994) sample using their original human capital data set and gets insignificant coefficients on both the domestic innovation and the technology diffusion component. Estimating the same equation for a sample of 25 OECD countries with the Barro and Lee (2001) and the De la Fuente and Domenéch (2002) human capital data sets, Engelbrecht (2003) also reports a positive and significant coefficient for the technology diffusion component, and a negative and sometimes significant coefficient for the domestic innovation component.

We proceed with our empirical analysis of the importance of education for productivity growth by adding to our basic specification the additional technological change determinants in order to clarify the different channels through which education exerts its influence and to check the robustness of the education results to the introduction of these variables (equation (3)).

[insert Table 2 here]

Table 2 reports the results of the estimation of the growth specification considering the different influences of R&D efforts proxied by R&D expenses as a percentage of GDP. The sample period was reduced to 30 years from 1970 to 2000 and the number of countries is now twenty-two (Turkey is not included) due to R&D data availability. We replicated the selected specification from the previous table in column (1) confirming the positive influence of average years of total schooling through technology diffusion.

Regarding the results when R&D expenses are introduced as an additional explanatory variable, the estimated coefficient of the interaction term between relative *TFP* and *TYR* do not change, i.e. it is always positive and statistically significant whatever the specification considered.

When the influence of R&D expenses is considered alone (column (2)) the estimated coefficient is positive and statistically significant as expected. In column (3) we introduce additionally the influence of R&D as a facilitator of technology diffusion but the estimated coefficient is negative, although not statistically significant, so we drop it from the analysis.

In columns (4)-(7) we test additionally the hypothesis that education enhances productivity growth benefits from R&D efforts by introducing interaction terms between *R&D* and the different education variables. The results confirm this hypothesis since the estimated coefficients of all interaction terms are positive and statistically significant as expected. When the interaction term between *R&D* and *TYR* (column (4)) is considered the direct impact of R&D becomes negative and statistically significant, in columns (5) and (6) it is negative but not statistically significant, and in column (7) it is positive and significant. We retain specification (6) that considers the interaction between *R&D* and *SHYR* as our preferred specification since it presents the highest R-squared. In column (8) we estimate the selected specification considering only the statistically significant influences. The results confirm the positive influence of both variables, *TYRxRTFP* and *R&DxSHYR*.

According to our results, education influences positively productivity growth through innovation activities due to its complementarity with R&D efforts. Additionally, it is not overall educational attainment that matters the most but only education at higher levels, secondary and tertiary. These results are in line with the predictions of Romer (1990b), Bailey and Eicher (1994), and Storesletten and Zilibotti (2000), i.e. they support the argument of endogenous growth theory that only that part of the labour force with advanced education will be able to conduct domestic R&D activities. We will consider the influence of R&D interacted with average years of secondary and tertiary schooling in our joint specification.

[insert Table 3 here]

Table 3 reports the results for the basic specification considering additionally the GDP ratio of imports of machinery (*IMPS*)[6] and its interaction with education as determinants of technology diffusion. The sample was reduced to twenty-two countries since Austria did not report imports data for the period 1980-1990. Column (1) replicates the selected specification for the baseline specification confirming the positive influence of *TYR* through technology diffusion.

Regarding the importance of imports of machinery for productivity growth, the results concerning the interaction term between relative TFP and *TYR* do not change. In column (2) we introduce the influence of *IMPS* alone confirming its positive influence. However, when the interaction term with the education variables is considered simultaneously (columns (3)-(6)) the estimated coefficient on the direct impact is not statistically significant (except in column (6)).

We select as our preferred specification (3) that considers the interaction term between imports and overall educational attainment since it presents the highest R-squared. In column (7) we drop the direct influence of *IMPS* from the regression since it was not statistically significant confirming the importance of

[6] We also run regressions considering the GDP ratios of imports of machinery and transportation equipment together and imports of transportation equipment alone. We concluded that the results in the first case were driven by the results relative to imports of machinery alone since the estimated coefficients when considering imports of transportation equipment separately were never statistically significant.

education to benefit from technology diffusion incorporated in imports of machinery.

The results achieved reveal that potential productivity growth improvements associated with technology spillovers incorporated in machinery imports are enhanced by education investments, as defended by among others Bartel and Lichtenberg (1987) and tested by Mayer (2001). Our joint specification of the importance of the different technological change determinants for TFP growth will thus include the interaction term between international trade and average years of total schooling.

[insert Table 4 here]

Table 4 reports the results for the basic specification considering now the GDP ratio of FDI inflows and its interaction with education as determinants of embodied technology diffusion. The sample was reduced to just nineteen countries since Greece, Norway, Portugal and Turkey did not report data for most of the period. We also had to reduce the period coverage to twenty years from 1980 to 2000.

Column (1) again replicates the selected specification from the baseline specification confirming the positive influence of *TYR* through technology diffusion. This result does not change when we introduce the different influences of FDI on productivity growth.

Regarding the importance of FDI inflows for TFP growth, when we consider its direct influence alone (column (2)) the respective estimated coefficient is positive and statistically significant as expected. When we additionally consider the interaction of FDI with the different education variables (columns (3)-(6)), the estimated coefficients on the interaction terms are all negative contrary to what expected and statistically significant when the interaction between FDI and *TYR* and FDI and *HYR* are considered, a result hard to reconcile with economic theory. The direct impact of FDI is still positive and statistically significant.

We retain specification (3) that considers the direct influence of FDI and the influence of FDI interacted with *TYR* on TFP growth as our preferred specification since it presents the highest R-squared.

Contrary to what expected, the results achieved reveal that potential productivity growth improvements associated with technology spillovers incorporated in FDI are hindered by investments in education, a result difficult to interpret in economic terms. Our joint specification will nevertheless include the direct influence of FDI and its interaction with total years of schooling.

Finally, we tested a joint productivity growth specification that retains the statistically significant influences identified in the previous analysis. From the empirical analysis of the basic specification we retain the influence of average years of total schooling in the absorptive capacity of the economies. The statistical significant influences retained from the previous sections concerning the additional technological change determinants are the interaction term between R&D efforts and average years of secondary and tertiary education, the interaction term between imports of machinery and average years of total schooling, the direct influence of FDI, and the interaction term between FDI and average years of total schooling.

[insert Table 5 here]

Table 5 reports the results of the estimation of the joint specification using the within groups and the first differenced GMM estimators. Data availability across R&D, imports and FDI data sets implied reducing the sample to just eighteen countries for the 1980-2000 period. Since the results for FDI reveal not to be robust we also test a specification without its influence for a sample of twenty-one countries for the period 1970-2000.

The results using the within groups (WG) estimator (columns (1)-(2)) confirm the positive and statistically significant influence of overall educational attainment through both disembodied and embodied technology diffusion and the influence of average years of secondary and tertiary education through its interaction with R&D efforts using either of the education data sets, and the direct influence of FDI and its interaction with average years of total schooling. In column (2) we thus ignore the FDI influences and confirm the remaining ones with both data sets.

In columns (3)-(4) we present the results using the first differenced GMM (Diff-GMM) estimator. We consider all the regressors as potentially endogenous and use the adequate lagged values as instruments. Since education is measured at the beginning of each period we consider it as predetermined. The remaining explanatory variables are measured as period averages so we consider them as weakly exogenous. The results with the Diff-GMM estimator confirm most of the previous results (the exception is the *IMPS* coefficient negative and statistically significant). In this case only the FDI influences reveal not to be statistically significant (column (3)). In column (4) we ignore the FDI influences and the results support the remaining influences. The employed specification tests support the GMM estimation of our model: the Sargan test and second-order serial correlation tests *p-values* are within the acceptable values (although the latter is not very high) and cannot reject the null hypothesis of correct specification of the different models.

In conclusion, the results of the estimation of the joint specification endorse the ones from the previous sections regarding the importance of education for productivity growth. As far as innovation activities are concerned, the direct role of education emphasized by endogenous growth literature is not confirmed but its influence in the production of new knowledge is still felt due to its association with R&D efforts, supporting in this respect the argument of endogenous growth theory that only that part of the labour force with advanced education will be able to conduct domestic R&D activities. The productivity growth benefits from education are not exhausted in innovation activities, as predicted by Nelson and Phelps (1966). Overall educational attainment that includes primary, secondary and tertiary schooling can accurately assess the importance of education to absorb both disembodied and embodied technology developed abroad.

The results do not support any influence for FDI, neither directly nor through its interaction with the education variables. This might indicate that FDI influences productivity growth through channels other than the existence of a qualified workforce. For instance, the positive impact of FDI might require a modern financial system and a sufficiently flexible regulatory framework that enables the creation of new firms by workers that acquired new knowledge when working for multinationals. It might also be the case that FDI does not have a positive impact in all industries (e.g. FDI crowds out domestic innovation) so that a country-level analysis does not allow us to distinguish between opposite sign effects that might cancel out in the aggregate.

Based on these results we can quantify the contribution of education for TFP growth in each OECD country highlighting the relative importance of its contribution through innovation and imitation activities.

We use the estimated coefficients from column (4), Table 5 concerning: (i) the interaction term between R&D and average years of secondary and tertiary education to quantify the impact of education through innovation activities

($\hat{n}_2$=0.002); (ii) the interaction term between relative TFP and average years of total education to quantify the impact through disembodied technology diffusion ($\hat{m}$=0.0085); and (iii) the interaction term between imports of machinery and average years of total schooling to quantify the impact through embodied technology diffusion ($\hat{\omega}_2$=0.0007).

This quantification is possible for the twenty-one countries that constitute the sample used to estimate our joint specification over the period 1970-2000 with the BL schooling data. For each country the contribution of education to productivity will depend positively on the respective average R&D expenditures, distance to the technological frontier, and GDP ratio of imports of machinery.

[insert Table 6 here]

Table 6 reports the results of the contribution of education to TFP in twenty-one OECD countries over the period 1970-2000. Regarding the impact of education through innovation activities it is higher in Sweden, the US, Japan, and Switzerland countries that spent on average more than 2.5% of its GDP in R&D. On the contrary it is lower in Greece, Portugal, Spain, and Ireland that spent on average less than 1% of its GDP in R&D.

The impact through disembodied technology diffusion was higher in the countries on average further away from the technological frontier Greece, Portugal, Japan, and Ireland, and lower in the leaders, Belgium, the US, France, and the Netherlands.

The impact through technology diffusion embodied in imports of machinery was higher in Belgium, Ireland, the Netherlands, and Sweden, smaller more open countries that present higher imports ratios, and lower in Japan, the US, Italy, and Germany, bigger less open countries.

In most countries the quantitative impact from imitation activities is higher than that of innovation activities. In the US, France, Japan, Germany, and Switzerland the impact of education through domestic innovation is quantitatively more important. In Sweden, the United Kingdom and the Netherlands it is roughly the same as through imitation activities. In Greece, Portugal, Ireland, Spain, New Zealand and Iceland the impact through the adoption of technology developed abroad is distinctively higher.

5. Summary and Conclusions

The aim of this paper was to conduct a systematic econometric search of the different ways through which education influences productivity growth at the aggregate cross-country level in OECD countries, highlighting possible interactions with other technological change determinants and specific roles for educational sub-categories. According to endogenous growth theory, while a university education is generally viewed as necessary condition for the domestic production of new knowledge, technology diffusion may only require skills provided by a broader educational category that includes primary, secondary and tertiary education.

The econometric analysis of the importance of education for productivity growth took the Benhabib and Spiegel (1994) specification as the benchmark regression but tried to improve it by conducting a systematic search of productivity growth determinants ignored by the authors but highlighted by the theoretical and empirical growth literature reviewed earlier on, R&D efforts, international trade and FDI, in a panel data framework.

The estimation of the basic specification revealed that education speeds technology diffusion among OECD countries with overall educational attainment as the relevant schooling variable to benefit from disembodied technology transfers. This result is contrary to that of Benhabib and Spiegel (1994) for their rich countries sample, according to which education matters for innovation but not for imitation activities, and is robust to the introduction of the additional determinants of technological change and growth. The estimated coefficient associated with the domestic innovation term, on the other hand, is never statistically significant.

Regarding the influence of the additional determinants of technological change, the results reveal that to fully exploit the benefits from R&D expenses in terms of productivity growth, OECD countries need a sufficient level of secondary and tertiary education, thus confirming the argument of endogenous growth theory that innovation is the engine of growth which in turn requires advanced skills.

Concerning the introduction of imports of machinery as the vehicle through which technology is transferred from the leader to the followers, the empirical findings endorsed the hypothesis that its productivity growth benefits are enhanced when interacted with the educational attainment of the population, with overall educational attainment as the relevant education variable to fully take advantage of this kind of embodied technology diffusion. Finally, the results regarding the introduction of FDI do not support the hypothesis of a positive direct influence neither its complementarity with education.

The confirmation that education has positive and statistically significant effects on productivity growth through both innovation and the absorption of technology from abroad allowed us to quantify its relative importance through these different channels for technological change in each country. This exercise revealed that the influence through the adoption of technology developed abroad is quantitatively more important in most countries. Since these benefits from technology diffusion are bound to be exhausted as countries close the technology gap, sustained productivity growth demands a change of focus from imitation to innovation activities. As expected, the countries responsible for most of the R&D efforts in the World economy, the US, France, Japan, and Germany, are the ones where the impact of education through innovation activities is quantitatively more important.

Some immediate policy implications follow from these findings. The main policy implication from our point of view is that policy reforms aimed at improving productivity growth cannot be undertaken separately – educational policy reforms should be outlined at the same time as R&D and trade policy reforms. These results imply a need for government policy to sustain incentives for human capital formation, R&D activities and a reduction of the costs associated with the adoption of technology incorporated in international trade. The coordination of such efforts is crucial for productivity growth.

Moreover, as far as educational policies are concerned, the composition of human capital is also important to fully exploit the growth benefits of the different technological change determinants, i.e. policy on education cannot focus solely on a quantity dimension. While education at the secondary and tertiary levels allows benefiting from growth due to domestic innovation, overall educational attainment is especially important to achieve productivity and growth improvements through technology spillovers embodied in imports of machinery. As OECD countries close the technology gap, only education at higher levels will allow them to sustain productivity improvements since this is the relevant schooling level to benefit from R&D efforts.

The evidence that we have presented is reassuring in the sense that it endorses investments in education as a means of improving the growth performance of

OECD countries. It is nevertheless open to improvements. The incorporation of the study of the impact of high quality tertiary educational capital (e.g. scientists and engineers), for instance, could provide an answer to the puzzling results regarding the direct role of education through the domestic rate of innovation. The importance of the different schooling levels and the several potential channels through which they exert their growth influence should also be explored in the context of other data sets covering wider country samples that include both developed and developing countries.

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APPENDIX

Table A.1. - Sample of OECD countries

Australia	Greece	Portugal
Austria	Iceland	Spain
Belgium	Ireland	Sweden
Canada	Italy	Switzerland
Denmark	Japan	Turkey
Finland	Netherlands	United Kingdom
France	New Zealand	United States
Germany	Norway	

Table A.2 - Descriptive statistics

Variable	Mean	Std. Dev.	Minimum	Maximum
Growth rate of TFP (%)	1.88	0.67	0.50	3.19
Distance to the leader (RTFP)	1.343	0.319	1.022	2.475
Average years of total schooling	7.757	2.219	1.860	11.892
Average years of secondary schooling	2.602	0.666		
Average years of tertiary schooling	0.316	0.256	0.014	1.333
R&D expenses as a percentage of GDP (%)	1.527	0.762	0.150	3.513
Imports of machinery as a percentage of GDP (%)	23.82	5.85	10.89	37.22
FDI inflows as a percentage of GDP (%)	1.67	2.25	0.012	12.91

Notes: Data at 5-year intervals for 23 OECD countries between 1960 and 2000. The distance to the leader is computed as $RTP=TFP_{leader}/TFP_{countryi}$. The technological leader presents a value equal to one. The further from the leader a country is, the higher this value. R&D data is for 21 countries for the period 1970-2000. Imports data is for 22 countries for the period 1960-2000. FDI data is for 19 countries for the period 1980-2000. See the main text for details.

Output: GDP in 1995 constant international USD. We converted data on real GDP at constant 1995 prices in local currency from the AMECO database, Spring 2005 edition into constant international USD using AMECO's GDP PPPs.

Physical capital: real capital stock expressed in 1995 constant international USD. We converted data on real physical capital stock at constant 1995 prices in local currency from the AMECO database, Spring 2005 edition into constant international USD using AMECO's GDP PPPs.

Labour input: annual hours worked from the Groningen Growth and Development Centre and The Conference Board, Total Economy Database, January 2005.

Education: average years of education, total and by schooling level, from Barro and Lee (2001) and De la Fuente and Doménech (2002).

R&D: Gross Domestic Expenditure on R&D (GERD) as a percentage of GDP from the OECD Main Science and Technology Indicators, OECD (2003b).

International trade: imports of machinery from the other 22 OECD countries as a percentage of GDP.

$$IMPS_{it} = \frac{IMPSMACH_{22t}}{GDP_{it}} x100$$

where $IMPSMACH_{it}$ is imports of machinery from the other 22 OECD countries of country i at time t in thousands of current USD and GDP_{it} is Gross Domestic Product at current market prices in thousands of USD. Imports data was taken from the OECD International Trade by Commodity Statistics database, OECD (2002d) and OECD (2005).

FDI: FDI inflows as a percentage of GDP. FDI data comes from the OECD International Direct Investment Statistics, OECD (2004a), and covers the period 1980 to 2000 expressed in millions of USD. We used data on GDP at current prices in USD from the AMECO database to compute the FDI GDP ratio as:

$$FDI_{it} = \frac{FDI\mathrm{inf}lows_{it}}{GDP_{it}} x100$$

where $FDIinflows_{it}$ is the amount of FDI received by country i at time t in millions of current USD and GDP_{it} is Gross Domestic Product at current market prices in millions of USD.

Table 1. The basic specification, OECD countries

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
TYR_{t-1}	0.0012	0.00005								
	(0.536)	(0.0203)								
$TYRxRTFP_{t-1}$		**0.0045**							**0.0043**	**0.0045**
		(2.59)							**(2.61)**	**(2.64)**
SYR_{t-1}			0.0032	0.0013						
			(1.15)	(0.489)						
$SYRxRTFP_{t-1}$				**0.0099**						
				(1.86)						
$SHYR_{t-1}$					**0.0037**	0.002			0.0029	
					(1.45)	(0.741)			(1.13)	
$SHYRxRTFP_{t-1}$						**0.009**				
						(1.92)				
HYR_{t-1}							**0.0150**	0.0024		
							(1.95)	(0.196)		
$HYRxRTFP_{t-1}$								**0.0632**		
								(2.31)		
$\bar{R}$ -squared	0.444	0.488	0.449	0.473	0.453	0.477	0.452	0.469	0.495	0.488
No. Countries	23	23	23	23	23	23	23	23	23	23
Time coverage	1960-2000	1960-2000	1960-2000	1960-2000	1960-2000	1960-2000	1960-2000	1960-2000	1960-2000	1960-2000
No. Obs.	184	184	184	184	184	184	184	184	184	184

Notes: Dependent variable is the 5-year average growth rate of TFP computed assuming a translog production function specification and adjusted for total hours worked. The results are robust to the use of alternative production function specifications (Cobb-Douglas) and employment as the labour input. TYR is average years of total schooling, SYR is average years of secondary schooling, SHYR is average years of secondary and tertiary schooling, HYR is average years of tertiary schooling, for the population aged 15 and over from the Barro and Lee (2001) data set measured at the beginning of each 5-year period. RTFP is the log of the coefficient of the TFP level of the leader over that of the country under analysis measured at the beginning of each 5-year period. All regressions include a full set of time dummies and country fixed effects. Heteroscedasticity-consistent t-statistics in parenthesis. Coefficients in bold are significant at least at the 10% significance level.

Table 2. The basic specification with R&D expenditures, OECD countries

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$(TYRxRTFP)_{t-1}$	**0.0055**	**0.0053**	**0.0061**	**0.0051**	**0.0054**	**0.0053**	**0.005**	**0.0052**
	(2.57)	**(2.46)**	**(1.61)**	**(2.39)**	**(2.43)**	**(2.42)**	**(2.39)**	**(2.43)**
$(R\&D)_t$		**0.0051**	**0.0068**	**-0.0088**	-0.003	-0.003	**0.0036**	
		(2.09)	**(1.94)**	**(-1.45)**	(-0.75)	(-0.77)	**(1.37)**	
$(R\&D)_t\ xRTFP_{t-1}$			-0.006					
			(-0.46)					
$(R\&D)_t\ xTYR_{t-1}$				**0.0014**				
				(2.38)				
$(R\&D)_t\ xSYR_{t-1}$					**0.0019**			
					(2.30)			
$(R\&D)_t\ xSHYR_{t-1}$						**0.0018**		**0.0014**
						(2.34)		**(2.98)**
$(R\&D)_t\ xHYR_{t-1}$							**0.0048**	
							(1.61)	
$\bar{R}$ -squared	0.277	0.291	0.292	0.316	0.316	0.318	0.3	0.316
No. Countries	22	22	22	22	22	22	22	22
Time coverage	1970-2000	1970-2000	1970-2000	1970-2000	1970-2000	1970-2000	1970-2000	1970-2000
No. Obs.	132	132	132	132	132	132	132	132

Notes: Dependent variable is the 5-year average growth rate of TFP computed assuming a translog production function specification and adjusted for total hours worked. The results are robust to the use of alternative production function specifications (Cobb-Douglas) and employment as the labour input. TYR is average years of total schooling, SYR is average years of secondary schooling, SHYR is average years of secondary and tertiary schooling, HYR is average years of tertiary schooling, for the population aged 15 and over from the Barro and Lee (2001) data set measured at the beginning of each 5-year period. RTFP is the log of the coefficient of the TFP level of the leader over that of the country under analysis measured at the beginning of each 5-year period. R&D is the GDP ratio of R&D expenditures measured as 5-year averages. All regressions include a full set of time dummies and country fixed effects. Heteroscedasticity-consistent t-statistics in parenthesis. Coefficients in bold are significant at least at the 10% significance level.

Table 3. The basic specification with imports of machinery, OECD countries

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$(TYRxRTFP)_{t-1}$	**0.0051**	**0.0058**	**0.0059**	**0.0062**	**0.0060**	**0.0055**	**0.0059**
	(2.42)	**(3.46)**	**(4.08)**	**(4.05)**	**(4.09)**	**(3.34)**	**(4.10)**
$IMPS_t$		**0.0038**	-0.001	0.0012	0.0009	**0.0025**	
		(2.60)	(-0.48)	(0.616)	(0.483)	**(1.38)**	
$IMPS_t$ x$(TYR)_{t-1}$			**0.0006**				**0.0005**
			(2.10)				**(3.96)**
$IMPS_t$ x$(SYR)_{t-1}$				**0.0008**			
				(1.91)			
$IMPS_t$ x$(SHYR)_{t-1}$					**0.0007**		
					(1.95)		
$IMPS_t$ x$(HYR)_{t-1}$						0.0020	
						(1.11)	
$\bar{R}$ -squared	0.406	0.448	0.474	0.472	0.472	0.456	0.473
No. Countries	22	22	22	22	22	22	22
Time coverage	1965-2000	1965-2000	1965-2000	1965-2000	1965-2000	1965-2000	1965-2000
No. Obs.	154	154	154	154	154	154	154

Notes: Dependent variable is the 5-year average growth rate of TFP computed assuming a translog production function specification and adjusted for total hours worked. The results are robust to the use of alternative production function specifications (Cobb-Douglas) and employment as the labour input. TYR is average years of total schooling, SYR is average years of secondary schooling, SHYR is average years of secondary and tertiary schooling, HYR is average years of tertiary schooling, for the population aged 15 and over from the Barro and Lee (2001) data set measured at the beginning of each 5-year period. RTFP is the log of the coefficient of the TFP level of the leader over that of the country under analysis measured at the beginning of each 5-year period. IMPS is the GDP ratio of imports of machinery measured as 5-year averages. All regressions include a full set of time dummies and country fixed effects. Heteroscedasticity-consistent t-statistics in parenthesis. Coefficients in bold are significant at least at the 10% significance level.

Table 4. The basic specification with FDI inflows, OECD countries

	(1)	(2)	(3)	(4)	(5)	(6)
$(TYRxRTFP)_{t-1}$	**0.0085**	**0.0097**	**0.0114**	**0.0098**	**0.0100**	**0.0109**
	(1.76)	**(2.47)**	**(2.73)**	**(2.41)**	**(2.42)**	**(2.59)**
FDI_t		**0.0016**	**0.0073**	0.0019	**0.0023**	**0.0036**
		(2.39)	**(1.61)**	(1.24)	**(1.30)**	**(2.36)**
FDI_t x$(TYR)_{t-1}$			**-.0006**			
			(-1.33)			
FDI_t x$(SYR)_{t-1}$				-.00005		
				(-0.209)		
FDI_t x$(SHYR)_{t-1}$					-.0002	
					(-0.43)	
FDI_t x$(HYR)_{t-1}$						**-0.003**
						(-1.43)
$\bar{R}$ -squared	0.274	0.348	0.362	0.348	0.349	0.360
No. Countries	19	19	19	19	19	19
Time coverage	1980-2000	1980-2000	1980-2000	1980-2000	1980-2000	1980-2000
No. Obs.	76	76	76	76	76	76

Notes: Dependent variable is the 5-year average growth rate of TFP computed assuming a translog production function specification and adjusted for total hours worked. The results are robust to the use of alternative production function specifications (Cobb-Douglas) and employment as the labour input. TYR is average years of total schooling, SYR is average years of secondary schooling, SHYR is average years of secondary and tertiary schooling, HYR is average years of tertiary schooling, for the population aged 15 and over from the Barro and Lee (2001) data set measured at the beginning of each 5-year period. RTFP is the log of the coefficient of the TFP level of the leader over that of the country under analysis measured at the beginning of each 5-year period. FDI is the GDP ratio of FDI inflows measured as 5-year averages. All regressions include a full set of time dummies and country fixed effects. Heteroscedasticity-consistent t-statistics in parenthesis. Coefficients in bold are significant at least at the 10% significance level.

Table 5. The joint specification, OECD countries

	(1) WG	(2) WG	(3) Diff-GMM	(4) Diff-GMM
$TYRxRTFP_{t-1}$	**0.0125**	**0.0058**	**0.0157**	**0.0085**
	(4.09)	**(3.83)**	**(2.26)**	**(2.05)**
$(R\&D)_t xSHYR_{t-1}$	**0.0010**	**0.0009**	**0.0047**	**0.0020**
	(1.58)	**(1.57)**	**(1.61)**	**(1.64)**
$(IMPS)_t xTYR_{t-1}$	**0.0005**	**0.0003**	**-0.0007**	**0.0007**
	(1.92)	**(2.31)**	**(-1.31)**	**(2.51)**
FDI_t	**0.0104**		0.0110	
	(2.70)		(0.920)	
FDI_t x$(TYR)_{t-1}$	**-0.001**		-0.0008	
	(-2.72)		(-0.62)	
$\bar{R}$ -squared	0.475	0.344		
Sargan test [*p-value*]			15.68 [0.267]	16.14 [0.849]
AR(2) [*p-value*]			0.4006 [0.689]	2.388 [0.017]
No. Countries	18	21	18	21
Time period	1980-2000	1970-2000	1980-2000	1970-2000
No. Obs.	72	126	54	105

Notes: Dependent variable is the 5-year average growth rate of TFP computed assuming a translog production function specification and adjusted for total hours worked. The results are robust to the use of alternative production function specifications (Cobb-Douglas) and employment as the labour input. TYR is average years of total schooling, SYR is average years of secondary schooling, SHYR is average years of secondary and tertiary schooling, HYR is average years of tertiary schooling, for the population aged 15 and over from the Barro and Lee (2001) data set, measured at the beginning of each 5-year period. RTFP is the log of the coefficient of the TFP level of the leader over that of the country under analysis measured at the beginning of each 5-year period. R&D is the GDP ratio of R&D expenditures measured as 5-year averages. IMPS is the GDP ratio of imports of machinery measured as 5-year averages. FDI is the GDP ratio of FDI inflows measured as 5-year averages. All regressions include a full set of time dummies. Heteroscedasticity-consistent t-statistics in parenthesis. Coefficients in bold are significant at least at the 10% significance level. Instruments used in Diff-GMM are values of all variables included in the respective specification lagged two to four periods. Since the cross-sectional dimension of our data set is small to avoid over-fitting problems we work with a reduced number of instrumental variables so we only use the first acceptable lag and lags up to the fourth as instruments for the endogenous variables (weakly exogenous and predetermined). Results for the one-step GMM estimator with standard errors robust to heteroscedasticity since the standard errors of the two-step GMM estimator can be seriously biased downwards.

Table 6. Contribution of education to TFP growth in 21 OECD countries, 1970-2000

Country	Av. R&D	Av. RTFP	Av. IMPS	Innovation ($\hat{n}_2$=0.002)	Disembodied Technology Diffusion ($\hat{m}$=0.0085)	Embodied Technology Diffusion ($\hat{\omega}_2$=0.0007)
Australia	1.24	0.1677	2.98	0.0025	0.0014	0.0021
Belgium	1.58	0.0218	7.89	0.0032	0.0002	0.0055
Canada	1.41	0.1100	5.57	0.0028	0.0009	0.0039
Denmark	1.37	0.1748	4.93	0.0027	0.0015	0.0034
Finland	1.66	0.2934	5.21	0.0033	0.0025	0.0036
France	2.07	0.0595	3.07	0.0041	0.0005	0.0021
Germany	2.39	0.1623	2.88	0.0048	0.0014	0.0020
Greece	0.31	0.4737	3.25	0.0006	0.0040	0.0023
Iceland	1.03	0.2932	4.61	0.0021	0.0025	0.0032
Ireland	0.89	0.3377	10.76	0.0018	0.0029	0.0075
Italy	0.98	0.1371	2.45	0.0020	0.0012	0.0017
Japan	2.49	0.3661	0.54	0.0050	0.0031	0.0004
Netherlands	1.97	0.0572	6.45	0.0039	0.0005	0.0045
New Zealand	0.90	0.2352	4.42	0.0018	0.0020	0.0031
Norway	1.42	0.1716	5.02	0.0028	0.0015	0.0035
Portugal	0.43	0.4664	5.53	0.0009	0.0040	0.0039
Spain	0.58	0.2420	3.12	0.0012	0.0021	0.0022
Sweden	2.55	0.2001	5.68	0.0051	0.0017	0.0040
Switzerland	2.48	0.1448	5.11	0.0050	0.0012	0.0036
United Kingdom	2.09	0.2471	3.97	0.0042	0.0021	0.0028
United States	2.51	0.0341	1.17	0.0050	0.0003	0.0008

Notes: the parameters used in the computations were taken from column (4), Table 5.
Av. R&D is the average of R&D expenditures as a percentage of GDP for the period.
Av. RTFP is the average of relative TFP for the period.
Av. IMPS is the average of imports of machinery as a percentage of GDP for the period.

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