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EDUCATION AND GROWTH: AN INDUSTRY-LEVEL ANALYSIS OF THE PORTUGUESE MANUFACTURING SECTOR

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Abstract

This paper investigates the education–growth link at the more disaggregate industry level in the Portuguese manufacturing sector with a focus on different levels of education. The insights from new growth theory and a modified and augmented version of the Benhabib and Spiegel (1994) specification are the basis for the empirical analysis of the role of education in innovation and imitation activities highlighting a role for specific schooling levels across industries according to their technological characteristics and its interaction with international trade. We use data for the period 1986–1997, fourteen Portuguese manufacturing industries and panel data econometric techniques. Our most robust finding concerns the relevance of technology spillovers embodied in imports for productivity growth, as long as manufacturing industries employ workers with skills provided by secondary education. The Portuguese manufacturing industry cannot rely on automatic technological catch up for productivity growth so active trade and education policies are crucial to recover from the present bottom position in the rank of OECD productivity levels.

JEL Classification: C23; I20; O30; O33

Keywords: education, innovation, technology diffusion, productivity growth, panel data

1. INTRODUCTION

This paper analyses the importance of education for productivity growth in the Portuguese economy at the sectoral level focusing on fourteen manufacturing industries during the period 1986–1997. The contribution of education for technological change and economic growth at the aggregate country level in the Portuguese economy has been addressed in a small set of papers but there is no work, to our knowledge, that studies this issue from this more disaggregate industry level perspective. This is in our opinion an important shortcoming of the analysis of the causes of growth in the Portuguese economy since the manufacturing sector has been responsible for most of the aggregate growth in developed countries (see Scarpetta et al. (2000)), Portugal included (see Aguiar and Martins (2005)).

We want specifically to investigate if disparities in productivity growth rates across Portuguese manufacturing industries are related to workers' education levels and international trade, an unquestionable source of growth of the Portuguese economy (see e.g., Silva Lopes (1996), Neves (1994), Afonso and Aguiar (2005)), particularly in what concerns industries with different technological characteristics since traditional industries represent the biggest share of the Portuguese manufacturing sector.

We use the predictions from endogenous growth theory on the relationship between human capital, technological change, and growth and a modified and augmented version of the Benhabib and Spiegel (1994) empirical growth specification to empirically asses the importance of education for productivity growth. Particularly, we want to estimate the effects of the two separate influences of education on Portuguese manufacturing industry's productivity performance – domestic innovation and technological diffusion (relative to the United States, the frontier country) - emphasizing the interactions with the other technological change determinant, international trade, and potential distinct roles for each educational sub-category.

The low educational levels of the Portuguese workforce can constitute impediments to higher rates of productivity growth if a skilled workforce contributes to higher productivity growth through its influence on the domestic rate of innovation and to the exhaustion of catch up gains from imitation. Since, as we show below, the levels of TFP in Portugal lie well below the US levels in all manufacturing industries throughout the sample period, none of the Portuguese manufacturing industries has exhausted the catch up gains from imitation and one of the main reasons for this situation can be the low education levels of its workforce. For instance, Lança (2000) based on a survey that included 1157 firms of the Portuguese manufacturing industry during 1996 and 1997, concludes that the educational attainment of the workforce constitutes the major comparative disadvantage of the manufacturing sector with 65% of the firms with employees with at most primary education and about half with no employee with tertiary education.

Empirical evidence for the Portuguese manufacturing industries favours the hypothesis that education at the secondary level is crucial to exploit the productivity growth benefits from embodied technology diffusion in all industries. Disaggregating the sample in low technology and high technology industries reveals that the only influence that is common to both industry groups is that of technology spillovers incorporated in imports from OECD countries, as long as industries employ a workforce with qualifications at least and the secondary level. Common to both industry groups is also the fact that the empirical evidence does not support a direct influence for relative TFP indicating that technological catch up is not an automatically guaranteed process. Additionally, the results concerning the influence of TFP growth of the leader for the whole sample are driven by low technology industries.

The remainder of this paper is structured as follows. The following section briefly describes the patterns of growth of the Portuguese manufacturing sector during the second half of the twentieth century. Section 3 describes the empirical specification and provides an overview of the data used. The results from the empirical analysis are presented in Section 4. Finally, conclusions may be found in Section 5.

0. PATTERNS OF GROWTH IN THE PORTUGUESE MANUFACTURING SECTOR

According to Scarpetta, Bassanini, Pilat and Schreyer (2000), in 1950 aggregate GDP per man-hour in Portugal was only 20 per cent of that of the United States, the second lowest value in the EU15 only surpassed by Greece with a GDP per man-hour at 19 percent of the US value, the country at the top of the OECD income distribution. By 1973, Portugal had considerably improved its situation with GDP per man-hour at 42 per cent of the US value and this improvement continued until 1998 (with GDP per man-hour at 50 per cent of the US value) although at a much slower rate in the 1980s and the 1990s. Over the last two decades of the twentieth century, GDP per man-hour grew around 2.2% annually in both decades, higher than the average OECD value.

Multi-factor productivity also grew at an average annual rate of 1.9% and 2.2%, respectively.

At the manufacturing sector level however the performance of the Portuguese economy was not so impressive. In 1950, GDP per person employed represented only 10.2% of the US level, by 1970 it had more than doubled its value reaching 21.1%, in 1980 it represented 26.3% of the US level, but it fell to 24.8% in 1990 and to 23.2% in 1995. Although most European countries showed the same tendency to stop converging to the US standards at the manufacturing sector level in the 1990's, Portugal's situation raises more concerns since it is still far behind and at the bottom rank of OECD productivity levels. In fact, in 1995 productivity in Portugal relative to the USA was lower than that of Mexico (25.6%) and Korea (43.3%) with this last country maintaining its tendency to converge to the US levels. The same conclusion is reached by Lança (2001) according to whom the performance of the Portuguese manufacturing sector productivity relative to the USA is especially poor from 1973 until 1972, especially when compared to that of Spain.

Aguiar and Martins (2005) analyse the growth cycles of the Portuguese industry[1] productivity, measured as value added per worker, during the twentieth century identifying industry productivity as the main factor behind the increase in Portuguese income per capita during this period[2]. According to the authors, the recent growth experience of the Portuguese industry can be divided into three broad episodes that cover the periods 1951-1973, 1974-1984, and 1985-2000. These fluctuations were a major determinant of the catch up (or lack of) of Portuguese income levels towards the developed countries levels and is thus of major importance to study its causes, especially since, as Aguiar and Martins (2005) point out, the performance of the Portuguese industry was rather disappointing when compared to the performance of the other fourteen EU member states.

During the first period, 1951-1973, that coincides with the "golden years" of the world economy, the Portuguese industry maintained reasonable growth rates, it grew on average 5.4%, a performance similar to that of European countries like the UK, Sweden or Ireland, but worst than that of Germany, Greece, or Spain. This positive performance was rooted not only on the favourable international context but also on new industrial

[1] Defined as including Manufacturing, Mining and Quarrying, Electricity, Gas and Water, and Construction.
[2] According to the authors, industrial productivity growth was the major contributor (50.16%, 1910-1995) to aggregate productivity growth during the twentieth century.

policies that favoured investment and mostly the opening up of the Portuguese economy by joining the EFTA as a founding member, the OECD, the IMF, the World Bank and GATT.

The manufacturing sector was responsible for more than 80% of industry productivity growth during this period, which the authors attribute to the fact that it incorporates the production of tradable goods and this was the period when Portugal opened up its economy having access to larger markets and becoming exposed to increased international competition. Within this sector the industries traditionally more important in the Portuguese economy, Textiles, Wood, and Food industries, lost ground to more modern industries, especially Fabricated Metal Products, Machinery and Equipment industries, responsible for 30% of the manufacturing sector productivity growth.

The second period that lasts from 1974 until 1984 and starts shortly after the international oil crisis and coincides with the political turmoil in the Portuguese society when democracy was restored, is characterized by negative industry productivity growth (1% on average). In fact, Portugal was the only EU member state that registered a negative average industry productivity growth rate. The performance of the manufacturing sector however continued to be positive although now the major contributors were the more traditional sub-sectors of Food, Beverages and Tobacco and Textiles, due to the depreciation of the Portuguese Escudo, while Fabricated Metal Products, Machinery and Equipment industries registered negative growth due to the high share of intermediate goods used in the production and the high capital-output ratio. The performance of the Food industries however was due mainly to the reallocation of resources from other industries while the performance of the Textiles industries was due to its modernisation.

A third episode of growth begins approximately in 1985 and lasts until the end of the twentieth century, when Portuguese industrial productivity growth recovered and was higher than in most other European countries (with the exception of Austria, Sweden, Norway, and Ireland). The recovery in the last fifteen years of the twentieth century was due to the achieved political, social and economic stability, joining the EEC in 1986 and the Common Market in 1992, and occurred despite the 1993 international recession and the desinflationary policy based on the appreciation of the PTE followed during the period.

As far as the manufacturing sector is concerned it registered a positive average growth rate of 4.1% but, contrary to what happened in the previous period, Textiles and Wood industries registered a very poor performance (negative productivity growth from 1993 onwards) not being able to face the international competition from developing countries. Food and Paper industries were able to restructure and adapt to new markets, especially the first one, and thus maintained its productivity growth. But the recovery was due mainly to the performance of Chemicals and Petroleum, Non-Metallic Mineral Products, Basic Metals, and Fabricated Metal Products, Machinery and Equipment industries, which leads the authors to conclude with a positive note on the ability of the Portuguese manufacturing industry to adapt to the increased international competition by reallocating resources to more modern industries. Since this period was also characterized by the loss of the importance of the Industry sector relative to the Services sector, further technological restructuring is needed in the Portuguese economy, especially in what concerns the adaptation to Information and Communication Technologies in order to fully exploit the potential productivity growth gains in the Services sector.

Nevertheless, according to Lança (2000) and Lança (2001) from 1970 until 1994, the Portuguese manufacturing sector was centred on the Textiles industries and, to a less extent, on Wood and Non-metallic Minerals industries that use Portugal's natural resources, which reflects major competitive disadvantages especially the low educational levels of the workforce employed in these industries where more than 90% of the employees have 6 years of education or less.

0. EMPIRICAL MODEL AND DATA USED

0.0. A TESTABLE EMPIRICAL SPECIFICATION

Endogenous growth theory emphasizes the role of technological change in determining economic growth where R&D activities play a fundamental role either by expanding the technological frontier (innovation) or by promoting knowledge spillovers (imitation) (see Nelson and Phelps (1966), Romer (1990), Aghion and Howitt (1992), Grossman and Helpman (1992)).

Building on Nelson and Phelps (1966) and Romer (1990), Benhabib and Spiegel (1994) develop a model to explain the effect of human capital on growth where a higher level of human capital in addition to allowing a country to close the gap between the current level of productivity and that of the technological leader faster, also enables the country to achieve a higher rate of expansion of the technology frontier by producing new knowledge.

We extend the Benhabib and Spiegel (1994) model by considering international trade as an additional source of foreign technology and its interaction effects with education. International trade has been identified as a major source of growth of the Portuguese economy at the aggregate level (see e.g. Afonso and Aguiar (2005)), so an industry level analysis should include its influence as a vehicle of technology transfers considering also that a more highly educated workforce is more likely to use technology incorporated in imports more effectively. We thus evaluate the contribution of this channel of technology diffusion and its interaction with education for TFP growth.

The econometric specification for TFP growth that we estimate in the empirical analysis is thus given by:

$$\Delta \log A_{it} = \beta_i + \beta_t + \lambda \Delta \log A_{it}^{USA} + \theta \log(\frac{A_{it-1}^{USA}}{A_{it-1}}) + gH_{it-1} + mH_{it-1}\log(\frac{A_{it-1}^{USA}}{A_{it-1}}) + \\ + \delta_1 IMPS_{it-1} + \delta_2 (IMPSxH)_{it-1} + \mu_{it} \qquad (1)$$

According to equation (1), the growth rate of *TFP* ($\Delta \log A_{it}$) in each Portuguese manufacturing industry is determined by: ***i)*** an industry-specific effect that captures idiosyncratic shocks to productivity growth, β_i; ***ii)*** a time-specific effect that captures year-specific shocks common to all industries, β_t; ***iii)*** the contemporaneous rate of TFP growth in its US counterpart, $\Delta \log A_{it}^{USA}$; ***iv)*** catch up with the level of *TFP* in its US counterpart proxied by $\log(\frac{A_{it-1}^{USA}}{A_{it-1}})$; ***v)*** domestic innovation influenced by the level of education of the workforce, H_{it-1}; ***vi)*** the influence of education over the capacity to absorb ideas developed abroad, $H_{it-1}\log(\frac{A_{it-1}^{USA}}{A_{it-1}})$; ***vii)*** exploring ideas induced by international trade ($IMPS_{it-1}$), ***viii)*** whose impact may also be determined by human capital availability, $(HxIMPS)_{it-1}$; and ***ix)*** a serially uncorrelated error term, μ_{it}.

3.2. OVERVIEW OF DATA

The focus of this work is on the manufacturing sector of the Portuguese economy. Data availability across the different data sets used resulted in a sample of fourteen manufacturing industries[3] for the period 1986-1997, classified according to the OECD classification scheme based on R&D intensities into low technology and high technology industries. In this section we highlight some features of the data. In the appendix we provide details about data sources and computation.

0.0.0. TFP GROWTH AND LEVELS

The level of TFP is measured as a superlative index number derived from a constant returns to scale translog production function[4] so that the level of *TFP* in Portugal's industry *i* relative to the level of *TFP* in USA's industry *i* at any point in time *t* (*RTFP*) is given by:

$$RTFP_{it} = \log\left(\frac{Y_{it}^{USA}}{Y_{it}^{PRT}}\right) - \left(1 - \frac{\alpha_{it}^{USA} + \alpha_{it}^{PRT}}{2}\right)\log\left(\frac{K_{it}^{USA}}{K_{it}^{PRT}}\right) - \frac{\alpha_{it}^{USA} + \alpha_{it}^{PRT}}{2}\log\left(\frac{L_{it}^{USA}}{L_{it}^{PRT}}\right) \qquad (2)$$

where *Y* is real value added, *K* is the real physical capital stock, *L* is a measure of the labour input, and α is the labour income share, all relative to industry *i* at time *t*. The first term on the right-hand side of equation (2) is the log difference in the industry value-added levels of the two countries. The other two terms adjust the relative value-added levels for differences in relative input levels. If, for instance, industry *i* in the USA produces twice as much output from twice as many inputs as industry *i* in Portugal, relative efficiency is one (i.e. $TFP_{USA}/TFP_{PRT}=1$); if industry *i* in the USA produces twice as much output with only the same level of inputs, relative efficiency is two.

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[3] The fourteen manufacturing industries are: FOOD - Food products, beverages and tobacco; TEX - Textiles, textile products, leather and footwear; WOOD - Wood and products of wood and cork; PAP - Pulp, paper, paper products, printing and publishing; RUB - Rubber and plastic products ONMP - Other non-metallic mineral products; BMI - Basic Metals Industries; FMP - Fabricated metal products, except machinery and equipment; OMAN - Manufacturing n.e.c.; CHE - Chemicals and chemical products; MAI - Machinery and equipment n.e.c. and Office, accounting and computing machinery MEL - Electrical machinery and apparatus and Radio, television and communication equipment; MTR - Transport equipment; MED - Medical, precision and optical instruments. The first nine industries form the low-technology cluster and the remaining five the high technology cluster. This classification is based on the R&D intensities of thirteen OECD manufacturing industries for the period 1991-1997. See OECD (2001), Annex I.

[4] Using a Cobb-Douglas specification does not significantly alter the results so we do not present them here.

The growth rate of TFP, $\Delta logTFP$, equals the rate of growth of industry value-added, $\Delta logY$, minus the rate of growth of the industry inputs, assuming that industry value-added is produced using physical capital, K, and labour, L, weighted by the respective income shares (where α is the labour input income share).

Industry level data for the Portuguese manufacturing industry has been originally put together by Nicita and Olarreaga (2001) using the Industrial Statistics of the United Nations Industrial Development Organization (UNIDO). Data to compute TFP growth and levels for the USA, the frontier country, comes also from Nicita and Olarreaga (2001), for comparison purposes.

Variables Y and K are real variables and have to be expressed in a common currency unit. In this paper they are expressed in constant 1995 USD[5]. Labour input is measured as total annual hours worked from O'Mahony and van Ark (2003). Finally, since the share of labour in value added is quite volatile, which is suggestive of measurement error, we use estimated values (obtained from regressing the labour share on the capital-labour ratio and industry fixed-effects) in order to obtain smoother, less volatile values[6].

Table 1 reports time-averaged TFP growth during 1986–1997 in Portugal and the USA. All industries registered a positive TFP growth rate in Portugal during this period. In the USA, FOOD, WOOD, and PAP registered negative rates of TFP growth. The remaining industries registered positive rates of TFP growth in both countries. OMAN, followed by ONMP and RUB were the industries with higher productivity growth rates in Portugal. In the USA, it was BMI, CHE and MEL that grew the most. In any case, business cycles seem to be synchronized in most industries (eleven out of fourteen) of the two countries. On average, in the USA high-tech industries registered higher growth rates. The same applies to Portugal if we exclude OMAN. All industries registered higher growth rates in Portugal than in the USA, a behaviour consistent with technological catch up.

[5] See the appendix for further details on the construction of these variables. Conceptually, the appropriate rate of exchange to convert the variables into a common currency unit is an industry-specific purchasing power parity (PPP) (see Sorensen (2001) for biases concerning cross-country comparability of TFP levels). Data restrictions did not allow us to use this ideal methodology.
[6] See Harrigan (1997) and Harrigan (1999).

Table 1. Average TFP growth 1986-1997 (%)

	Portugal	USA
Low technology		
FOOD	2.63	-0.19
TEX	5.67	3.16
WOOD	4.33	-0.21
PAP	2.33	-0.55
RUB	7.46	3.95
ONMP	7.97	3.33
BMI	6.46	4.72
FMP	7.11	1.39
OMAN	18.57	1.81
Mean	*6.95 (5.50[a])*	*1.93*
Standard Deviation	*4.81 (2.18[a])*	*1.96*
High technology		
CHE	4.44	2.87
MAI	7.33	4.46
MEL	7.09	3.98
MTR	6.91	0.47
MED	5.66	2.61
Mean	*6.71*	*2.27*

Notes: FOOD - Food products, beverages and tobacco; TEX - Textiles, textile products, leather and footwear; WOOD - Wood and products of wood and cork PAP - Pulp, paper, paper products, printing and publishing; CHE - Chemicals and chemical products; PETRO - Coke, refined petroleum products and nuclear fuel; RUB - Rubber and plastic products ONMP - Other non-metallic mineral products; BMI - Basic Metals Industries; FMP - Fabricated metal products, except machinery and equipment; MAI - Machinery and equipment n.e.c. and Office, accounting and computing machinery; MEL - Electrical machinery and apparatus and Radio, television and communication equipment; MTR - Transport equipment; MED - Medical, precision and optical instruments; OMAN - Manufacturing n.e.c. [a]Excluding OMAN.

Table 2 reports the level of TFP in Portugal relative to the USA (TFP_{PRT}/TFP_{USA}) at the beginning and end year of the sample period. As is clear from Table 2, all Portuguese industries were considerably less productive than the corresponding US industries at the beginning and end of the period. OMAN was by far the less productive, followed by MED and MEL. The most productive industry relative to the USA in 1985 was PAP followed by BMI and RUB. In 1997 it was FMP followed by PAP and WOOD. The period as a whole was characterized by convergence of Portugal's TFP towards US levels since in all manufacturing industries relative levels of TFP were higher in 1997 than in 1985.

Table 2. Relative levels of TFP (*TFP_{PRT} /TFP_{USA}*), %

	1985	1997
*Low tech*nology		
FOOD	15.46	26.24
TEX	14.25	24.02
WOOD	16.02	40.04
PAP	21.96	42.60
RUB	19.19	32.77
ONMP	18.01	39.88
BMI	20.92	30.86
FMP	17.30	50.61
OMAN	1.80	13.52
*H*igh *tech*nology		
CHE	17.55	27.59
MAI	15.87	32.72
MEL	13.25	22.19
MTR	11.52	29.02
MED	9.50	20.61
Mean	*15.19*	*30.91*

Notes: The relative level of TFP is measured by taking exponents of the *RTFP* computed as described in the text and then computing its inverse. A value equal to 100% corresponds to the same level of efficiency in the respective industry of Portugal and the USA. Values lower than 100% mean that the Portuguese industry is less efficient than the corresponding US industry. FOOD - Food products, beverages and tobacco; TEX - Textiles, textile products, leather and footwear; WOOD - Wood and products of wood and cork PAP - Pulp, paper, paper products, printing and publishing; CHE - Chemicals and chemical products; PETRO - Coke, refined petroleum products and nuclear fuel; RUB - Rubber and plastic products; ONMP - Other non-metallic mineral products; BMI - Basic Metals Industries; FMP - Fabricated metal products, except machinery and equipment; MAI - Machinery and equipment n.e.c. and Office, accounting and computing machinery MEL - Electrical machinery and apparatus and Radio, television and communication equipment; MTR - Transport equipment; MED - Medical, precision and optical instruments; OMAN - Manufacturing n.e.c.

Figures 1 and 2 relate initial (inverse) RTFP with the average growth rate of TFP in low-tech and high-tech industries, respectively. The negative relationship between the two suggests that there was catch-up with the US productivity levels during the period, although this correlation is much weaker for high-tech industries.

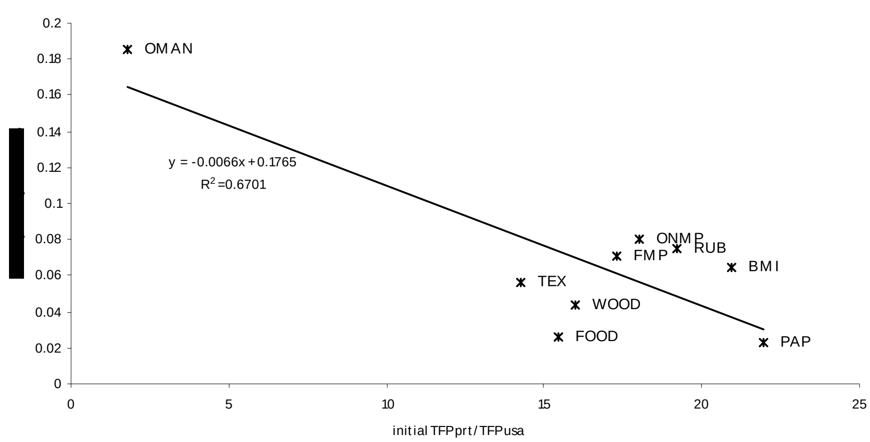

Chart 1. Technological catch-up in low-tech industries, Portugal 1986-1997

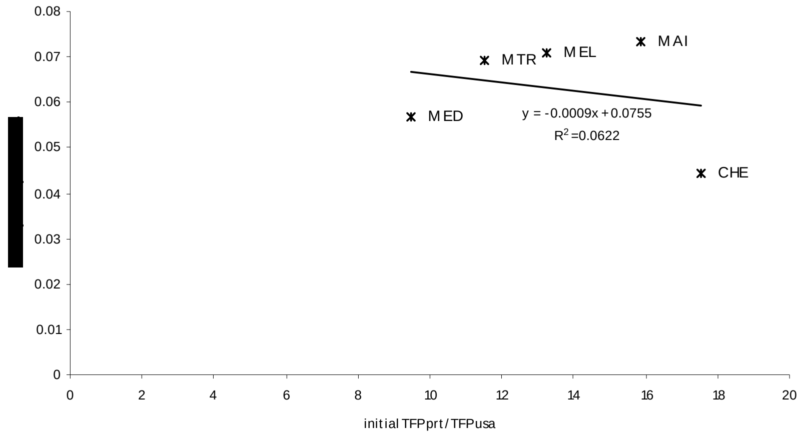

Chart 2. Technological catch-up in high-tech industries, Portugal 1986-1997

0.0.0. EDUCATION

The industry-specific human capital proxy refers to average years of education, total and by schooling level, of the workforce employed in each industry *i* at time *t*. We compute these series using data on the number of workers with a given schooling level employed in each industry-year from the *Quadros de Pessoal* database from the Portuguese government department *Ministério da Segurança Social e do Trabalho* for the period 1985-1997. This database is the result of an annual compulsory survey conducted by the *Ministério da Segurança Social e do Trabalho* where firms are required to provide information about their workers on items such as monthly compensation, highest schooling level attained, age, tenure and monthly hours worked.

We use the data on the number of workers of industry *i* for which schooling level *s* is the highest level attained to compute average years of schooling, total, primary, secondary, and tertiary, of the workforce employed in each industry *i* at time *t*. For the years 1985 to 1993 the schooling levels are classified according to twelve education categories[7]; for the years 1994 to 1997 the schooling levels are classified according to eigth education categories[8].

Based on the assumed durations for the different schooling levels in Domingos (1997), Teixeira (2004b) and Pereira (2003a) we assigned a cumulated duration in years, *Dur_s*[9], to each schooling level *s* in order to compute average years of schooling according to the formulas below[10], assuming that all workers completed the respective highest schooling level attained:

$$TYRind_{it} = Dur\_1x\frac{L_{1it}}{L_{it}} + Dur\_2x\frac{L_{2it}}{L_{it}} + Dur\_3x\frac{L_{3it}}{L_{it}} + Dur\_4x\frac{L_{4it}}{L_{it}} + Dur\_5x\frac{L_{5it}}{L_{it}} + Dur\_6x\frac{L_{6it}}{L_{it}} + + Dur\_7x\frac{L_{7it}}{L_{it}} + Dur\_8x\frac{L_{8it}}{L_{it}} + Dur\_9x\frac{L_{9it}}{L_{it}} + Dur\_10x\frac{L_{10it}}{L_{it}} + Dur\_11x\frac{L_{11it}}{L_{it}} + Dur\_12x\frac{L_{12it}}{L_{it}} \quad (3)$$

$$PYRind_{it} = Dur\_1x\frac{L_{1it}}{L_{it}} + Dur\_2x\left(\frac{L_{2it} + L_{3it} + L_{4it} + L_{5it} + L_{6it} + L_{7it} + L_{8it} + L_{9it} + L_{10it} + L_{11it} + L_{12it}}{L_{it}}\right) \quad (4)$$

$$SYRind_{it} = (Dur\_3 - Dur\_2)x\frac{L_{3it}}{L_{it}} + (Dur\_4 - Dur\_2)x\frac{L_{4it}}{L_{it}} + + (Dur\_5 - Dur\_2)x\left(\frac{L_{5it} + L_{6it} + L_{7it} + L_{8it} + L_{9it} + L_{10it} + L_{11it} + L_{12it}}{L_{it}}\right) \quad (5)$$

$$HYRind_{it} = (Dur\_10 - Dur\_5)x\frac{L_{10it}}{L_{it}} + (Dur\_11 - Dur\_5)x\left(\frac{L_{11it} + L_{12it}}{L_{it}}\right) \quad (6)$$

where $TYRind_{it}$ is average years of total schooling, $PYRind_{it}$ is average years of primary schooling, $SYRind_{it}$ is average years of secondary schooling, $HYRind_{it}$ is average years of tertiary schooling all relative to the workforce employed in industry *i* at time *t*, L_{sit} is the number of workers with schooling level *s* in industry *i* at time *t*, and L_{it} is the total number of workers in industry *i* at time *t*.

Table 3 reports some summary data for the different education series in the fourteen manufacturing industries in the period 1985-1997. In every industry except BMI the

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[7] 0-Illiterate (não sabe ler nem escrever); 1-can read and right (sabe ler e escrever); 2-basic 1st cycle (ensino básico primário); 3-basic 2nd cycle (ensino básico preparatório); 4-lower secondary (Curso geral dos liceus); 5-upper secondary (Curso complementar dos liceus); 6-commercial vocational training (Ensino Técnico Comercial); 7-industrial vocational training (Ensino Técnico Industrial); 8-agriculture vocational training (Ensino Técnico Agrícola); 9-other secondary schooling (Outros ensinos secundários); 10-higher education, short courses (Ensino médio); 11-higher education, 1st cycle (Bacharelato); 12-higher education, 2nd cycle (Licenciatura).

[8] 1-Less than basic (< ensino básico); 2-basic 1st cycle (1º ciclo); 3-basic 2nd cycle (2º ciclo); 4-lower secondary (3º ciclo); 5-upper secondary (ensino secundário); 6-vocational training (cursos das escolas profissionais); 7-higher education, 1st cycle (Bacharelato); 8-higher education, 2nd cycle (Licenciatura).

[9] 0; 1; 4; 6; 9; 12; 12; 12; 12; 12; 14; 17; 17 years, respectively, for the twelve schooling levels of the 1985-1993 period; and 1; 4; 6; 9; 12; 12; 17; 17 years, respectively, for the eight schooling levels of the 1994-1997 period.

[10] These formulas refer to the 1985-1993 period when workers are classified according to twelve education levels. Similar formulas apply to the 1994-1997 period when only eight schooling levels are considered.

average educational attainment of the workforce increased during the period. This increase was due mostly to the increase in average years of secondary and tertiary education, with average years of primary education also growing but at a much lower rate. The average educational attainment of the workforce is higher in the high-tech industries but PAP, a low-tech industry, also presents values similar or higher than those of some high-tech industries. Average years of primary education are similar in all industries, while average years of secondary and tertiary education are higher in high-tech industries.

Table 3. Average years of schooling of the manufacturing industry workforce, Portugal 1985-1997

	TYRind			PYRind			SYRind			HYRind		
Industries	Average value	Total growth	Av. annual growth	Average value	Total growth	Av. annual growth	Average value	Total growth	Av. annual growth	Average value	Total growth	Av. annual growth
Low-tech												
FOOD	5.195	28.47%	2.09%	3.613	11.35%	0.90%	1.456	77.17%	4.77%	0.126	90.77%	5.38%
TEX	5.023	35.25%	2.52%	3.709	5.46%	0.44%	1.275	181.35%	8.62%	0.039	36.46%	2.59%
WOOD	4.649	29.48%	2.15%	3.621	12.32%	0.97%	0.992	119.43%	6.55%	0.036	-1.08%	-0.09%
PAP	6.564	35.92%	2.56%	3.777	6.69%	0.54%	2.574	84.63%	5.11%	0.213	162.65%	8.05%
RUB	5.676	27.70%	2.04%	3.682	7.35%	0.59%	1.850	73.10%	4.57%	0.144	108.57%	6.13%
ONMP	5.066	29.73%	2.17%	3.561	13.32%	1.04%	1.399	79.47%	4.87%	0.106	71.28%	4.48%
BMI	5.888	-0.56%	-0.05%	3.749	5.43%	0.44%	1.950	-4.08%	-0.35%	0.189	-41.43%	-4.46%
FMP	5.434	20.82%	1.58%	3.737	5.92%	0.48%	1.601	61.27%	3.98%	0.096	43.89%	3.03%
OMAN	5.298	12.20%	0.96%	3.721	7.22%	0.58%	1.518	24.93%	1.85%	0.059	47.77%	3.25%
High-tech												
CHE	7.211	25.03%	1.86%	3.780	4.23%	0.35%	3.019	48.55%	3.30%	0.411	87.35%	5.23%
MAI	6.110	24.48%	1.82%	3.790	4.36%	0.36%	2.157	64.50%	4.15%	0.164	82.97%	5.03%
MEL	6.949	32.27%	2.33%	3.809	2.99%	0.25%	2.838	82.06%	4.99%	0.302	68.44%	4.34%
MTR	6.270	41.48%	2.89%	3.825	6.93%	0.56%	2.222	117.72%	6.48%	0.222	100.60%	5.80%
MED	6.325	29.42%	2.15%	3.775	1.01%	0.08%	2.408	81.08%	4.95%	0.141	133.88%	7.08%
TOTAL MAN	5.391	24.64%	1.84%	3.705	7.66%	0.61%	1.572	72.79%	4.56%	0.115	53.58%	3.58%

0.0.0. INTERNATIONAL TRADE

To study the influence of international trade we use data from the OECD, Bilateral Trade, 2000 edition database (OECD (2000)). Our measure of international trade is the ratio of a Portuguese industry's imports from the OECD to gross output. Table 4 reports this data for the fourteen manufacturing industries over the period 1980-1997. The import ratios are higher for the high-tech industries since these are more capital intensive or use more intermediate goods in their production than the traditional industries.

Table 4. Ratio of Portuguese industries imports from the OECD to gross output (%), 1985-1997

	Low technology									High technology				
Year	**FOOD**	**TEX**	**WOOD**	**PAP**	**OMAN**	**RUB**	**ONMP**	**BMI**	**FMP**	**CHE**	**MAI**	**MEL**	**MTR**	**MED**
1985	11.30	12.56	2.15	10.56	122.49	18.05	7.12	74.26	341.21	48.45	192.36	56.00	79.89	354.56
1986	12.58	15.10	4.20	11.84	210.59	25.03	10.78	82.80	472.19	52.64	274.12	79.91	101.02	394.14
1987	18.23	22.07	7.31	11.36	414.15	34.38	13.05	97.54	615.33	62.35	385.79	92.91	136.87	502.40
1988	20.63	26.88	7.87	17.80	479.24	39.45	14.84	104.93	801.00	55.66	472.90	103.95	187.92	661.56
1989	20.41	30.45	7.71	15.89	475.43	41.60	14.26	117.42	775.74	63.12	471.16	99.67	165.07	620.28
1990	16.28	21.84	5.31	16.91	70.27	41.91	11.01	86.21	399.71	76.60	216.34	79.21	147.01	506.34
1991	17.35	23.48	6.12	17.86	66.28	46.89	10.74	100.46	349.86	79.43	174.57	81.40	162.33	370.77
1992	16.88	25.23	8.21	19.16	67.75	49.91	10.92	105.10	384.18	80.48	185.18	85.66	198.28	381.25
1993	17.26	21.90	7.45	18.90	62.15	47.19	10.30	85.36	336.42	80.83	144.97	71.62	184.20	297.12
1994	19.51	22.48	7.27	18.65	59.46	43.54	9.68	123.16	357.26	92.86	134.07	76.36	186.72	269.14
1995	21.82	24.05	7.26	18.96	53.24	44.93	10.53	114.00	348.21	92.70	145.12	83.46	115.84	280.12
1996	21.31	25.73	8.00	19.53	54.05	46.29	11.42	101.63	346.15	92.73	147.19	80.19	112.57	270.28
1997	21.11	28.47	9.52	18.98	59.02	48.33	12.16	108.91	351.85	100.12	149.66	85.59	121.02	300.33
Mean	*18.05*	*23.10*	*6.80*	*16.65*	*168.78*	*40.58*	*11.29*	*100.14*	*452.24*	*75.23*	*237.96*	*82.76*	*146.06*	*400.64*

1. EMPIRICAL FINDINGS

The empirical analysis is conducted in three separate stages. In the first, we estimate equation (1) including only education variables as regressors (besides TFP growth of the leader and relative TFP) in order to select the appropriate schooling level that explains productivity growth, through both innovation and imitation activities.

In the second stage and in light of the conclusions concerning the influence of the educational sub-categories, we add international trade to the productivity growth regression so that we can select a final specification with all the relevant technological change determinants.

In the third stage, we repeat the analysis for the two technology groups considered, low technology and high technology industries, in order to identify potential differences concerning the influence of the different technological change determinants according to technological characteristics.

We estimated a fixed effects regression model, so as to capture the industry-specific effects (within-groups). Furthermore, we added time-dummies to capture time-specific effects and used the Huber-White sandwich estimator of variance to correct for heteroscedasticity. Finally, we use the first-differenced GMM estimator to obtain results robust to the possible endogeneity of the regressors.

1.1. RESULTS FOR THE FOURTEEN MANUFACTURING INDUSTRIES

Table 5 presents the estimation results for the whole sample of fourteen manufacturing industries. Columns (1) to (8) give the results regarding the effect of education and its sub-categories on TFP growth where TFP growth depends only on TFP growth of the leader, the USA, $\Delta logTFP_{USA}$, the technological gap proxied by relative TFP, *RTFP*, and the education variables under analysis. Our aim is to select the relevant schooling level or educational sub-category, if any, for innovation and imitation activities in the Portuguese manufacturing sector.

Empirical evidence favours the existence of a long run relationship between TFP growth of the Portuguese manufacturing industries and the respective US counterparts since in all specifications the estimated coefficient is positive and statistically significant.

As for the existence of technological catch up, Portuguese manufacturing industries only grow faster the further they are from the leader industry if the interaction term with the education variable is not considered. This seems to indicate that technological catch up is not automatic but requires a sufficient educational level. However, this is not the case since all the education variables interacted with the technological gap revealed not to be statistically significant. These results indicate that education does not facilitate the assimilation of disembodied technology (columns (2), (4), (6) and (8)).

Since the direct influence of any of the education variables is also not statistically significant (columns (1), (3), (5) and (7)) there seems to be no evidence supporting a role for the educational attainment of the workforce in the Portuguese manufacturing sector productivity growth, either through innovation activities or disembodied technology diffusion. It can be the case nevertheless that education matters through embodied technology diffusion so we proceed to the analysis of the influence of international trade (*IMPS*) on technological change and growth of the Portuguese manufacturing sector, retaining only as statistically significant influences TFP growth of the leader and *RTFP*.

Table 5. Roles of the different schooling levels in TFP growth, 14 Portuguese manufacturing industries

	1	2	3	4	5	6	7	8
$\Delta logTFP_{USAit}$	**0.2516**	**0.2831**	**0.25**	**0.2841**	**0.2468**	**0.2806**	**0.2333**	**0.2651**
	(1.56)	**(1.80)**	**(1.55)**	**(1.82)**	**(1.53)**	**(1.80)**	**(1.45)**	**(1.68)**
$RTFP_{it-1}$	**0.1719**	-0.127	**0.1718**	0.053	**0.1717**	0.061	**0.1706**	0.1392
	(1.45)	(-0.36)	**(1.44)**	(0.28)	**(1.44)**	(0.33)	**(1.43)**	(0.95)
TYR_{it-1}	0.0004	-0.054						
	(0.01)	(-0.77)						
$(TYRxRTFP)_{it-1}$		0.058						
		(1.07)						
SYR_{it-1}			0.004	-0.074				
			(0.08)	(-0.85)				
$(SYRxRTFP)_{it-1}$				0.084				
				(1.21)				
$SHYR_{it-1}$					0.0093	-0.058		
					(0.20)	(-0.76)		
$(SHYRxRTFP)_{it-1}$						0.075		
						(1.20)		
HYR_{it-1}							0.2408	-0.255
							(0.75)	(-0.41)
$(HYRxRTFP)_{it-1}$								0.5239
								(0.94)
$\bar{R}$ -squared	.5112	.5120	.5112	.5128	.5113	.513	.5123	.5130
Root MSE	.16394	.1638	.16393	.16367	.16392	.16364	.16374	.16363

Notes: Dependent variable is the rate of TFP (translog) growth adjusted for total hours worked. $\Delta logTFP_{USA}$ is TFP growth of the leader, the USA; RTFP is relative TFP; TYR is average years of total schooling; HYR is average years of tertiary schooling; SYR is average years of secondary schooling; SHYR is average years of secondary and tertiary schooling, all industry-specific. The sample includes 168 observations between 1986 and 1997. All columns include a full set of time dummies and industry fixed effects. Heteroscedasticity-consistent t-statistics in parenthesis. Coefficients in bold are significant at least at the 10% significance level.

Table 6 presents the results of the estimations to investigate the role of international trade as an additional technological change determinant, highlighting the possible complementarity with education. When the proxy for technology spillovers through international trade is introduced on its own (column (1)) the estimated coefficient is positive and significant as expected and the remaining influences also remain statistically significant except for relative TFP, which might indicate that embodied technology diffusion is more important for productivity growth in the Portuguese manufacturing sector than disembodied technology diffusion proxied by the technology gap.

In column (2) we drop *RTFP* from the regression and proceed to examine the hypothesis of complementarity between education and international trade (columns (3)-(8)). When the different interaction terms are introduced the direct influence of international trade becomes statistically insignificant. Regarding the estimated coefficients of the interaction terms, only the interaction terms with secondary education and secondary and higher education together are statistically significant and positive as expected.

We retain specification (4) as our preferred specification since it presents a higher R-squared, and in column (7) we present the results of regressing TFP growth on the identified statistically significant influences, TFP growth of the leader and the complementarity between international trade and secondary education.

In column (8) we estimate our selected specification using the Diff-GMM estimator. We consider all the regressors but TFP growth of the leader as potentially endogenous and use the adequate lagged values as instruments (see the notes on each table for details). Since explanatory variables are measured at the beginning of each period we consider them as predetermined. The results with the Diff-GMM estimator confirm the previous results. 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 and cannot reject the null hypothesis of correct specification of the different models.

Table 6. Roles of the different schooling levels and international trade in TFP growth, 14 Portuguese manufacturing industries

	1	2	3	4	5	6	7	8 Diff-GMM
$\Delta logTFP_{USAit}$	**.2478** **(1.50)**	**.2478** **(1.47)**	**.27** **(1.67)**	**.2858** **(1.76)**	**.2801** **(1.72)**	**.2472** **(1.47)**	**.2826** **(1.69)**	**0.4001** **(2.23)**
$RTFP_{it-1}$	.0668 (0.59)							
$IMPS_{it-1}$	**.0581** **(2.02)**	**.0764** **(1.95)**	-.119 (-0.76)	-.008 (-0.13)	.0020 (0.03)	.0838 (1.25)		
$(IMPSxTYR)_{it-1}$			**.038** **(1.38)**					
$(IMPSxSYR)_{it-1}$				**.0594** **(2.01)**			**.0546** **(2.23)**	**0.0711** **(3.86)**
$(IMPSxSHYR)_{it-1}$					**.0499** **(1.75)**			
$(IMPSxHYR)_{it-1}$						-.0976 (-0.22)		
$\bar{R}$ -squared	.5282	.5281	.5300	.5337	.5320	.5252	.5369	
Root MSE	.16106	.16107	.16074	.16012	.1604	.16158	.15957	0.1662
Sargan test								24.54
[*p-value*]								[0.220]
AR(2)								0.5311
[*p-value*]								[0.595]

Notes: Dependent variable is the rate of TFP (translog) growth adjusted for total hours worked. $\Delta logTFP_{USA}$ is TFP growth of the leader, the USA; RTFP is relative TFP; TYR is average years of total schooling; HYR is average years of tertiary schooling; SYR is average years of secondary schooling; SHYR is average years of secondary and tertiary schooling, all industry-specific. IMPS is the ratio of an industry's imports from the OECD to gross output. The sample includes 168 observations between 1986 and 1997. All columns include a full set of time dummies and industry fixed effects. Heteroscedasticity-consistent t-statistics in parenthesis. Coefficients in bold are significant at least at the 10% significance level. Column (8) estimates the specification in column (7) using as instruments all values of $\Delta logTFP_{USA}$ and values of IMPSxSYR lagged two 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 as instrument for the endogenous variables (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.

The above-described results indicate that the dominant effect of education on productivity growth of the Portuguese manufacturing sector is felt through the assimilation of ideas and technologies developed abroad, with no evidence of a robust direct role of education in the production of new ideas and technologies. Since the Portuguese manufacturing industries are, as we saw in the previous section, still far behind the respective US counterparts, with relative TFP levels not higher than fifty per cent in 1997, this is not a surprising result – the Portuguese economy is mainly a follower economy not a technological leader. This feature renders education a fundamental role in the process of technological catch up – it is crucial to exploit the productivity growth benefits of embodied technology spillovers. Furthermore, the assimilation of foreign technologies requires more than basic skill levels: embodied technology diffusion requires skills acquired in secondary education.

In the next sections we proceed with the empirical analysis by disaggregating the sample of fourteen manufacturing industries according to the OECD technology classification based on R&D intensities into a group of nine low technology industries and a group of five high technology industries. Our aim is to test the robustness of the results from this section to the consideration of different technological characteristics.

1.2. RESULTS FOR THE LOW TECHNOLOGY INDUSTRIES

We start by presenting the results of the estimations to select the relevant education variables for productivity growth in low technology industries in Table 7. For this group, TFP growth of the leader has a positive and statistically significant influence on productivity growth in all regressions, and stronger than for the aggregate sample of fourteen manufacturing industries. Regarding the influence of relative TFP, its estimated coefficient is both positive and negative but not statistically significant (except in column (2)).

Regarding the direct influence alone of the different education variables (columns 1, 3, 5, and 7) none of the estimated coefficients is statistically significant. When both the direct and indirect influences are considered however the estimated coefficients on the direct influence become statistically significant (except for the direct role of higher education, column (8)), but since they are negative this is a result difficult to interpret in economic terms.

We retain the specification in column (4) that considers the influence of secondary education since it presents the highest R-squared and estimate it in column (9) dropping the none statistically significant influence, *RTFP*. In this case only the influence of TFP growth of the leader is statistically significant and positive as expected so in column (10) we regress TFP growth on this influence alone.

As in the fourteen manufacturing industries sample, in low-tech industries the evidence also does not support the hypothesis that education influences TFP growth through innovation nor through disembodied technology diffusion. In the next table we check the robustness of these results to the introduction of the additional technological change determinant (*IMPS*) and whether there is still a possible role for education through its complementarity with embodied technology diffusion.

Table 7. Roles of the different schooling levels in TFP growth, 9 Portuguese low technology industries

	1	2	3	4	5	6	7	8	9	10
$\Delta logTFP_{USAit}$	**0.6375**	**0.7091**	**0.6367**	**0.7092**	**0.6344**	**0.6984**	**0.5888**	**0.6056**	**.68**	**.7385**
	(1.77)	**(2.10)**	**(1.77)**	**(2.10)**	**(1.76)**	**(2.06)**	**(1.62)**	**(1.68)**	**(1.88)**	**(2.22)**
$RTFP_{it-1}$	0.1387	**-0.494**	0.1389	-0.073	0.1385	-0.048	0.1368	0.1186		
	(0.94)	**(-1.30)**	(0.94)	(-0.44)	(0.94)	(-0.28)	(0.93)	(0.68)		
TYR_{it-1}	-0.017	**-0.16**								
	(-0.29)	**(-1.52)**								
$(TYRxRTFP)_{it-1}$		**0.1285**								
		(1.67)								
SYR_{it-1}			-0.023	**-0.21**					-.1544	
			(-0.37)	**(-1.57)**					(-1.17)	
$(SYRxRTFP)_{it-1}$				**0.1686**					.1177	
				(1.69)					(1.12)	
$SHYR_{it-1}$					-0.012	**-0.171**				
					(-0.20)	**(-1.49)**				
$(SHYRxRTFP)_{it-1}$						**0.1436**				
						(1.72)				
HYR_{it-1}							0.3235	-0.268		
							(0.77)	(-0.25)		
$(HYRxRTFP)_{it-1}$								0.467		
								(0.56)		
$\bar{R}$ -squared	.5249	.5298	.5249	.5299	.5248	.5287	.5259	.5216	.5344	.5077
Root MSE	.17432	.17341	.1743	.17339	.17433	.17362	.17412	.17491	.17257	.17137

Notes: Dependent variable is the rate of TFP (translog) growth adjusted for total hours worked. $\Delta logTFP_{USA}$ is TFP growth of the leader, the USA; RTFP is relative TFP; TYR is average years of total schooling; HYR is average years of tertiary schooling; SYR is average years of secondary schooling; SHYR is average years of secondary and tertiary schooling all industry-specific. The sample includes 108 observations between 1986 and 1997. All columns include a full set of time dummies and industry fixed effects. Heteroscedasticity-consistent t-statistics in parenthesis. Coefficients in bold are significant at least at the 10% significance level.

Table 8 reports the results for the regressions that consider the influence of international trade on productivity growth of low-tech industries. The influence of TFP growth of the leader remains positive and statistically significant in all specifications. When only the direct influence of international trade is considered, the respective estimated coefficient is positive and significant as expected (column (1)). When we test the complementarity between international trade and the different education variables (columns (2)-(5)) all estimated coefficients are positive and statistically significant as expected (except in column (5)) but render the direct influence negative and statistically significant in columns (2) and (4). Specification (3) that considers the interaction term between international trade and secondary education presents the highest R-squared so we retain only this influence on our preferred specification for low technology industries, column (6), dropping the direct influence of *IMPS* since it is not statistically significant.

Productivity growth in low technology industries is thus determined by productivity growth of the leader and the influence of secondary education on the absorption of technologies incorporated in imports from OECD countries.

In column (7) we estimate our selected specification using the Diff-GMM estimator. We consider all the regressors but TFP growth of the leader as potentially endogenous and use the adequate lagged values as instruments (see the notes on each table for details). Since explanatory variables are measured at the beginning of each period we consider them as predetermined. The results with the Diff-GMM estimator confirm the previous results on the influence of the TFP growth of the leader and *IMPSxSYR*. The second-order serial correlation test and the Sargan test support the GMM estimation of our model: the *p-value* is within the acceptable values and cannot reject the null hypothesis of correct specification of the different models.

The results are thus similar to the ones for the fourteen manufacturing industries together.

Table 8. Roles of the different schooling levels and international trade in TFP growth, 9 low technology industries

	1	2	3	4	5	6	7 Diff-GMM
$\Delta logTFP_{USAit}$	**.6838**	**.6274**	**.6049**	**.6078**	**.7231**	**.6386**	**0.5613**
	(1.86)	**(1.73)**	**(1.67)**	**(1.68)**	**(1.82)**	**(1.76)**	**(1.44)**
$IMPS_{it-1}$	**.07581**	**-.3405**	-.0786	-.0738	.1637		
	(1.35)	**(-1.69)**	(-1.17)	(-1.19)	(0.94)		
$(IMPSxTYR)_{it-1}$		**.0839**					
		(1.72)					
$(IMPSxSYR)_{it-1}$			**.1244**			**.0649**	**0.0766**
			(1.45)			**(1.41)**	**(2.16)**
$(IMPSxSHYR)_{it-1}$				**.1149**			
				(1.54)			
$(IMPSxHYR)_{it-1}$					-1.44		
					(-0.69)		
$\bar{R}$ -squared	.5528	.5585	.5622	.56	.5613	.5638	
Root MSE	.16912	.16804	.16733	.16775	.16751	.16703	0.1788
Sargan test [*p-value*]							25.87 [0.170]
AR(2) [*p-value*]							0.9965 [0.319]

Notes: Dependent variable is the rate of TFP (translog) growth adjusted for total hours worked. $\Delta logTFP_{USA}$ is TFP growth of the leader, the USA; RTFP is relative TFP; TYR is average years of total schooling; HYR is average years of tertiary schooling; SYR is average years of secondary schooling; SHYR is average years of secondary and tertiary schooling all industry-specific. IMPS is the ratio of an industry's imports from the OECD to gross output. The sample includes 108 observations between 1986 and 1997. All columns include a full set of time dummies and industry fixed effects. Heteroscedasticity-consistent t-statistics in parenthesis. Coefficients in bold are significant at least at the 10% significance level. Column (7) estimates the specification in column (6) using as instruments all values of $\Delta logTFP_{USA}$ and values of IMPSxSYR lagged two 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 as instruments for the endogenous variables (predetermined). Results for the one-step GMM estimator with standard errors robust to heteroskedasticity since the standard errors of the two-step GMM estimator can be seriously biased downwards.

1.3. RESULTS FOR THE HIGH TECHNOLOGY INDUSTRIES

The results regarding the selection of the relevant education variables to explain productivity growth in the group of high technology industries are reported in Table 9. The estimated coefficient on TFP growth of the leader is positive but never statistically significant contrary to the results for the previous two samples. The estimated coefficient on *RTFP* is positive and significant when only the direct influence of the education variables is considered (columns (1), (3), (5) and (7)).

Regarding the direct influence of education (columns (1), (3), (5), and (7)) all the estimated coefficients are positive but not statistically significant. When the interaction term with relative TFP is also included (columns (2), (4), (6), and (8)) its estimated coefficient is always positive but statistically significant only with *SHYR* and *HYR*.

We retain the influence of the interaction term between higher education and relative TFP (column (8)) since it has the highest R-squared. In this case the estimated coefficients on TFP growth of the leader, relative TFP and the direct influence of *HYR* are not statistically significant so we drop them from our preferred specification in column (9). TFP growth of high technology industries is thus only explained by the interaction term between *HYR* and relative TFP so that there is technological catch up with its US counterparts but only if the Portuguese high tech industries employ a workforce with qualifications at the tertiary level.

We next check the robustness of this result to the introduction of international trade as a determinant of TFP growth.

Table 9. Roles of the different schooling levels in TFP growth,
5 Portuguese high technology industries

	1	2	3	4	5	6	7	8	9
ΔlogTFP_{USAit}	0.103 (0.66)	0.1451 (0.82)	0.0851 (0.55)	0.1423 (0.81)	0.0881 (0.57)	0.1516 (0.87)	0.1039 (0.71)	0.201 (1.13)	
$RTFP_{it-1}$	**0.23** **(2.33)**	-0.307 (-0.48)	**0.234** **(2.28)**	-0.074 (-0.26)	**0.233** **(2.28)**	-0.089 (-0.34)	**0.23** **(2.31)**	0.0529 (0.32)	
TYR_{it-1}	0.006 (0.05)	-0.072 (-0.49)							
$(TYRxRTFP)_{it-1}$		0.089 (0.85)							
SYR_{it-1}			0.083 (0.57)	-0.064 (-0.33)					
$(SYRxRTFP)_{it-1}$				0.149 (1.19)					
$SHYR_{it-1}$					0.069 (0.52)	-0.056 (-0.35)			
$(SHYRxRTFP)_{it-1}$						**0.1462** **(1.35)**			
HYR_{it-1}							0.099 (0.16)	-0.630 (-0.76)	
$(HYRxRTFP)_{it-1}$								**1.199** **(1.50)**	**1.156** **(2.51)**
$\bar{R}$ -squared	.4199	.4122	.4235	.4221	.423	.4251	.4201	.4296	.4502
Root MSE	.15152	.15252	.15105	.15122	.15111	.15083	.15149	.15025	.14751

Notes: Dependent variable is the rate of TFP (translog) growth adjusted for total hours worked. ΔlogTFP_{USA} is TFP growth of the leader, the USA; RTFP is relative TFP; TYR is average years of total schooling; HYR is average years of tertiary schooling; SYR is average years of secondary schooling; SHYR is average years of secondary and tertiary schooling all industry-specific. IMPS is the ratio of an industry's imports from the OECD to gross output. The sample includes 60 observations between 1986 and 1997. All columns include a full set of time dummies and industry fixed effects. Heteroscedasticity-consistent t-statistics in parenthesis. Coefficients in bold are significant at least at the 10% significance level.

Table 10 reports the results for the group of five high technology industries considering the additional influence of international trade. Regarding the results from the introduction of international trade alone (column (1)), the estimated coefficient on the direct impact of international trade is positive and statistically significant as expected but renders the estimated coefficient on *RTFPxHYR* not statistically significant. We thus drop its influence in the following regressions. When the interaction terms between *IMPS* and the different education variables are introduced (columns (2)-(5)) the direct impact of international trade becomes statistically insignificant.

We selected specification (3) as our preferred specification since it presents a higher R-squared so that as in the previous sample embodied technology diffusion is the main determinant of TFP growth and, in the case of high tech industries, the only one. In column (6) we regress TFP growth of high-tech industries on the interaction term between secondary education and international trade alone, getting a positive and statistically significant coefficient as expected.

In column (7) we estimate our selected specification using the Diff-GMM estimator. We consider all the regressors but TFP growth of the leader as potentially endogenous and use the adequate lagged values as instruments (see the notes on each table for details). Since explanatory variables are measured at the beginning of each period we consider them as predetermined. The results with the Diff-GMM estimator confirm the previous results. 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 and cannot reject the null hypothesis of correct specification of the different models.

Table 10. Roles of the different schooling levels and international trade in TFP growth, 5 Portuguese high technology industries

	1	2	3	4	5	6	7 Diff-GMM
$(HYRxRTFP)_{cit-1}$	.6160 (1.29)						
$IMPS_{cit-1}$	**.0545 (1.32)**	-.1905 (-0.59)	-.1058 (-0.98)	-.0934 (-0.85)	.0758 (1.23)		
$(IMPSxTYR)_{cit-1}$		.0476 (0.81)					
$(IMPSxSYR)_{cit-1}$			**.1034 (1.66)**			**.0474 (2.44)**	**0.0599 (3.73)**
$(IMPSxSHYR)_{cit-1}$				**.0909 (1.55)**			
$(IMPSxHYR)_{cit-1}$					.0367 (0.08)		
$\bar{R}$ -squared	.4625	.4558	.4748	.4719	.4491	.4792	
Root MSE	.14585	.14676	.14417	.14457	.14765	.14356	0.14
Sargan test [*p-value*]							8.119 [0.617]
AR(2) [*p-value*]							-0.3464 [0.729]

Notes: Dependent variable is the rate of TFP (translog) growth adjusted for total hours worked. TYR is average years of total schooling; HYR is average years of tertiary schooling; SYR is average years of secondary schooling; SHYR is average years of secondary and tertiary schooling all industry-specific. IMPS is the ratio of an industry's imports from the OECD to gross output. The sample includes 60 observations between 1986 and 1997. All columns include a full set of time dummies and industry fixed effects. Heteroscedasticity-consistent t-statistics in parenthesis. Coefficients in bold are significant at least at the 10% significance level. Column (7) estimates the specification in column (6) using IMPSxSYR lagged two periods as instruments. 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 as instruments for the endogenous variables (predetermined). Results for the one-step GMM estimator with standard errors robust to heteroskedasticity since the standard errors of the two-step GMM estimator can be seriously biased downwards.

1.4. QUANTIFYING THE CONTRIBUTION OF EDUCATION FOR TFP GROWTH

In the case of the Portuguese manufacturing industries, the evidence only supports the importance of education for productivity growth through technology spillovers and specifically embodied technology diffusion, both in low technology and high technology industries. Additionally, it is education at the secondary level that allows these industries to imitate technology embodied in international trade.

In Table 11 we quantify the contribution of education for TFP growth in each low-tech and high-tech industry in the period 1986-1997 based on the estimated coefficients from the previous sections. For each industry the total impact of education on productivity growth will differ according to its import ratio so that industries that use a higher proportion of imported goods in its production will have higher growth returns to increased educational attainment at the secondary level. The estimated impact of education through embodied technology diffusion is given by $\hat{\delta}_2 IMPS$, where $\hat{\delta}_2$ is equal to 0.0766 in low-tech industries and 0.0599 in high-tech industries.

Table 11. Contribution of education to TFP growth in the Portuguese manufacturing industries (1986-1997)

Industry	avIMPS	Embodied Technology Diffusion
Low-tech		
FOOD	0.181	0.0138
TEX	0.231	0.0177
WOOD	0.068	0.0052
PAP	0.166	0.0128
RUB	1.230	0.0942
ONMP	0.113	0.0087
BMI	1.001	0.0767
FMP	4.522	0.3464
OMAN	1.688	0.1293
	Mean	*0.0783*
High-tech		
CHE	0.752	0.0451
MAI	2.380	0.1425
MEL	0.828	0.0496
MTR	1.461	0.0875
MED	4.006	0.2400
	Mean	*0.1129*

Notes: The parameters used in the computations are those in column (8), Table 5.10 for low-tech industries and column (7), Table 5.12 for high-tech industries. Av.IMPS is the average of the imports ratio for the period.
FOOD - Food products, beverages and tobacco; TEX - Textiles, textile products, leather and footwear;
WOOD - Wood and products of wood and cork PAP - Pulp, paper, paper products, printing and publishing;
CHE - Chemicals and chemical products; RUB - Rubber and plastic products ONMP - Other non-metallic mineral products;
BMI - Basic Metals Industries; FMP - Fabricated metal products, except machinery and equipment;
MAI - Machinery and equipment n.e.c. and Office, accounting and computing machinery
MEL - Electrical machinery and apparatus and Radio, television and communication equipment;
MTR - Transport equipment; MED - Medical, precision and optical instruments; OMAN - Manufacturing n.e.c.

The impact of secondary education on productivity growth is on average higher in high technology industries. However, the highest impact is on FMP, a low-tech industry, since this industry presents by far the highest import ratio. The other three low-tech industries with an impact of education on the respective productivity growth higher than in some high-tech industry are OMAN, RUB and BMI. In the group of high-tech industries, CHE presents the lowest impact of education but the figure is any case much higher (more than two times) than the ones for the low-tech industries that occupy the bottom five positions.

2. SUMMARY AND CONCLUSIONS

The purpose of this paper was to analyse the importance of education for technological change and growth in the Portuguese economy at a sectoral level. We looked at the role of education, and education sub-categories, in the production of new knowledge and in the process of assimilation and diffusion of technologies as in the Benhabib and Spiegel (1994) model. We also investigated whether a large stock of educated workers is beneficial in order to internalise spillovers from international trade, as in Cameron, Proudman and Redding (2005). Total factor productivity is thus explained not only by human capital acquired in the formal education sector but also international trade. We used panel data for fourteen manufacturing industries for Portugal over the period 1986-1997. The method is similar to the one employed in the previous chapter.

Concerning the attempt to unravel the several potential roles of education in productivity growth, directly through innovation activities and indirectly through disembodied and embodied technology diffusion, the results only support the indirect role through the enhancement of the assimilation of technology from abroad embodied in international trade. Distinguishing between low-tech and high-tech industries does not change this result.

Our most robust finding thus concerns the relevance of technology spillovers embodied in imports from OECD countries for productivity growth, as long as manufacturing industries employ workers with skills provided by secondary education. Afonso and Aguiar (2005) also stress the importance of increased international trade and its interaction with the industrialization process to the process catch up of the Portuguese economy at the aggregate country level in the second half of the twentieth century. The Portuguese manufacturing industry cannot rely on automatic technological catch up for productivity growth so active trade and education policies are crucial to recover from the present bottom position in the rank of OECD productivity levels.

Portugal has known several attempts to redesign its education policy in the last two decades. Our results seem to favour a redefinition of education policy based not only on quantitative goals but, more importantly, on the definition of a structure for the education system that allows the economy to fully exploit the benefits from its technological backwardness, i.e., to produce a growth enhancing human capital. Besides registering a general lack of human capital when compared with other EU countries and the US (see chapter 2), Portugal needs to concentrate its efforts at the secondary education level. Bearing also in mind that Portuguese students tend to perform badly in international assessment tests this redefinition involves not only a quantity but also a quality dimension since higher quantity does not necessarily provide the necessary skills for growth, as pointed out by Pina and St Aubyn (2005). On the other hand, as Portugal approaches the technological frontier more attention needs to be devoted to education at the tertiary level since productivity growth will be based essentially in innovation activities that require a highly educated labour force, whereas before imitation activities could be carried out by workers with tertiary but also secondary (and eventually primary) education. Failing to promote higher education at this stage can put Portuguese growth at risk.

The lack of results concerning the direct influence of education on TFP growth might indicate that it is not sufficient only to concentrate on general educational levels, but that the distribution of skill groups as well as their educational level, for example science and engineering vs. humanities degrees or general vs. vocational education, might be a more important determinant of technological innovations and economic growth.

3. APPENDIX - DATA SOURCES

Output: value added in 1995 USD. Data on value added expressed in current USD was taken from Nicita and Olarreaga (2001) that provide industry production and trade data for 67 developed and developing countries collected from the CD-ROM versions of United Nations Industrial Development Organization (UNIDO) Industrial Statistics Database, available at www.worldbank.org/research/trade. We do not use data from the OECD, STAN database, 2004 edition due to its more limited data availability for Portugal. To compute real value added in 1995 USD we computed industry-specific US value added deflators using data on nominal and real value added from the OECD, STAN database, 2004 edition.

Physical capital: real capital stock expressed in 1995 USD. For the years 1976 through 1995 data on gross fixed capital formation (GFCF) expressed in current USD was taken from Nicita and Olarreaga (2001) and for the years 1996 and 1997 from the OECD, STAN database, 2004 (expressed in local currency and converted to USD using the yearly nominal exchange rate). To compute real GFCF in 1995 USD we used the US deflator for GFCF computed using the available data for each US industry on nominal and real GFCF from the OECD, STAN database, 2004. Finally, the perpetual inventory method was used to construct a proxy for the real physical capital stock, K, as a distributed lag of past investment flows, I, as:

$$K_{it} = (1-d)K_{it-1} + I_{it-1} \qquad (7)$$

$$K_{i0} = \frac{I_{i0}}{(g_{GFCFi} + d)} \tag{8}$$

where the capital stock in year *t* does not include investment in year *t*, but only investment up to *t-1*, and *d* is the common depreciation rate. Nadiri and Prucha (1996) estimate that *d*=0.059 for the US total manufacturing sector and this is the value we use for the depreciation rate, common across all industries. K_0 is the initial real physical capital stock, and g_{GFCF} is the average annual growth rate of *I* over the period where data is available.

Labour input: we use data on hours worked from the Groningen Growth and Development Centre, Industry and Labour Productivity Database, O'Mahony and van Ark (2003), downloadable from http://www.ggdc.net/index-dseries.html#top available only for the 1979-1997 period.

Education: average years of education, total and by schooling level, of the workforce employed in each industry *i* at time *t* computed using data on the number of workers with a given schooling level employed in each industry-year from the *Quadros de Pessoal* database from the Portuguese government department *Ministério da Segurança Social e do Trabalho* for the period 1985-1997. See the main text for details.

International trade: ratio of imports from the OECD to gross output:

$$IMPS_{it} = \frac{TIMPS_{it}}{PROD_{it}} x100 \tag{9}$$

where *TIMPS* is total imports from the OECD of industry *i* at time *t* and *PROD* is gross output in industry *i* at time *t*. Gross output data is from Nicita and Olarreaga (2001). Imports data is from the OECD, Bilateral Trade Database, 2000 edition available for the years 1980-1997.

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