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Human capital, trade and long-run productivity. Testing the technological absorption hypothesis for the Portuguese economy, 1960-2001

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Abstract. An important characteristic of the role of foreign trade in the technological catch-up of countries is the complementary nature of technological change and human capital formation. In this context, the level of education is likely to have a crucial impact on total factor productivity because it determines the capacity of an economy to carry out technological innovation, and to adopt and to implement efficiently technology from abroad. However, the role of human capital as a pre requisite for technology absorption although theoretically acknowledged has been empirically neglected. One of the main problems with empirical studies in this domain is that they do not clearly test the mechanisms through which trade, namely the import of capital goods, affects total factor productivity or, roughly the level of technological development of a given country. Through cointegration techniques, we demonstrate the relevance of the technological absorption hypothesis. We show that the interaction between human capital and (lagged) machinery imports – that is, the technological absorption capability - is the most critical determinant of Portuguese long-run total factor productivity.

Key words: Human capital – Innovation – Trade – Economic growth – Cointegration

JEL Classification: C22, J24; O30; O40

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1 Introduction

Advances in the theory of endogenous technological progress have led to a renewed interest in the relation between trade, technological change, human capital and economic growth (Xu and Chiang, 2005). In literature on the determinants of economic growth there are some arguments suggesting that openness would allow reaching higher growth rates. Nevertheless, some theoretical models show an ambiguous relationship between both variables. In some cases, as in Lucas (1993), the trade openness is positively related with growth, because it allows a higher accumulation of human capital in the way of learning by doing. On the other hand, some models as in Young (1991), conclude that trade openness is negative for developing countries, since these countries would produce goods of a very low learning rate.

More recently, a number of studies have identified channels though which productivity levels of countries are interrelated, emphasizing the role of international trade (Coe and Helpman, 1995; Coe et al., 1997; Keller, 1998). Theory suggests various channels by which technology can be transmitted across countries. Technology is embodied in capital and intermediate goods so the direct import of these goods is one channel of transmission. This channel is consistent with the models of Eaton and Kortum (2001), Grossman and Helpman (1991), and Caselli and Wilson (2004). These authors postulate that a country that is more open to machinery and equipment imports derives a larger benefit from foreign innovation efforts, and show empirically that countries that have experienced faster growth in total factor productivity have imported more from the world's technology leaders.

The possibility of technological transfer, however, is influenced by several factors, such as the social capacity of an economy (Abramovitz, 1986). Social capacity in turn is largely determined by the human capital available in an economy, since knowledge and expertise make it more likely to adopt technologies from abroad (Gerschenkron, 1962; Nelson and Phelps, 1966; Badinger and Tondl, 2002). Human capital in the lagging economy tends therefore to be important by improving the absorptive capacity for technology transfer of lagging countries (Benhabib and Spiegel, 1994; Parent and Prescott, 1994).

Thus, the theory predicts that there might be important interactions between technology imports and educational attainment, because imports of machinery and equipment (capital goods) boost productivity only when the economy has an educational attainment that is high enough to allow for an efficient use of the imported technology (Mayer, 2001).

One of the main problems with empirical studies in this domain is that they do not clearly test the mechanisms through which trade, namely imports of machinery and equipment goods, affects total factor productivity or, roughly the level of technological development of a given country (Alvarez, 2001). Moreover, the role of human capital as a pre requisite for absorption although theoretically acknowledged has been empirically neglected. This article is a contribution in that direction. We argue that trade may impact positively to growth because it encourages a higher technological absorption, that is the impact of imports of machinery and equipment on country's productivity is higher the higher the economy's human capital stock, which would allow for an efficient use of the imported technology.

The issue of the interrelationship between trade, human capital and growth is likely to be a major issue for Portugal. First, the escalating openness to international trade after the Second World War is considered an "inescapable feature" in the development of the Portuguese economy (Afonso and Aguiar, 2005). Second, in the same period the structure of imports changed, being observed an upward trend in investment goods (Courakis et al., 1990). These were, according to the comprehensive study of Afonso and Aguiar (2005) decisive to industrialization, not only as providers of inputs but also as a vehicle of technological transfer.

Based on the above discussion from different theoretical perspectives, a better understanding of the Portuguese real sources of growth thus requires examining the human capital-trade-growth nexus. Using cointegration techniques, results obtained for the period 1960-2001 seem to be consistent with theoretical presumptions**.**

The paper is organized as follows. The next section discusses the theory and empirical literature on the relationship between human capital, trade and economic growth, discussing in particular the potential role of capital goods imports and the importance of the human capital on a country's economic performance. Section 3 provides some background on the dynamics of the Portuguese capital imports and economic growth and Section 4 discusses the data sources and proxies for the relevant variables. Section 5 highlights our econometric identification, and Section 6 concludes.

2 Trade, technological change, human capital, and economic growth: a review

A number of studies have identified channels through which productivity levels of countries are interrelated, emphasizing the role of international trade. The early catching-up literature resting on the neoclassical growth model suggests that technological transfer is an important source of technological advance of poor economies (Gerschenkron, 1962; Nelson and Phelps, 1966; Abramovitz, 1986; Bernard and Jones, 1996; Savvides and Zachariadis, 2005). Advances in the theory of endogenous technological progress have led to a renewed interest in the relation between trade, technological change, human capital and economic growth. More precisely, endogenous growth models with trade integration, as Rivera-Batiz and Romer (1991), attribute a central role to international technology spillovers (Saggi, 2002).

As argued in the modern trade literature and integration theory, trade triggers important supply-side effects, which induce efficiency improvements in the enterprise sector and finally lead to additional growth (Balassa, 1961; Grossman and Helpman, 1991; Baldwin, 1993; Keuschnigg and Kohler, 1996). In this context, economies importing goods from other countries with a higher technological level can import technological progress and may be able to renounce of own innovation activity (Rivera-Batiz and Xie, 1993). Empirically, a number of studies for different set of countries have shown that foreign trade is promoting growth (e.g., Balassa, 1978; Kormendi and Meguire, 1985; Dollar, 1992). For EU countries this has been verified in studies such as Baldwin and Seghezza (1996), Ben-David (1996) and Badinger (2001).

In the same line of reasoning, Coe and Helpman (1995), Coe et al. (1997) and Keller (1998) consider foreign trade as a carrier of knowledge and assess the importance of imports in introducing foreign technology into domestic production and spurring total factor productivity. They conjecture that a country that is more open to machinery and equipment imports derives a larger benefit from foreign R&D, and show empirically that countries that have experienced faster growth in TFP have imported more from the world's technology leaders. A related logic underlines Benhabib and Spiegel (1994), who focus on the role of human capital in economic development. Contrasting with studies based on the human capital augmented Solow model (Mankiw et al., 1992), which treat human capital as a separate factor of production, the results of their cross-country, growth accounting exercise suggest that the role of human capital in economic growth is one of facilitating the adoption of technology from abroad and the creation of appropriate domestic technology.

The traditional arguments on the role of human capital go back to Lucas (1988) who views human capital – in the sense of knowledge – as a central factor of production, which enables sustained growth due to its non-decreasing returns. Mankiw et al. (1992) extend the neoclassical growth model by human capital as an additional accumulable factor and concluded that changes in human capital translate into significant changes of growth rates. Yet there are other channels how human capital can influence the growth rate. First human capital is a central prerequisite for innovation activity as set out in Romer (1990a). Second, human capital influences the capacity to adapt technological advances from abroad – the technological absorption hypothesis (Nelson and Phelps, 1966). Acemoglu (2002) finds, for instance, that technical change has been skill-biased over the past 60 years. The level of education has a crucial impact on the growth of TFP because it determines the capacity of an economy to carry out technological innovation (Romer, 1990a) and, most importantly for developing countries, to adopt and to implement efficiently technology from abroad (Nelson and Phelps, 1966).

Technological catching-up depends therefore on the ability of an economy to make use of internationally available technologies. Thus, human capital in the lagging economy is important (Gerschenkron, 1962; Nelson and Phelps, 1966; Abramovitz, 1986) and R&D of lagging OECD countries improves the absorptive capacity for technology transfer (Parent and Prescott, 1994; Benhabib and Spiegel, 1994). As claimed by Crespo et al. (2002), international diffusion of technology channeled by imports is only likely to be conducive to income convergence across OECD countries if the less technologically developed countries make a greater effort to enhance their domestic R&D and human capital stocks.

In summary, there might be important interactions between technology imports and educational attainment, because imports of machinery boost productivity only when the economy has an educational attainment that is high enough to allow for an efficient use of the imported technology.

3 Dynamics of the Portuguese capital imports and economic growth

Several thorough studies (Aguiar and Figueiredo, 1999; Silva Lopes, 2002; Lains, 2003) documented that the convergence of the Portuguese per capita product relative to the most developed European countries is an undeniable fact of twentieth century economic growth.

This dynamics might be explained, at least in part, by the interrelationship between trade, human capital and growth. In fact, this is likely to be a major issue for Portugal. First, the escalating openness to international trade after the Second World War is considered an "inescapable feature" in the development of the Portuguese economy (Afonso and Aguiar, 2005). Second, in the same period the structure of imports changed, being observed an upward trend in investment goods (Courakis et al., 1990). These were, according to Afonso and Aguiar (2005) decisive to industrialization, not only as providers of inputs but also as a vehicle of technological transfer.

In fact, Portuguese technology (capital goods) imports (encompassing imports of machinery, transport equipment and other capital goods), in its majority from technologically more advanced countries (e.g., the US, Japan and Germany), have gained considerable importance over the last forty years, representing in 2000 around 40% of total imports growing from 21.5% in 1960 (in the case of machinery, the figures were, respectively, 22% and 13.5%).

Taking both in real terms (Figure 1) and as a ratio to GDP (Figure 2), imports of machinery and equipment have presented in the period of study considerable dynamism, with annual average growth rates of, respectively, 7.3% and 2.9%. This dynamism is even more remarkable in the recent decade, 1993-2000, presenting average growth rates of, respectively, 12.7% and 7.8% per year.

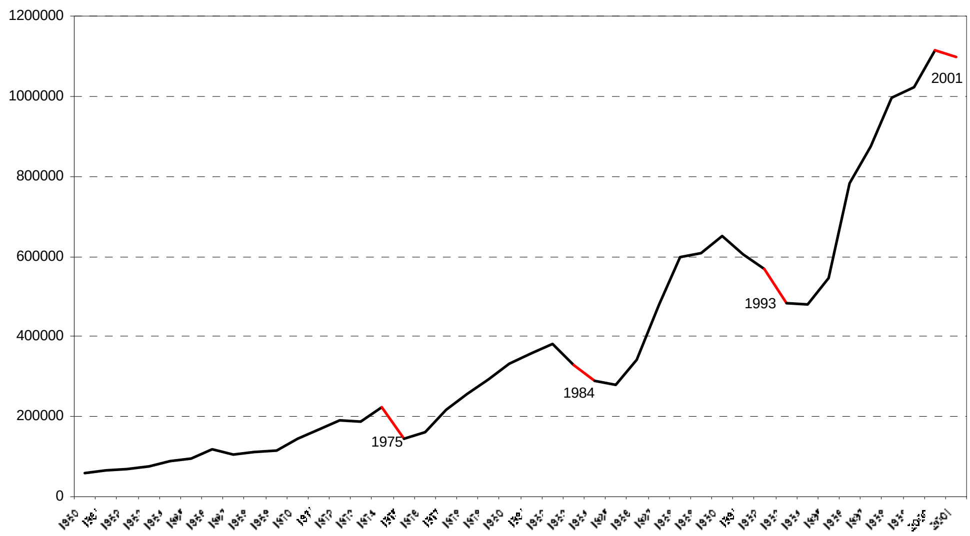

Figure 1: Real imports of machinery and equipment, Portugal, 1960-2001

Source: Authors' computations based on data from Banco de Portugal, Séries Longas (1960-1995) and INE (1996-2001).

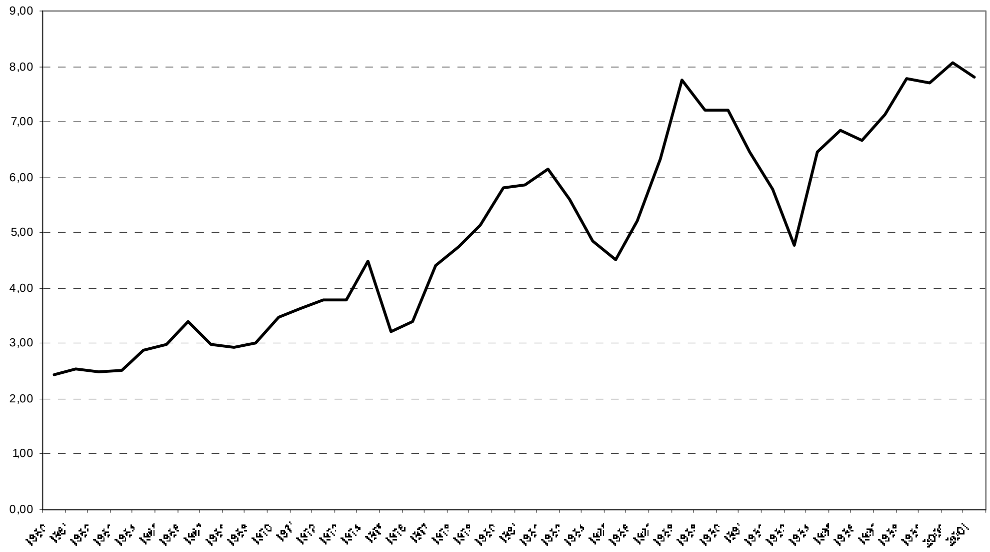

Figure 2: Imports of machinery and equipment in GDP (%), Portugal, 1960-2001
Source: Authors' computations based on data from Banco de Portugal, Séries Longas (1960-1995) and INE (1996-2001).

In order to test whether in the long run the potential interactions between technology imports and educational attainment, through imports of machinery and equipment, are likely to positively impact on country's total factor productivity, and thus to better understand the Portuguese real sources of economic growth, we examine the human capital-trade-growth nexus. The estimation of the cointegration relation requires building proxies for the relevant variables – total factor productivity, human capital and imports of capital goods. Next section briefly describes the proxies used.

4 The proxies for relevant variables

4.1 Total factor productivity (TFP)

The most commonly used measures of countries' economic performance are output per worker (or hours per worker) and total factor productivity (TFP) or "residual of Solow". The output per worker measures productivity growth as the difference between the growth rate in the output index based on gross domestic product (GDP) at constant prices and an employed population index or the number of hours per worker. The second measure, TFP, subtracts from the first measure an estimate of the contribution of physical capital to productivity growth, based on the growth of the capital/labor ratio, weighted by the capital factor share on total returns relative to all the factors.[1]

Similarly to Teixeira and Fortuna (2004), in the present study, TFP is used as a proxy for technological progress. It is important to stress that notwithstanding, as Abramovitz (1993) emphasized, "… TFP (total factor productivity) … is properly interpreted as reflecting the influence of all the unmeasured sources of growth … it includes, besides technological advance, also changes in labour quality due to education or otherwise, gains from the better allocation of resources and those from the economies of scale - unless these are somehow measured."

4.2 Human capital stock

A review of the measures of the stock of human capital used in empirical growth research reveals that human capital is generally poorly proxied (Wößmann, 2003), measurement problems being particularly acute concerning this variable (Hanushek, 1996). In spite (or because) of this there has been considerable work expended to improve international measures of human capital (e.g., Barro and Lee, 2000; de la Fuente and Doménech, 2002).

Alternative proxies for human capital encompass school enrolment ratios, adult literacy rates, levels of education attainment and average years of schooling, monetary value of human capital stock and international test scores of students (Teixeira, 2005). The first two proxies were extensively used in growth regressions (Azariadis and Drazen, 1990; Romer, 1990b; Barro, 1991; Levine and Renelt, 1992; Mankiw et al., 1992) on the ground of their easy availability and broad coverage. However, adult literacy rates ignore most of the investments made in human capital as they do not include qualifications obtained above the basic levels of education. In relation to school enrolment ratios, they constitute a poor measure of the stock of human capital available for current production. Enrolment ratios are flow variables, and the children currently enrolled in schools are by definition not yet part of the labor force. Therefore, enrolment ratios may not even accurately represent changes in human capital stock, especially during periods of rapid educational and demographic transition.

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[1] Both measures are associated with the problems of determining an adequate price index as a GDP deflator, and of measuring the quantity and quality of labor factor; the second measure has the additional problem of the quantification of capital and its rate of use (Griliches, 1988).

Given the shortcomings of existing human capital proxies, levels of education and average years of schooling (cross-country data: Psacharopoulos and Arriagada; 1986; Kyriacou, 1991; Barro and Lee, 1993; 1996; 2002; and time series data: Teixeira, 1998, 1999, 2005; Pereira, 2005) have become the most popular and commonly used measures. Educational attainment is clearly a stock variable, and it takes into account the total amount of formal education received by the labor force. Nevertheless, specifying human capital by average years of schooling implicitly gives the same weight to any year of schooling acquired by a person and ignores the fact that one-year of schooling does not raise the human capital stock by an equal amount regardless of the quality of the education system that provided it (Wöβmann, 2003).

Alternative proxies, such as money value of human capital stock (Laroche and Mérette, 2000; Pereira, 2005) do not assume that the productivity differential among workers is proportional to the differential in educational attainment. This proxy tries to capture differences in the quality of education as well as the market relevance of different types of education and of working experience. However, there are potential problems with the available estimates of return to education because of biases arising from unmeasured characteristics such as ability, and because of their disregard of social benefits (Barro and Lee, 2000) and, in the case that wages change substantially, this measure tends to fluctuate unnecessarily (Mulligan and Sala-i-Martin, 1995).

International test scores for students provide useful information on the quality of education and the international adult literacy survey (OECD and Human Resources Development Canada, 1998) represents a major attempt to measure directly the skills of the labor force for international comparison. Nevertheless, these measures are at present restricted by the limited size of the sample. Therefore, data on educational attainment still provide the best available information about the amount of human capital stock of a country.

This study uses average years of schooling of the working age population as a proxy for human capital stock following the methodology of Teixeira (1998, 1999) to extend the series of human capital till 2001 (Teixeira, 2005).[2]

[2] Pina and St. Aubyn (2002) also estimate a time series for human capital using the methodology described in Teixeira (1998). They, however, introduce some methodological changes and consider a more comprehensive concept of human capital, which, besides schooling, includes professional training. These authors have also recognized that this use of a more comprehensive concept does not significantly change the results obtained.

4.3 Capital goods imports and the technological absorption hypothesis

Some researchers specialized in economic growth analyze the export-led growth in many countries and insist upon the importance of openness to increase real GDP (Chuang, 2000). Often this type of beneficial effect seems very clear but it does not always happen that way. Sharing the view of Guisan (2004), the important question in our perspective is not only to increase the degree of openness due in order to increase foreign demand but also to relate foreign trade with supply side having into account the general positive effects of imports, namely of machinery and equipment on the domestic growth.

Here we follow Azariadis and Drazen (1990) and Chong and Zanforlin (2002) by hypothesizing a macro link between newly transferred technologies on output (and productivity) via imports of machinery and equipment. The introduction of technology new to the country may have little or no effect on growth rates and output. It is argued that a critical mass of technology or know-how may be required. In fact, any new innovation may have limited impact on overall output and productivity if complementary technological developments are not in place, namely the adequate amount of human capital (e.g. know-how complementarities, training of the workforce).

Empirical work along these lines has been pursued by Levin and Raut (1997), who, in exploring the issue of the time devoted to "preparation and learning" show that training is necessary for foreign technology to be efficiently adopted. They explain how this process requires more specialized human capital. In particular, they use a panel of 30 semi-industrialized developing nations between 1965 and 1984 to explore the evidence on policies that stimulate long-run growth by simultaneously promoting investment in human capital and in the manufacturing export sector, on the assumption of complementarity between exports and education expenditures. According to these authors, "educated workers may be able to adapt more quickly to the sophisticated technology and rapid production changes required for competitiveness in the world markets" (p. 166). Similarly, Goldin and Katz (1998) study the origins of technology-skill complementarity in manufacturing in the United States. They offer evidence of the existence of technology-skill and capital-skill (relative) complementarities from 1909 to 1929, and suggest that they are associated with "continuous-process and batch methods and the adoption of electric motors." Finally, Temple (1998) argues, though does not prove, that when a new technology is adopted it requires investment in training and reorganization, as well as in machinery; in addition, De Long and Summers (1991 and 1993) and Lee (1995) emphasize the plausibility of the hypothesis that equipment investment is a key mechanism of technology transfer.

In this paper, we evaluate the contribution of a channel of technology diffusion to the growth of TFP productivity. Following the insights of R&D endogenous growth models, one indicator of technology diffusion is considered, imports of capital goods, more specifically machinery and equipment. The measure of the intensity of machinery goods imports is computed as the share of machinery and equipment goods imports in country's Gross Domestic Product.

The degree of technology diffusion will also depend on the "absorptive capacity" of each country (Savvides and Zachariadis, 2005). One of the main determinants of "absorptive capacity" is the level of a country's human capital, as emphasized by the seminal paper of Nelson and Phelps (1966). In addition to the channel of technology diffusion described above, a measure of human capital is here considered (education level) as a direct determinant of TFP growth. Building on Nelson and Phelps (1966), Benhabib and Spiegel (1994: 145) have argued that human capital plays a dual role in promoting TFP growth: first, it enables a country to "... directly influence productivity by determining the capacity of nations to innovate new technologies suited to domestic production; second, a higher level of human capital enhances the capacity of a country to absorb foreign technology allowing a country to close the gap between the current level of productivity and that of the leading technology country. "

Thus, as specified in the next section, in addition to including human capital as a direct determinant of total factor productivity, we also include interaction effects between human capital and foreign technology sources, in line with the "absorptive-capacity" hypothesis. A more highly educated workforce can better take advantage of foreign R&D-induced ideas, and is also more likely to use capital goods imports (embodying advanced foreign technologies) more effectively. In fact Coe et al. (1997) consider an interaction effect between foreign R&D stocks and education levels while Borensztein et al. (1998) and Xu (2000) find a threshold level of human capital that is necessary for foreign technological sources to exert beneficial effects on growth.

5 Specification and estimation of the econometric model

5.1 Specification of the econometric model

The purpose of this section is to estimate the long-run structural relations between total factor productivity, human capital and trade (machinery and equipment goods imports) for the Portuguese economy in the period 1960-2001.

These structural relations are based on a log-linear specification of the joint evolution of total factor productivity (proxy for technological progress), imports of machinery and equipment (proxy for technology diffused from more technology developed countries) and human capital stock (average number of years of schooling):

$$f_t = \beta_{1,0} + \beta_{1,1} h_t + \beta_{1,2} imach_t + u_{1t}, \qquad (1)$$

where f_t is the (natural) logarithm of the total factor productivity level, for the year t; h_t is the logarithm of the average number of years of schooling (proxy for human capital), for the year t; isk_t is the logarithm of the imports of machinery and equipment in GDP, for the year t; $\beta_{1,1}$ and $\beta_{1,2}$ are the TFP elasticities with respect to human capital stock and capital goods imports, respectively; and, finally, u_{1t} is a random perturbation term.

The theory suggests that productivity tends to increase when human capital stock h grows, *ceteris paribus*. It also suggests that a larger technology diffusion from abroad, reflected by a larger imports of capital goods, namely machinery and equipment *imach*, is associated with greater productivity. Therefore, productivity will be positively related to human capital stock and capital goods imports, that is, $\beta_{1,1} > 0$ and $\beta_{1,2} > 0$.

In the case that the theory is valid, we expect that any departure in productivity, concerning long-run equilibrium (expressed by the equation above), will necessarily be of a temporary nature. Therefore, an additional basic assumption of the theory is that the sequence u_{1t} is stationary.

In order to analyze potential interactions between human capital and the imports of superior technology equipment from abroad (capital goods imports), we estimate in addition the following relations:

$$f_t = \beta_{2,0} + \beta_{2,1} h_t + \beta_{2,3} himach_t + u_{2t}, \qquad (2)$$

$$f_t = \beta_{3,0} + \beta_{3,1} h_t + \beta_{3,2} imach_t + \beta_{3,3} himach_t + u_{3t}, \qquad (3)$$

where $himach_t = H_t\, imach_t$ with the index H_t of the average number of years of schooling, for the year t.

If $\beta_{2,3}, \beta_{3,3} > 0$, then the effect of capital goods imports on productivity tends to be greater when the population is more educated; or, in other words, the effect of human capital stock on productivity is directly related to the magnitude of the acquisition of superior technology equipment from abroad (*the absorption hypothesis*).

Total factor productivity, human capital and machinery and equipment imports variables exhibit strong trends, that is, they are non-stationary. In this case, the use of conventional estimation methods (based on the classical hypotheses on perturbation terms) in the models that include such variables, tend to lead to erroneous statistical inference (Rao, 1994). Statistical reliability of classical estimation methods is based on the hypothesis that variables means and variances are well-defined, time independent constants. However, when means and variances change with time (non-stationary variables), all statistics that use such means and variances will also be dependent on time and therefore do not converge to the true (population) values when sample size tends towards infinity. Moreover, hypothesis tests, based on those statistics, will also be biased towards the rejection of the null hypothesis of absence of a relation between the dependent and independent variables. Thus, in the presence of non-stationary variables, the use of conventional estimation methods also brings the danger of obtaining "spurious regression" (Granger and Newbold, 1974), whose estimates are deprived of any economic meaning. Studies of time series analysis (Engle and Granger, 1987; Johansen, 1988), point to cointegration techniques as the most adequate estimation method when the variables of a model are non-stationary.

Given the characteristics of non-stationarity inherent in the series of our study, we judge that the use of classical estimation methods would be unsatisfactory and, guided by the latest econometric advances in time series analysis, we decided to opt for use of cointegration techniques.

5.2 Estimation of the model

Cointegration allows estimating equilibrium, or long-run parameters, in a relationship that includes unit root (non-stationary) variables. In this study, the use of this econometric analysis is motivated, on the one hand, by an interest in estimating long-run relationships between total factor productivity, human capital and capital goods imports and, on the other hand, by the statistical properties of considered time series. The econometric software EViews 5.0® was used in the estimation. The three considered time series exhibit strong trends, noticeable in Figure 3 (in Appendix B) and confirmed by the tests for non-stationarity (presented in Tables 3-5 in Appendix C).

The idea behind cointegration is that, in the long-run, if two or more series evolve together, then a linear combination of them might be stable around a fixed mean, despite their individual trends (which cause non-stationarity). Thus, when there is a long-run relationship between variables, the regression of all the variables (cointegrating regression) has stationary perturbation terms, even though no variable, individually considered, is stationary.[3]

The results of Augmented Dickey-Fuller (ADF) (Dickey and Fuller, 1979; 1981) and Phillips-Perron (PP) (Phillips and Perron, 1988) tests applied to the variables in this study, indicate that twice differenced series are stationary, that is, the variables will be integrated, at most, at second order, i.e. $I(2)$. Comparing the values of the test statistics obtained with the corresponding critical values, we conclude that all variables differenced once are stationary (that is, they do not have unit roots). Thus, it is reasonable to suppose that all the series in the model are at most $I(1)$. Finally, we can conclude from Table 5 that the (level) variables of the model are non-stationary (the statistical evidence does not reject a non-stationarity hypothesis – the existence of a unit root).

From the above we can conclude that the series of the model are $I(1)$. Consequently, the series could perhaps be cointegrated (Dickey et al., 1991), that is, there could be one or more stationary linear combinations of the series, suggesting a stable long-run relationship between them.

Since the number of cointegration vectors is unknown, and since it is necessary to guarantee that all variables are potentially endogenous (and then to test for exogeneity), it seems wise to use the methodology developed by Johansen (Johansen, 1988; Johansen and Juselius, 1990).

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[3] In technical terms, the class of non-stationary series contains a special group composed of integrated known variables, having important statistical properties of significance at the level of economics relationships. A series y_t is said to be integrated at order d, denoted by I(d), if $\Delta^d y_t = (1-L)^d y_t$ is a stationary series (where L is a backshift operator: $Ly_t = y_{t-1}$). In other words, a series is integrated to the order d if it becomes stationary when differenced d times.

Let z_t be a vector of n potentially endogenous variables. The vector autoregressive (VAR) representation of the data generating process z_t, having k lags, can be written as:[4]

$$z_t = A_1 z_{t-1} + \ldots + A_k z_{t-k} + u_t \,;\; u_t \sim \text{IN}(0, \Sigma) \quad (4)$$

Reformulated as a Vector Error-Correction Model (VECM), this becomes:

$$\Delta z_t = \Gamma_1 \Delta z_{t-1} + \ldots + \Gamma_{k-1} \Delta z_{t-k+1} + \Pi z_{t-k} + u_t \quad (5)$$

where

$$\begin{aligned} \Gamma_i &= -(I - A_1 - \ldots - A_i) \qquad i = 1,\ldots,k\text{-}1 \\ \Pi &= -(I - A_1 - \ldots - A_k) \qquad \Pi = \alpha\beta' \end{aligned} \quad (6)$$

with the matrix β of long-run parameters and the matrix α of the parameters of velocity adjustment. Thus, VECM contains information on adjustments of the variations of z_t both in the short and long-run, via Γ_i and Π, respectively. Assuming that z_t is a vector of non-stationary series $I(1)$, the series Δz_{t-k} are $I(0)$. For u_t to be white noise, Πz_{t-k} has also to be stationary (that is, $I(0)$). This happens when there are $r \leq (n\text{-}1)$ cointegrating vectors in β, that is, when r columns of β form r linearly independent combinations between the variables included in z_t, each of these combinations being stationary. In Johansen's methodology, determining the number of vectors r is equivalent to testing for the reduced rank of the matrix Π. Thus, the number of cointegrating vectors can be obtained by testing for significance of the eigenvalues of the matrix Π. These tests can be carried out through the following test statistics:

$$\begin{aligned} \lambda_{trace}(r) &= -T \sum_{i=r+1}^{n} \ln\left(1 - \hat{\lambda}_i\right) \\ \lambda_{\max}(r, r+1) &= -T \ln\left(1 - \hat{\lambda}_{r+1}\right) \end{aligned} \quad (7)$$

where $\hat{\lambda}_i$ are the eigenvalue estimates obtained from $\hat{\Pi}$ and T is the number of observations.[5]

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[4] The VAR model is a way of estimating dynamic relationships between potentially endogenous variables, not imposing, *a priori*, strong restrictions on exogeneity of the variables and on their structural relationships.

[5] The λ_{trace} statistic tests the null hypothesis that the number of cointegrating vectors is less than or equal to r against the alternative hypothesis that there are n vectors. The λ_{max} statistic tests the null hypothesis that the number of cointegration vectors is r, against the alternative hypothesis that there are r+1 vectors.

As mentioned above, the structural regression to be estimated involves a relationship between productivity, human capital stock and capital goods imports for the Portuguese economy in the period 1960-2001, expressed by (1)-(3).

In cointegration notation, using (3), the vectors of potentially endogenous variables z_t and the normalized cointegrating vectors β's can be represented as

$$z_t = \left(f_t \;\; h_t \;\; imach_t \;\; himach_t \right), \qquad \beta_i = \left(1 \; -\beta_{1i} \; -\beta_{2i} \; -\beta_{3i} \right). \tag{8}$$

In order to carry out the cointegration test, we needed to make an assumption regarding the trend underlying our data. We allowed for a linear deterministic trend in the level data, but the cointegrating equations only have intercepts because we believe all trends are stochastic. In the period 1960-2001, the λ_{trace} and λ_{max} tests do not reject the hypothesis that there is one cointegrating vector. Choosing $r = 1$, we obtain the estimates of the cointegrating vector presented in Table 1.

Table 1. Results of Johansen's cointegration test. Portugal, 1960-2001

r	$\hat{\lambda}_i$	λ_{trace}	p-value	λ_{max}	p-value
none	0.590	57.483	0.005	30.339	0.022
at most 1	0.347	27.143	0.098	14.498	0.326
at most 2	0.231	12.645	0.129	8.935	0.292
at most 3	0.103	3.710	0.054	3.710	0.054

Note: MacKinnon at al. (1999) *p*-values.

We applied the Johansen procedure to test whether there is a cointegration relationship between the TFP, the human capital, the imports of machinery, and the variable proxying the absorption capability (as described in (1), (2) and (3)). Since this involves technology transference from the 'frontier' countries (e.g., the US, Japan, and Germany) to a more laggard country (Portugal), we want to allow for a time lag in the transfer of knowledge through capital goods imports in the methodological line of Lichtenberg (1992) and Kocherlataka and Yi (1997). Thus we estimate alternative specifications using the import variable lagged. This will convey the empirically reasonable idea that the absorption of new technology from abroad, and the corresponding impact on productivity, require a considerable amount of time (Savvides and Zachariadis, 2005). While here we report estimates for six lags, we experimented with alternative lag structures and (results) confirm the robustness of the estimates computed.

It is interesting to observe that when using current instead of lagged imports, results fail to corroborate the theory. In the first specification, data do not evidence any long-term relation between total factor productivity (TFP), human capital and imports of machinery. In the second and third specifications, although cointegration is observed (almost all) estimates are not statistically significant. Results dramatically change when we use lagged imports of machinery, supporting in this case the theoretical framework.

Table 2. Estimates of the long-run TFP elasticities. Portugal, 1960-2001

		Current Imports			Lagged Imports		
		(1)	(2)	(3)	(1)	(2)	(3)
h	*Human capital (direct effect)*	0.222	0.063	0.035	0.075	0.142*	0.249*
imach	*Imports of machinery (diffusion of superior technology from abroad)*	0.746		0.244	0.558*		0.313*
himach	*Technology absorption capability (human capital indirect effect, through imports)*		0.971*	0.687		0,922*	0.333*
Long-run cointegration?		no	Yes	yes	yes	yes(1)	Yes

Notes: * Significant at 1% level; (1) the cointegration test is specified with 1 lags in the level series and a linear deterministic trend; for the remaining specifications was used 2 lags in level series and a linear deterministic trend.

According to the economic theory underlying the model, TFP is positively related to the human capital stock, the imports of machinery (diffusion of superior technology from abroad) of an economy. Moreover, the long-run parameter associated with the variable that takes into account interactions between human capital stock and the imports of technology from abroad *himach* is theoretically expected also to be positive, meaning that the elasticity of total factor productivity with respect to internal stock of knowledge $\beta_{3i}H$ is larger for higher levels of schooling of the population. In other words, the influence of imports of machinery on productivity is a positive function of the human capital stock of the economy.

According to the results presented in Table 2, the estimated cointegration relationships are consistent with theoretical presumptions if and only if we consider the lagged imports of technology from abroad. Thus, it takes time, in the Portuguese case around 6 years, for the imports of machinery to (directly and indirectly) impact on total factor productivity.

Additionally, the evidence shows that Portuguese productivity has greatly benefited from human capital (education) accumulation both directly but also indirectly through the imports of capital goods. Indeed the long-run elasticity of the proxy for technology absorption capability emerges as the most important determinant of Portuguese long-run total factor productivity. More precisely, for the period in analysis, 1960-2001, we estimate that a 1 percentage point increase in the average number of years of schooling for the Portuguese population (aged 25 years or older) leads, for a fixed level of machinery imports, to a direct increase in the productivity of the economy of about 0.25 percentage points. The relevance of trade, specifically the diffusion of superior technology from abroad, for the Portuguese long-term productivity performance is here underlined. In fact, a 1 percentage point increase in the (lagged) imports of machinery tends, *ceteris paribus*, to directly increase productivity by 0.33 percentage points.

The macro link hypothesized by Azariadis and Drazen (1990) and Chong and Zanforlin (2002) between newly transferred technologies and productivity via imports of machinery and equipment comes corroborated by the Portuguese long term data. Accordingly, a critical mass of know-how or human capital may be required to absorb successfullly technology from abroad. Data seems therefore to sustain that the impact of new technology embodied in imports of machinery on total factor productivity is significant if complementary technological developments are in place, namely the adequate amount of human capital. Note that long-run elasticity associated with the proxy for the technology absorption capability achieves the highest figure, 0.333 percentage points.

This comes to corroborate Levin and Raut's (1997) thesis, who, in exploring the issue of the time devoted to "preparation and learning" show that human capital (more specifically training) is necessary for foreign technology to be efficiently adopted, in the sense that highly educated workers are able to adapt more quickly to the new, (presumably) more sophisticated technology imported from foreign countries. It is interesting to recall that Verspagen (1993) had already reported that indigenous innovation efforts (proxied by the internal R&D stock) was not the fundamental variable in the process of economic growth in small open economies such as Portugal; to this author the capability for absorption of innovation did seem to be more important than domestic innovation efforts *per se*.

Such evidence unequivocally supports Nelson and Phelps' (1966) seminal contribution and Benhabib and Spiegel (1994) arguments, conveying the idea that human capital plays indeed a dual role in promoting (total factor) productivity of countries.

6 Conclusions

A number of studies within economic growth literature (e.g., Coe and Helpman, 1995; Coe et al., 1997; Keller, 1998) have identified channels through which productivity levels of countries are interrelated, emphasizing the role of international trade. They argue that a country that is more open to capital goods imports is likely to obtain a larger benefit from foreign technological efforts.

An important characteristic of the role of foreign trade in the technological catch-up of countries is the complementary nature of technological change and human capital formation. It is argued that human capital (namely, the level of education) is likely to have a crucial impact on total factor productivity because it determines the capacity of an economy to carry out technological innovation (Romer, 1990a), and to adopt and to implement efficiently technology from abroad (Nelson and Phelps, 1966). More specifically, there might be important interactions between technology imports and educational attainment, because imports of machinery and equipment boost productivity only when the economy has an educational attainment that is high enough to allow for an efficient use of the imported technology (Benhabib and Spiegel, 1994; Parent and Prescott, 1994; Mayer, 2001).

However, empirical studies in this domain fail to clearly test the mechanisms through which trade, namely imports of machinery and equipment goods, affects total factor productivity or, roughly the level of technological development of a given country (Alvarez, 2001). More important, the role of human capital as a pre requisite for absorption although theoretically acknowledge has been empirically neglected.

In the present article, we tried to overcome such limitations constructing empirical testable specifications which accounted for both the direct and indirect (through imports of machinery) impact of human capital on long-run total factor productivity of a country. We thus followed Pack's (1994) advice by testing the implications of new endogenous growth theory more directly that is, testing its insights against the economic evolution of an individual country using time series data.

The issue of the interrelationship between trade, human capital and growth is a major issue for Portugal, as the escalating openness to international trade after the Second World War is considered an "inescapable feature" in the development of the Portuguese economy (Afonso and Aguiar, 2005) and an upward trend was observed in investment goods in the same period (Courakis et al., 1990). Moreover, in the last two decades, after a long period of massive investments in tangible goods, policy makers seemed to have (finally) realized that Portugal was falling behind in what concerns investment in less tangible, more human capital-related goods (Teixeira, 1999).

Results obtained for the period 1960-2001 showed that the indirect effect of human capital through lagged capital goods imports - the technological absorption hypothesis – emerged as a critical determinant of Portuguese long-run total factor productivity. In the preferred specification (involving the three relevant variables and considering the imports of machinery with a lag of 6 years), we estimate that 1 percentage point increase in the average number of years of schooling for Portuguese adult population leads, *ceteris paribus*, to an increase of productivity of the economy by about 0.25 percentage point. The importance of technology absorption capability appears here even more highlighted - the elasticity of total factor productivity with respect to machinery imports is larger for greater level of schooling of the population, i.e., the long-run elasticity of technology absorption is 0.33 point percentage. Thus, likewise Engelbrecht (2002) who used a sample of 61 developing countries to re-estimate the models of Coe et al. (1997), we identified a positive role for human capital in the absorption of international technological advances favouring therefore the Nelson – Phelps hypothesis.

Concluding, our study proved that there are important interactions between technology imports and educational attainment, as imports of machinery tend to boost productivity to a larger extent the larger the economy educational attainment, which allows for an efficient use of the imported technology. Such evidence unequivocally conveys the idea that human capital plays indeed a dual role – direct and through international trade - in promoting (total factor) productivity of countries.

A Time series used to compute relevant variables

The time series used to compute the relevant variables are presented in Table 3.

Notes: GDP at constant prices of 1990 in million *contos* (1000 PTE); Labour - people employed (thousand); Physical capital stock in thousand *contos* was estimated by permanent inventory method using Gross Capital Formation (GFCF) and a depreciation rate of 10%; TFP index (1990 = 100) was computed using the formula $F = Y / \left(L^{\alpha} K^{1-\alpha} \right)$, where α is the average (1985-2001) labour share in total income (52.9%); the accumulated R&D expenditures (thousand *contos*) were computed by permanent inventory method using R&D expenditures and a depreciation rate of 5%; H - average schooling years of the Portuguese adult population (25 years old or more).

Sources: GDP; GFCF; Labour; Imports of machinery – "Séries Longas do Banco de Portugal"; GDP deflator - Barreto, A. (Org.) (1999), *A Situação Social em Portugal*, 1960-1999; Physical capital stock in 1960 - Neves (1994), *The Portuguese Economy in Figures*; Human capital – Teixeira (2005).

B Plots of the variables in levels

Plots of the variables in levels are presented in Figure 1.

C Tests for non-stationarity or unit roots

Tests for non-stationarity or unit roots are presented in Tables 4-6. For the ADF test, we used the AIC with an upper bound for the lag length as the integer part of $12(T/100)^{1/4}$ defined in Hayashi (2000), p. 594, where T is the sample size. The upper bound for the data set considered in the paper is 9. For the PP test, the bandwidth parameter for the kernel-based estimator of the residual spectrum at frequency zero was obtained by the Newey-West (1994) method using Bartlett kernel.

Notes for Table 4: For these series we specify a random walk (i.e., the AR model); MacKinnon (1991, 1996) critical values for rejection of hypothesis of a unit root.

Notes for Table 5: For these series, *f* and *h* are specified with a random walk with drift (i.e., the AR model with constant), and the remaining variables with a random walk; MacKinnon critical values for rejection of hypothesis of a unit root.

Notes for Table 6: For these series, excluding *himach*, we specify a trend stationary form (i.e., the AR model with constant and time trend); for *himach* we specified a random walk with drift; MacKinnon critical values for rejection of hypothesis of a unit root, that is non-stationarity..

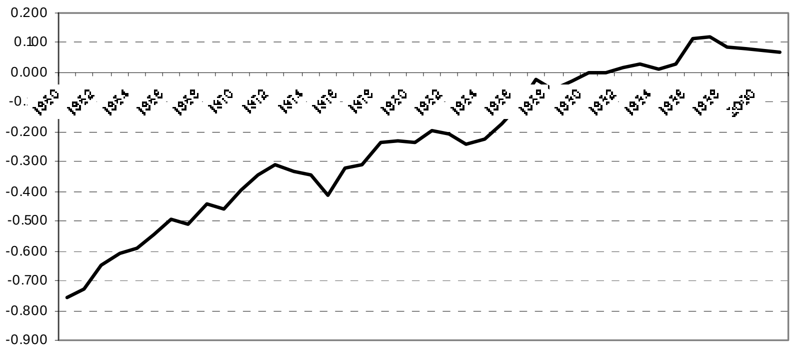
Legend for Tables 4-6: f: natural logarithm of Portuguese TFP index 1960-2001; *h*: natural logarithm of the index of average years of schooling of Portuguese adult population, 1960-2001; *imach*: natural logarithm of the index of Portuguese imports of machinery to GDP ratio, 1960-2001; *himach=H·imach*: where *H* is the index of the average years of schooling of Portuguese adult population.

Table 3. Time series used to compute relevant variables

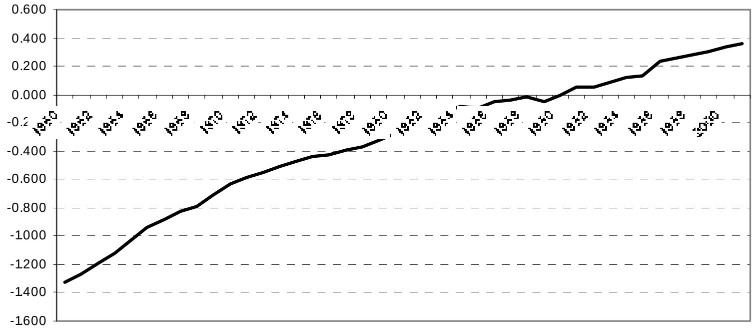
Year	GDP	Labour	Physical capital stock	TFP Index	Ratio of machinery and equip. imports to GDP in t-6	Human capital stock
1960	2464368	3309	4919	0.468003	0.018	1.36
1961	2566396	3295	5047	0.482590	0.019	1.45
1962	2807537	3299	5137	0.523197	0.019	1.56
1963	2975382	3318	5287	0.545379	0.022	1.68
1964	3067390	3359	5350	0.555466	0.023	1.84
1965	3230505	3440	5286	0.580951	0.022	2.01
1966	3518268	3518	5576	0.609727	0.024	2.13
1967	3477995	3535	5591	0.600417	0.025	2.25
1968	3818754	3550	5837	0.644640	0.025	2.33
1969	3843836	3599	6051	0.633249	0.025	2.53
1970	4199176	3637	6338	0.673102	0.028	2.74
1971	4606770	3682	6795	0.709999	0.028	2.88
1972	4983097	3748	7310	0.735084	0.033	2.98
1973	4959212	3796	7562	0.715076	0.028	3.12
1974	5000901	3781	7891	0.708289	0.028	3.23
1975	4474037	3696	7369	0.662372	0.029	3.34
1976	4774313	3624	7145	0.724586	0.033	3.38
1977	4882417	3672	7171	0.734666	0.035	3.47
1978	5393675	3770	7392	0.788996	0.036	3.55
1979	5669101	3862	7837	0.796516	0.034	3.72
1980	5683577	3944	7791	0.791993	0.039	3.91
1981	6126696	3939	8417	0.823638	0.026	4.24
1982	6218352	3965	8872	0.812669	0.029	4.41
1983	5873156	3879	8675	0.784835	0.036	4.59
1984	5926447	3937	8349	0.799996	0.041	4.74
1985	6188363	3932	8185	0.843802	0.043	4.69
1986	6529012	3900	8188	0.893951	0.047	4.90
1987	7593006	4007	9106	0.974828	0.050	4.96
1988	7727170	4096	9907	0.942369	0.052	5.10
1989	8429756	4236	10823	0.968716	0.044	4.91
1990	9047713	4279	11622	1.000000	0.039	5.15
1991	9385634	4335	12329	1.001975	0.037	5.41
1992	9849644	4360	13151	1.016960	0.044	5.46
1993	10126309	4295	13904	1.026491	0.058	5.62
1994	10130336	4293	14310	1.013318	0.068	5.80
1995	10480499	4315	14837	1.027795	0.065	5.90
1996	11724515	4251	15853	1.123343	0.065	6.53
1997	12263903	4332	17011	1.125343	0.058	6.67
1998	12823638	4739	18166	1.087946	0.053	6.82
1999	13305785	4825	19444	1.082854	0.045	7.00
2000	13793738	4909	20839	1.076714	0.044	7.19
2001	14058502	4989	21638	1.068853	0.049	7.41

Figure 1. Plots of the variables in levels

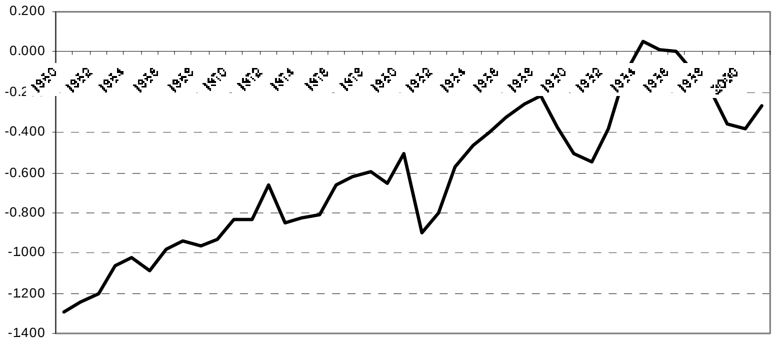
f



h



im



him

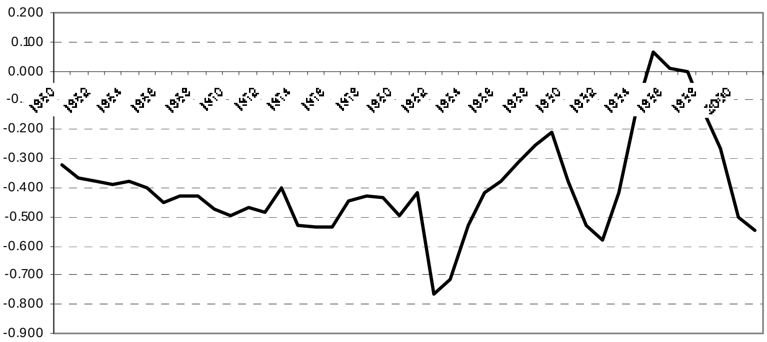


Table 4. Unit root tests - variables in *second* differences

Series	Mean	ADF test	lags	*P*-value*	PP test	*P*-value*
f	-0.000950	-4.805092	7	0.000019	-27.008930	0.000000
h	-0.000821	-6.902036	1	0.000000	-22.062327	0.000000
imach(t)	0.001900	-3.648280	9	0.000816	-24.473292	0.000000
imach(t-6)	0.001341	-4.434826	9	0.000069	-26.926831	0.000000
himach(t)	0.003569	-4.085838	9	0.000256	-13.427084	0.000000
himach(t-6)	-0.000054	-4.600368	9	0.000042	-19.599191	0.000000

Table 5. Unit root tests - variables in *first* differences

Series	Mean	ADF test	lags	*P*-value*	PP test	*P*-value*
f	0,020143	-6,410431	0	0,000003	-6,521405	0,000002
h	0,041294	-4,505302	0	0,000838	-4,556900	0,000722
imach(t)	0,020390	-0,955086	9	0,293856	-5,486376	0,000002
imach(t-6)	0,024986	-1,247318	9	0,190474	-5,649260	0,000000
himach(t)	-0,001439	-0,894976	9	0,318612	-4,322061	0,000081
himach(t-6)	-0,005496	-1,051937	9	0,257780	-4,557052	0,000030

Notes: The p-value is computed with MacKinnon (

Table 6. Unit root tests - variables in levels

Series	Mean	ADF test	lags	*P*-value*	PP test	*P*-value*
f	-0,235272	-2,773592	2	0,215071	-2,559645	0,299770
h	-0,324377	-2,747141	0	0,224267	-2,746944	0,224340
imach(t)	-0,521864	-4,326477	4	0,009057	-2,606929	0,279722
imach(t-6)	-0,611921	-2,067238	7	0,544813	-2,839720	0,192126
himach(t)	-0,300462	-3,262647	1	0,024831	-2,564757	0,109760
himach(t-6)	-0,396784	-0,910137	7	0,943165	-2,686413	0,247222

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