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HUMAN CAPITAL, INNOVATION CAPABILITY AND ECONOMIC GROWTH

Portugal, 1960 - 2001

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ABSTRACT

In this paper, we study human capital effects on economic growth of Portugal from 1960 to 2001. By using VAR and cointegration analyses, we obtain 0.42 long-run estimate for human capital elasticity, 0.30 long-run estimate for internal knowledge elasticity, and 0.40 long-run estimate for the elasticity related with the composite variable that measures the interaction between human capital and innovation capability. These estimates seem to confirm that human capital and indigenous innovation efforts are enormously important to the process of Portuguese economic growth during the period 1960-2001, though the relevance of the former overpasses that involving the creation of an internal basis of R&D. In addition, the indirect effect of human capital, through innovation, emerges here as critical, showing that a reasonably higher stock of human capital is important to enable a country to reap the benefits of its innovation indigenous efforts.

Keywords: human capital, innovation, economic growth

JEL-Classification: J24; O30; O40

RESUMO

Neste artigo estudamos os efeitos do capital humano no crescimento económico português entre 1960 e 2001. Utilizando as metodologias VAR e de cointegração, obtemos as estimativas de longo prazo para as elasticidades do capital humano (0,42), do conhecimento interno (0,30) e da variável compósita que mede a interacção entre capital humano e capacidade de inovação (0,40). Estas estimativas parecem confirmar que o capital humano e os esforços internos de inovação foram extremamente importantes no processo e crescimento económico português durante o período 1960-2001, embora a relevância do primeiro ultrapasse o da criação de uma base interna de I&D. Adicionalmente, o efeito indirecto do capital humano, através da inovação, surge aqui como crítico, demonstrando que a detenção de um stock de capital humano razoavelmente elevado é importante para permitir a um país colher os benefícios dos seus esforços internos de inovação.

Palavras-chave: capital humano, inovação, crescimento económico

JEL-Classificação: J24; O30; O40

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1. INTRODUCTION

Neither classical nor neoclassical authors on economic growth gave much attention to the role of human capital as one of the sources of growth. In contrast, other authors, for example, Mankiw *et al.* (1992), postulated later that there is a significant relationship between investment in human capital and economic growth. In theory, since human capital is related to knowledge and qualifications, and since economic growth depends on the progress of technological and scientific knowledge, it is reasonable to expect that growth is a function of human capital.

In the 1980's, seminal works of Romer (1986) and Lucas (1988) revolutionized the neoclassical theory of economic growth by introducing endogenous growth models. The 'new neoclassical theories' put emphasis not on direct sources of economic growth but on mechanisms and incentives linked to dynamics of the growth itself. This new methodology set human capital as a critical factor to generate technological progress and, as a consequence, steady-state economic growth.

We follow the argument of Pack (1994), for whom tests concerning endogenous models have to be applied using economic time series data from each country separately. The present study involves an empirical application to the economy of Portugal, during the period 1960-2001. Our goal is therefore to empirically evaluate the importance of human capital as a direct or indirect (through innovation) cause for Portuguese economic growth since 1960's till present. This is achieved by using cointegration techniques.

The rest of the paper is structured as follows. In Section 2, we briefly portray, in theoretical terms, the relationship between human capital, technological progress and economic growth. In Section 3, we provide an overview of related empirical work. In Section 4, we describe the data set that we use. The empirical analysis of a long-run stable relationship between productivity, human capital and innovation capability is presented in Section 5. Finally, in Section 6, we conclude with a summary of estimation results for the Portuguese economy during the period 1960-2001.

2. HUMAN CAPITAL, INNOVATION AND ECONOMIC GROWTH: BRIEF REVIEW OF THE THEORETICAL LITERATURE

In spite of contributions of authors, preceding[1] and contemporary[2] with Solow, it was with his seminal publication *"A contribution to the theory of economic growth"* of 1956 that one has truly engaged in a systematic and quantified analysis of questions related to economic growth, clearly separating economic growth and economic development.

The basic neoclassical model of economic growth, associated with the pioneering of Solow (1956), assumes however that disembodied technological progress (as the population growth and the workforce) is exogenous to the model.[3] New theories of economic growth (Romer 1986, Lucas 1988) went beyond the limitations of exogenous technological innovation underlying the work of Solow, by considering accumulation of human capital as a determinant source of economic growth. This change of focus is well expressed by Lucas:

> The main engine of growth is the accumulation of human capital - of knowledge - and the main source of differences in living standards among nations is differences in human capital. Physical capital accumulation plays an essential but decidedly subsidiary role. Human capital takes place in schools, in research organizations, and in the course of producing goods and engaging in trade." (Lucas, 1993: 270)

For most neoclassical models, a determinant factor of economic growth is endogenous innovation. However, this innovative action is itself influenced by human capital endowment of the economy. These models of endogenous growth share the idea of Arrow (1962) of existence of important externalities inherent to accumulation process

[1] Smith (1776), Malthus (1798), Ricardo (1817), Ramsey (1928), Young (1928), Schumpeter (1912) and Knight (1944) provided basic ideas that were a starting point of the modern theory of economic growth: competitive behavior, equilibrium dynamics, the role of decreasing revenues and its relation to accumulation of human and physical capital, interactions between revenues *per capita* and rate of population growth, effect of technological progress on either a better form of labor specialization or discovery of new goods and processes, etc. See Barro and Sala-i-Martin (1995, Chapter 1) for a more detailed description of contributions before Solow.

[2] Stiglitz and Uzawa (1969) constitute an excellent collection of articles of some of the most important authors of the time of Solow, representing not only neoclassical growth theory but also other theoretical alternatives. See, for example, Part III of the collection referring to contributions of the Cambridge (England) school (*e.g.*, Kahn, Kaldor e Robinson).

3 The term *"disembodied"* means that the pace of investment does not influence the rate that technology improves. It is as *"... all technical progress were something like time-and-motion study, a way of improving the organization and operation of inputs without reference to the nature of the inputs themselves."* [Solow (1959: 90-91)].

of technological knowledge.[4] These externalities take the form of generic technological knowledge that can be used to develop new production methods and be available to all the firms. For Lucas (1988), the externalities take the form of public learning that increases the stock of human capital. In addition to the effects of individual on one's own productivity or an "internal effect" of human capital, Lucas also considered, on a general skill level, an "external effect" expressed by the level of human capital/aggregated qualification that contributed to the productivity of all factors.[5]

In technical terms, the general form of the models of Romer (1986) and Lucas (1988) assumes that technological progress enters into the production function of some given firm in two distinct ways: a term that describes the effect of private investments on knowledge and that exhibit the usual characteristics (decreasing marginal revenues); a second term, describes existence of knowledge spillovers that are linked to the investments in knowledge by other firms. Formally, we have:

$$Y_i = F_i(H_i, L_i, H)$$

where Y_i is the output of the *i*th firm, H_i is the stock of investment in technological progress (representing the human capital in Lucas (1988)) of the i^{th} firm, L_i is the quantity of labor force used by the i^{th} firm, H is the total amount of stock of investment in technological progress available to all firms of the economy (in Romer (1986), represented by a sum of all individual H_i's, and in Lucas (1988), expressed by an average level of human capital). The production function of the economy follows from a simple aggregation of firms that are considered identical (or, alternatively, the i^{th} firm is considered a representative agent).

The works on endogenous growth of the second wave, Romer (1990a), Grossman and Helpman (1990, 1991), and Aghion and Howitt (1992), try to end the excessive aggregation of the previous approaches by attesting microeconomic reasons for economic growth. These models retake the hypothesis of catch-up by suggesting a

[4] The publication of the article of Arrow (1962) on learning-by-doing caused an increase of interest in dynamic models of economic growth induced by increasing revenues. In his model, Arrow supposed that the productivity of a given firm was an increasing function of cumulative aggregated investment of industry. Arrow advocated that increasing revenues occur as a result of discoveries of new knowledge, as investments and production take place. The revenues will be external to firms, considered separately, if not such knowledge will have turned public. Arrow (1962) calls knowledge acquisition 'learning', this being a result of experience and, therefore, only having place as a consequence of productive actions.

[5] Lucas (1988) calls this effect "external" given that no decision on human capital accumulation has a noticeable effect over aggregated level of human capital whence an individual does not take into account this effect in his decision of distributing time.

possibility of higher productivity growth in countries that are initially behind, as a result of the diffusion of knowledge already available in industrialized countries, that is, "their initial backwardness offers an opportunity to be exploited." (Pack, 1994: 62). Moreover, the growth of productivity in these countries depends simultaneously on the intensity of international trade and the capacity of internal technological adoption, only possible for higher levels of human capital, as suggested by Lucas (1988) and Romer (1990a, b).[6]

3. HUMAN CAPITAL, INNOVATION AND ECONOMIC GROWTH: REVIEW OF MAIN EMPIRICAL RESULTS

3.1. Human capital and economic growth

At the world level, there is substantial empirical evidence that accumulation of human capital constitutes an important determinant of economic growth. This evidence is so numerous that, according to Romer (1990b: 273), "... it is a challenge for a non specialist to read even the surveys in the area.".

In a study of 98 countries during the period from 1960 to 1985, Barro (1991) concluded that the rate of output growth is strongly related to the initial quantity of human capital. Levine and Renelt (1992) confirmed the results of Barro concerning the effect of human capital on the rate of real growth of output *per capita*, by using the initial rate of high school education as an indicator for human capital. Based on the empirical analysis for South Korea and Taiwan in the framework of dynamic equilibrium, Lee, Liu and Wang (1994) showed that economic growth is facilitated by improvement of aggregate supply, this being translated into technological progress and formation of human (and physical) capital.

In a more complex approach, Benhabib and Spiegel (1994) modeled technological progress (growth of total factor productivity) as a function of education level, and, as in Romer (1990a), considered the hypothesis that human capital affects growth not only directly – influencing the rate of technological innovation of a country -, but also indirectly – influencing the pace of adoption of technologies that come from the outside.[7] This last aspect is particularly important for small countries as Portugal where

[6] Nelson and Phelps (1966) have already advocated that human capital will only be productive when changes occur in technology – education will increase the individual capacity to react to rapid changes in knowledge.

[7] This idea is not novel. Nelson and Phelps (1966) have already suggested that technical progress (or *residual of Solow*) depends on the gap between the knowledge level of a country, *A(t),* and the level of "theoretical knowledge", *T(t).* For these authors, the rate at which this gap reduces depends on the level of

growth process is essentially based on diffusion of technology rather than its creation. Verspagen (1993: 101) refer precisely to this feature, when characterizing the "catching-up countries" (among which Portugal is included): "These countries ... combine low population growth with high investment ratios, but relatively low R&D intensities. Thus, they appear to rely on diffusion of knowledge rather than on creation of knowledge."

The results obtained by Benhabib and Spiegel from a cross-country sample of 78 countries during the period 1960-1985, suggest that the role of human capital, as a necessary condition for adoption and creation of technology adapted to internal needs, is more important than that of being a production factor.

Although at cross-country level there is reasonable evidence on the effect of human capital on economic growth, studies specific to one country are rare. For instance, concerning the Portuguese economy, and according to Pina and St. Aubyn (2002), the studies of Dias (1992) and Teixeira (1997) are the only ones (before Pina and St. Aubyn's) that estimate the contribution of human capital to economic growth. Similarly to Teixeira (1997), Pina and St. Aubyn (2002) conclude that there is statistical evidence of a (meaningful) long-run economic relationship between output and human capital, that is, human capital emerges as an important variable for explaining economic growth.

Despite no presentation of any quantification of human capital, Nunes, Mata and Valério (1989) pointed out that the real problem inherent to the weak performance of Portugal in respect to other European economies, during the period 1833-1985, is associated with incipient basic and technical education, and also with a lack of entrepreneurial initiative. These authors thus suggested that inefficiency of education system, translated into increased illiteracy, lack of engineers and capable managers, contributed to Portugal falling behind during that period. In addition, they also brought up the decisive role of structural policies in implementing education, during the Republican Regime (1910-1926), to tackle the problem of lack of human resources, with positive effects on economic growth.

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human capital (*H*), via a function *c (H)*, where $\frac{\partial c}{\partial H} > 0 : \frac{dA}{A} = c(H) \cdot \left(\frac{T(t) - A(t)}{A(t)} \right)$. But, despite that the growth of total factor productivity $\left(\frac{dA}{A} \right)$ is influenced by *H* in the short run, this growth will tend to stabilize at the level of the (exogenous) rate of theoretical knowledge growth in the long run.

3.2. Innovation and economic growth

Presently, it is common to suppose that new technologies are the driving force of the long run productivity growth. Countries can benefit from a high degree of external R&D, without great internal expenditures on R&D, through acquisition of rights for patents, franchising and exchange of goods in which external R&D is incorporated. Various authors identified these international spillovers of R&D and of learning-by-doing. In addition to Coe, Helpman and Hoffmaister (1995), Griliches (1995), Caballero and Jaffe (1993) and Coe and Helpman (1993) among others, Englander and Gurney (1994) estimate that the US were responsible for 56% of industrial R&D in most OECD countries in 1973, and for 47.5% in 1990.[8] According to these authors, this reduction of productivity gap between the US and other countries was a sign that R&D of other countries had been in part directed by the adoption and acquisition of technologies from the US.

Concerning the importance of technological innovation capacity in the context of new models of exogenous growth, respective empirical implementation turns out to be complex. An appropriate test requires a system of equations, including one for the sector of technological production. A less ambitious approach consists of trying an equation of reduced form, having efforts in R&D and/or human capital as possible explanatory variables. By using this latter approach, Coe and Helpman (1993) studied the relation between R&D and productivity in twenty-two industrialized economies,[9] from 1971 to 1990, relating increase in "total factor productivity" (TFP) – that is, gains on the output level that are not derived from the use of additional capital or labor – to changes in stock of R&D (estimated by the cumulative cost of R&D, taking into account depreciation). Their results confirmed a positive relationship between R&D stock of a country and its own productivity – typically, a 1 percentage point increase in stock of R&D of the seven main industrialized countries leads to 0.23 percentage points increase in productivity; the fifteen economies of smaller size enjoy proportionally smaller gains: typically, a 1 percentage point increase in R&D stock of one of these economies raises the respective productivity merely by 0.07 percentage points. In addition, they also found that expenditures on research of each country significantly influence productivities of other countries – about ¼ of gains of investment in R&D of larger size countries return to other countries. Major spillovers come from the US,

[8] See Englander and Gurney (1994: 62).
[9] Twenty-one OECD economies plus Israel.

which has the highest R&D stock – each percentage point increases in stock raises the productivity of other countries by 0.04 percentage points (estimated value). Complementary, small economies benefit more from external R&D stock than big economies. According those same authors, in small-industrialized economies, expenditures on external R&D (those made in other countries) have a bigger effect on the respective productivity rather than their own research effort. For example, it was estimated that a 1 percentage point increase in external R&D stock of Portugal in 1990, raised the Portuguese productivity (TFP) by about 0.12 percentage points.[10]

In this study, we explore the relation of internal knowledge stock (capability of innovation) and human capital to productivity. Not neglecting the fundamental importance of international spillovers, we are interested here in internal spillovers, that is, those of innovation production/diffusion sectors to others.

4. The proxies of relevant variables [11]

4.1. Total factor productivity

In theoretical literature on economic growth, technological progress has been viewed in three ways: as a free good,[12] as a by-product (externality) of other economic activities,[13] and also as a result of R&D activities undertaken by private firms.[14] Despite that the first two forms of technological progress share some merits – on one hand, the basic research at universities and other public R&D institutions supply substantial inputs for technological progress; on the other hand, learning-by-doing, practice and interaction constitute important factors for technological progress -, the third form of technological progress – innovation as a result of activities undertaken by private firms – is increasingly considered as the most relevant source of technological progress in capitalist economies.

The most often used measures of economic growth are output per worker (or hours per worker) and total factor productivity (TFP) or "residual of Solow". The first measures

[10] Coe *et al.* (1995) specified this asymmetry in distribution of spillovers, suggesting that small economies can greatly benefit from external R&D by international trade. By importing from technologically more advanced countries, small economies acquire inputs of advance technology that make their own industries more efficient.
[11] In Appendix, we present the series used in estimation in this paper.
[12] For example, in the model of Solow (1956).
[13] The models of learning-by-doing of Arrow (1962) and Romer (1986).
[14] Romer (1990a), Grossman and Helpman (1991), Aghion and Howitt (1992), Segerstrom (1991), Caballero and Jaffe (1993), among others.

the productivity growth as the difference between the rate of growth of 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 capital/labor ratio, weighted by capital factor share on total returns relative to all the factors.[15]

In this study, TFP is used as a proxy of technological progress. We do so but also realize its limitations, as put by Abramovitz (1994), "… TFP [total factor productivity] … it is properly interpreted as reflecting the influence of all the unmeasured sources of growth … it includes, besides technological advance, also changes in labor 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

The modern theories of economic growth consider accumulation of human capital (as that of physical capital) a driving force of economic growth, but recognize that its quantification, at the aggregate level, is more complex than that of physical capital. To evaluate effects of human capital, however, economists need to know how to measure it.

A great part of theoretical models of endogenous growth, as those of Lucas (1988), Becker *et al.* (1990), Romer (1990a), Mulligan and Sala-i-Martin (1993), Caballé and Santos (1993) and Upadhay (1994), bring the role of human capital in the form of education levels. Empirical studies behind these models as Romer (1990b), Barro (1991), Kyriacou (1991), Nunes (1993), Barro and Lee (1993), Benhabib and Spiegel (1994), Villanueva (1994) use educational proxies for human capital. However, as realized by Barro and Lee (1993: 363-364), "[t]hese studies ... have been hampered by the limited educational data that are available on a consistent basis...".

The use of literacy rates as a proxy of human capital (Romer, 1990b; Nunes, 1993) is unsatisfactory. The literacy rates measure only the current human capital component, not reflecting the qualifications obtained beyond the basic level of education. Literacy constitutes only the first phase of human capital creation. There exist also other aspects as or more important to labor productivity, for example, analytical, logical and

[15] 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 an additional problem, that is the quantification of capital and its rate of use (Griliches, 1988).

monetary reasoning in addition to various types of technological knowledge. Thus, using literacy to measure human capital stock implies the implicit assumption that education beyond the most basic level does not significantly contribute to productivity.

Another way to measure human capital is through schooling rates (schooling enrolment ratios). Since these rates are easily available in many countries they have been used in numerous studies (Barro, 1991; Levine and Renelt, 1992; Easterly and Rebelo, 1993; Barro and Sala-i-Martin, 1995). The main drawback of these rates (real or gross) is that they only reflect the current flows of education. The accumulation of these flows is an element of human capital stock that will be available in the future.[16] As education process evolves over various years, temporal lag between flows and stocks is generally very high. Even if an adequate temporal lag is considered, determining human capital stock requires an estimate of initial stock.

Unsatisfied by schooling and literacy rates, many authors, such as Psacharopoulos and Arriagada (1986), Kyriacou (1991) and Barro and Lee (1993), constructed more elaborate measures for human capital stock. The most elaborate attempt to quantify the stock of human capital for different countries is that of Barro and Lee (1993). These authors present a comparison of schooling ratios for 129 countries during the period 1960-1985. These ratios show the percentage of men and women, 25 years old or older, which attained different schooling levels (that is, no schooling, primary school, high school or university).

Empirical studies of Portuguese economic growth have generally used literacy rates as the proxy for human capital. This is in large part justified by the already mentioned broader availability of this indicator and the fact that Portuguese development level is low enough that illiteracy may still be considered a hurdle. To our best knowledge, Teixeira (1997, 1998) was the first attempt to estimate a time series of human capital for Portugal. By using a methodology similar to that of Barro and Lee (1993), the author estimated an average time of schooling for the population of 25 years old or older, during the period from 1960 to 1992.

[16] Other drawbacks inherent to these rates are related to mortality and migration. In addition, since real rates are in general not available, another source of error is introduced, that caused by repetition of the years and withdrawal from the schooling process.

This study follows the methodology of Teixeira (1997) to extend the series of human capital till 2001.[17] By using available data of census as a reference, we estimate the lacking observations by a permanent inventory method (considering the census values as stock reference and using the schooling rates to estimate the variations related to that stock), using the following formulas:

$$h_{1,t} = \left(1 - \frac{L25_t}{L_t}\right) \cdot h_{1,t-5} + \frac{L25_t}{L_t} \cdot \left(PRIM_{t-15} - HIGH_{t-10}\right) ,$$

$$h_{2,t} = \left(1 - \frac{L25_t}{L_t}\right) \cdot h_{2,t-5} + \frac{L25_t}{L_t} \cdot \left(HIGH_{t-10} - UNIV_{t-5}\right) ,$$

$$h_{3,t} = \left(1 - \frac{L25_t}{L_t}\right) \cdot h_{3,t-5} + \frac{L25_t}{L_t} \cdot \left(UNIV_{t-5}\right) ,$$

where $h_{jt} = \frac{H_{jt}}{L_t}$ is the proportion of the adult population for which *j* was the highest level of schooling attained; L_t is the size of the population of 25 years or older, at the moment *t*; H_{jt} is the number of individuals whoa are 25 years or more for which *j* is the highest level of schooling obtained [*j*: no school (0), primary school (1), high school (2) and university (3)]; $PRIM_{t-\tau}$, $HIGH_{t-\tau}$, $UNIV_{t-\tau}$ are the ratios of gross enrolment in primary school, high school and university, respectively, observed at the moment $t-\tau$; and $L25_t$ is the size of the population in the age group [25, 29] at the moment *t*; representing the individuals that entered, during the past five years, into the population group of 25 years or older.

The average number of schooling years (for all levels of schooling) for the population of 25 years or older is given by:

$$H_t = 4h_{1,t} + 12h_{2,t} + 18h_{3,t} .$$

Estimation of h_t is achieved by using census data, the formulas given above and filling in the missing values with econometric estimates.

[17] Pina and St. Aubyn (2002) also provide a series of human capital constructed by using the methodology of Teixeira (1997). They, however, introduced some methodological changes and considered a more comprehensive concept of human capital that includes, besides schooling, professional training. The authors recognized, however, that this use of a more comprehensive concept does not significantly change the results obtained.

4.3. Stock of knowledge or innovation capability

Knowledge stock has been approximated by various proxies: the number of scientists and engineers (Jones, 1993; Kortum, 1994), patented inventions (Fagerberg, 1987, 1988; Kortum, 1994), strength of R&D - R&D/GDP ratio – (Griliches, 1988), expenses accumulated in R&D (Coe and Helpman, 1993; Coe *et al.* 1995) and others. Quantifying R&D contribution to economic growth has turned to be particularly complicated, on one hand, caused by actual impossibility to measure productivity precisely, especially in sectors intensive in R&D and services (that have increased in respect to the rest of economy); on the other hand, caused by inability to estimate correctly the dimension of R&D spillovers between firms, industries and countries. Fagerberg (1987) divides measures of technological level and technological activities into two types: technological input measures (expenses in education, expenses in R&D, employment of scientists and engineers); technological output measures (patents). Measures of the first type are directly related to innovation capacity of a country and also to its own imitation capacity, in the way that a certain scientific basis is necessary for imitation process to be successful. Technological output measures are only related to innovation activity – innovation of processes and products.

In this study, we favor technological input measures (more precisely, accumulated expenditures in R&D) because Portuguese economic growth has been characterized by adoption and diffusion of knowledge, and not so much by its creation (Verspagen, 1993). Similarly to the empirical work of Coe and Helpman (1993), we use accumulated expenditures in R&D as a proxy for knowledge stock (innovation capability). Thus, we constructed a proxy of internal knowledge stock for Portugal, based on internal expenditures in research and development of firms (R&D).[18]

[18] The estimates of capital stock in R&D, Total and of Firms, were constructed from the data of R&D published by Junta Nacional de Investigação Científica (JNICT), later replaced by the Observatório para a Ciência e Tecnologia (OCT), and Instituto Nacional de Estatística (INE): for 1964-72, we used the *Indicadores de Ciência e Tecnologia para Portugal* of JNICT (1986); for 1976-90, we use the *Anuário Estatístico do INE* (1973-93) and for 1992-2001, the Folhas Informativas of JNICT (1995), of Observatório para a Ciência e Tecnologia and Observatório do Ensino Superior related to *Potencial Científico e Tecnológico Nacional.*

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 innovation capacity (knowledge stock) 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 of technological progress), internal knowledge stock (accumulated expenses in R&D) and human capital stock (average number of years of schooling):

$$F_t = \beta_0^1 + \beta_1^1 H_t + \beta_2^1 ISK_t + u_t^1$$

where F_t is the (natural) logarithm of the total factor productivity (TFP) level, for the year t; H_t is the logarithm of the average number of years of schooling (proxy of human capital), for the year t; ISK_t is the logarithm of the accumulated expenses in R&D (proxy of internal stock of knowledge or internal innovation capability), for the year t; β_1 and β_2 are the TFP elasticities of human capital stock and internal stock of knowledge, respectively; and, finally, u_t is a random perturbation term.

Theory suggests that productivity tends to increase when human capital stock (H) grows, *ceteris paribus*. It also suggests that a larger innovation capability, reflected by a larger internal stock of knowledge (ISK), is associated with a greater productivity. Therefore, productivity will be positively related to human capital stock and innovation capability, that is, $\beta_1 > 0$ e $\beta_2 > 0$.

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

In order to analyze potential interactions between human capital and innovation capability (internal stock of knowledge), we estimate in addition the following relations:

$$F_t = \beta_0^2 + \beta_1^2 H_t + \beta_2^2 HISK_t + u_t^2$$
$$F_t = \beta_0^3 + \beta_1^3 H_t + \beta_2^3 ISK_t + \beta_3^3 HISK_t + u_t^3 ,$$

where $HISK_t = h_t \times ISK_t$ with an index h_t of the average number of years of schooling, for the year t. If $\beta_2^2 , \beta_3^3 > 0$, then the effect of internal stock of knowledge on productivity tends to be greater when the population is more educated; equivalently, the effect of human capital stock on productivity is directly related to the magnitude of internal stock of knowledge.

Total factor productivity, human capital and internal stock of knowledge proxies exhibit strong trends, that is, they are nonstationary. 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). Thus, in the presence of nonstationary variables, the use of conventional estimation methods brings the danger of obtaining "spurious regression" (Granger and Newbold, 1974) whose estimates are deprived of any economic meaning. Recent studies of time series analysis (Engle and Granger, 1987; Johansen, 1988), point to cointegration techniques as the most adequate estimation method when variables of a model are non-stationary.

5.2. Estimation of the model by cointegration

Cointegration allows estimate equilibrium, or long run parameters in a relationship that includes unit root (nonstationary) variables. In this study, the use of this econometric analysis is motivated, on one hand, by interest in estimating long run relationships between total factor productivity, human capital and innovation capability of Portuguese economy, and, on the other hand, by statistical properties of considered time series. The three considered time series exhibit strong trend, easily noticeable in Plots 1-4 (in the appendix) and confirmed by tests for nonstationarity (presented in Tables 1-3 in the appendix).

The basic idea behind cointegration is that, in a long run, if two or more series evolve together, then a linear combination of them might be stable around a fixed mean, despite of their individual trends (that cause nonstationarity). 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.[19]

[19] In technical terms, the class of nonstationary series contains a special group composed of integrated known variables, having important statistical properties of consequence at the level of economics relationships. A series y_t is said to be integrated of 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 of order d if it becomes stationary when differenced d times.

The results of Dickey-Fuller (DF), Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests applied to the variables of the study, indicate that twice differenced series are stationary, that is, the variables will be integrated of at most second order, i.e. I(2). Comparing the values of obtained test statistics to 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 3 that the (level) variables of the model are nonstationary (the statistical evidence does not reject nonstationarity hypothesis – existence of a unit root).

From the above we conclude that the series of the model are integrated of order 1 [I(1)]. Consequently, the series could perhaps be cointegrated (Dickey, Jansen e Thornton, 1994), that is, there could be one or more stationary linear combination of the series, suggesting stable long run relationship between them.

Since the number of cointegration vectors in 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.

Let z_t be a vector of n potentially endogenous variables. In our case, we have $z_t = [F_t \; SI_t \; H_t]$. The VAR representation of the data generation process of z_t, having k lags, can be written as:[20]

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

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

$$\Delta z_t = \Gamma_1 \Delta z_{t-1} + ... + \Gamma_{k-1} \Delta z_{t-k+1} + \Pi z_{t-k} + u_t \, ,$$

where

$$\Gamma_i = -(I - A_1 - ... - A_i) \qquad i = 1,...,k-1$$
$$\Pi = -(I - A_1 - ... - A_k)$$
$$\Pi = \alpha\beta'$$

with the matrix β of long run parameters and the matrix α of parameters of velocity adjustment. Thus, VECM contains information on adjustments of the variations of z_t

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

both in short and long runs, via Γ_i and Π, respectively. Assuming that z_t is a vector of nonstationary 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 $r \leq (n-1)$ 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 the methodology of Johansen, 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, for example, through the following test statistics:

$$\lambda_{Trace}(r) = -T\sum_{i=r+1}^{n}\ln\left(1-\hat{\lambda}_i\right)$$
$$\lambda_{Max}(r, r+1) = -T\ln\left(1-\hat{\lambda}_{r+1}\right)$$

where $\hat{\lambda}_i$ are the eigenvalue estimates obtained from $\hat{\Pi}$ and T is the number of observations.[21]

As mentioned above, the structural regression to be estimated involve a relationship between productivity, human capital stock and innovation capability (internal stock of knowledge) for Portuguese economy in the period 1960-2001, expressed by

$$F_t = \beta_0 + \beta_1 H_t + \beta_2 ISK_t + \beta_3 HISK + u_t \ .$$

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

$$z_t = \left[F_t \;\; H_t \;\; ISK_t \;\; HISK_t\right];\; \beta_i = \left[1 \; -\beta_{1i} \; -\beta_{2i} \; -\beta_{3i}\right]$$

Actually, we estimate three regressions, the basic one, mentioned above, and two additional ones, which include time dummies for 1980 and 1985. The option for including these latter derived from Chow tests that indicated statistically significant changes in structure for the time series in analysis.

For the econometric specification considered, by using the diagnostic tests and the Pandula procedure, we estimate VECM with two lags, including a trend component for

[21] 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.

the (level) variables. In the period 1960-2001, the λ−Trace and λ−Max tests do not to reject the hypothesis that there is one cointegrating vector. Choosing r = 1, we obtain the following estimates of the cointegrating vectors.

Table 1: Estimates of the long-run total factor productivity elasticities. Portugal, 1960-2001

Variables	Without time dummy	Time dummy for 1985
Human capital (direct effect)	0.4186	0.4205
Internal stock of knowledge (indigenous innovation efforts)	0.3040	0.2781
Innovation absorption capability (human capital indirect effect, through innovation)	0.4021	0.3610

According to the economic theory underlying the model, total factor productivity is positively related to human capital stock and innovation capability (internal stock of knowledge) of an economy. Moreover, the long run parameter associated with the variable that takes into account interactions between human capital stock and innovation capability (*HISK*) is theoretically expected to be also positive meaning that the elasticity of total factor productivity with respect to internal stock of knowledge ($\beta_{3i} \times h$) is larger for greater level of schooling of the population. In other words, the influence of internal stock of knowledge on productivity is a positive function of human capital stock of the economy.

Therefore, the estimated cointegration relationships estimated are consistent with theoretical presumptions. The evidence shows that Portuguese productivity has benefited from human capital (education) more than from investments in internal innovation capability. More precisely, focusing on the period 1960-2001, we estimate that 1 percentage point increase in the average number of years of schooling for Portuguese population (with 25 years or older) leads, for a fixed level of knowledge, to an increase of productivity of the economy by about 0.42 percentage point. The importance of indigenous innovation efforts, even if in lesser extent than that of the human capital, appears here as well highlighted. In fact, a 1 percentage point increase in the internal stock of knowledge tends, *ceteris paribus*, to increase productivity by 0.30 percentage points. In addition to the direct effect mentioned above, human capital also influences total factor productivity indirectly, through innovation; specifically, results obtained demonstrate that the elasticity of total factor productivity with respect to internal stock of knowledge is larger for greater level of schooling of the population (i.e., the long-run elasticity of innovation absorption capability is 0.40 point percentage). The introduction of the time dummy did not change the results in a fundamental way. Human capital continues to emerge as the essential variable.

These results are, in some way, confirmed by other recent empirical studies. Concerning human capital elasticity, Pina and St. Aubyn (2002) obtained estimates similar to ours (between 0.396 and 0.4073, respectively without or with training included, for the tradable sector of the Portuguese economy). Concerning the greater importance of human capital compared to that of indigenous innovation efforts, Coe and Helpman (1993) and Verspagen (1993) already had reported that the internal stock of knowledge is not the fundamental variable in the process of economic growth of small open economies, such as Portugal. As our results show, in these economies, the capability of absorption of innovation seems indeed to be more important.

In summary, based on our estimation results, it is possible to deduce existence of stable structural (long run) relationships. The estimates of the parameters seem to confirm that human capital and indigenous innovation efforts are enormously important to the process of Portuguese economic growth during the period 1960-2001 though the relevance of the former overpasses that involving the creation of an internal basis of R&D. In addition, the indirect effect of human capital, through innovation, emerges here as critical denoting the importance of having a reasonably higher stock of human capital to enable a country to reap the benefits of its innovation indigenous efforts.

6. Conclusions

The main goal of this work was to investigate effects of human capital on economic growth, measured by growth of total factor productivity, roughly considered as an approximation of technological progress. This goal was achieved by empirically testing for the main hypotheses found in the literature of this area, namely that a greater aggregated economic activity will be caused by a higher endowment in human capital and/or a greater innovation capability (these two factors being interrelated, as more human capital tends to stimulate innovation capability of an economy). We estimated structural (long run) relationship between total factor productivity (proxy of technological progress), human capital stock (average number of years of schooling), internal innovation capability (internal stock of knowledge – measured by the real accumulated expenditures on firms R&D), and absorption capability (composite variable involving human capital stock and the internal stock of knowledge). Due to inherent characteristics associated with variables (evidence of strong trends), this estimation was carried out by using cointegration techniques, specifically the Johansen methodology.

Main estimation results emphasize that human capital stock is more important than internal innovation capability (internal stock of knowledge) to explain the Portuguese productivity (1960-1991). More precisely, the estimate of elasticity of total factor productivity with respect to human capital stock is 0.42 percentage points, against 0.30 percentage points of the analogous estimate for internal stock of knowledge. Moreover, elasticity of total factor productivity with respect to innovation absorption capability is 0.40 percentage points. These values, in addition to confirming a stable long run relationship between productivity, human capital and internal innovation capability, also indicate that human capital is extremely important to the Portuguese economic growth, directly, through its impact on productivity and, indirectly, via its relation with innovation efforts.

REFERENCES

Abramovitz, M. (1993), "The search for sources of growth: areas of ignorance, old and new", *The Journal of Economic History,* 53(2), pp. 217-243.

Aghion, P. and Howitt, P. (1992), "A model of growth through creative destruction", Econometrica, 60 (2), pp. 323-351.

Arrow, K. J. (1962), "The economic implications of learning by doing", *Review of Economic Studies*, 29, pp. 155-173; in *Readings in the modern theory of economic growth*, Edited by J.E. Stiglitz and H.Uzawa, The MIT Press, 5th Ed., 1979.

Barro, R.J. (1991), "Economic growth in a cross-section of countries", *The Quarterly Journal of Economics*, Vol. CVI, 2, pp. 407-443.

Barro, R.J. and Lee, J.-W. (1993), "International comparisons of educational attainment", *Journal of Monetary Economics*, 32, pp. 363-394.

Barro, R.J. and Sala-i-Martin, X. (1995), *Economic growth*, New York: McGraw-Hill, Advanced Series in Economics.

Becker, G.S., Murphy, K.M. and Tamura, R. (1990), "Human capital, fertility, and economic growth", *Journal of Political Economy*, Vol. 98 (5), S12-S37.

Benhabib, J. and Spiegel, M.M.(1994), "The role of human capital in economic development: evidence from aggregate cross-country data", *Journal of Monetary Economics*, 34, pp. 143-173.

Caballé, J. and Santos, M. (1993), "On endougenous growth with physical and human capital", *Journal of Political Economy*, 101 (6), 1042-1067.

Caballero, R. and Jaffe, A. (1993), "How high are the giants' shoulders: an empirical assessment of knowledge spillovers and creative destruction in a model of economic growth", in *National Bureau of Economic Research Macroeconomics Annual Meeting*, MIT Press, Cambridge, Mass., pp. 15-74.

Coe, D.T. and Helpman, E. (1993), "International R&D spillovers", *National Bureau of Economic Research,* Working Paper Nº 4444.

Coe, D.T., Helpman, E. and Hoffmaister, A. W. (1995), "North and South spillovers", *National Bureau of Economic Research,* Working Paper Nº 5048.

Dias, A.M. (1992), "Avaliação do QCA do lado da oferta", *mimeo, DPP*, Lisboa.

Dickey, D.A. and Fuller, W.A. (1987), "Co-integration and error correction: representation, estimation and testing", *Econometrica*, 55, pp. 251-276.

Easterly, W. and Rebelo, S. (1993), "Fiscal policy and economic growth: an empirical investigation", *Journal of Monetary Economics*, 32, pp. 417-58.

Englander, A.S. and Gurney, A. (1994), "Medium-term determinants of OECD productivity", *OECD Economic Studies*, Nº 22, pp. 49-109.

Fagerberg, J. (1987), "A technology gap approach to why growth rates differ", *Research Policy*, Vol. 16, pp. 87-99, in *The Economics of innovation*, C. Freeman, 1990, pp. 55-67.

Fagerberg, J. (1988), "Why growth rates differ?", in G. Dosi, C. Freeman, R. Nelson, G. Silverberg and L. Soete, eds., *Technical Change and Economic Theory*, Pinter Publishers, London, pp. 432-457.

Granger, C. and Newbold, P. (1974), "Spurious regressions in econometrics", *Journal of Econometrics*, 2, pp. 111-120.

Griliches, Z. (1988), "Productivity puzzles and R&D: another nonexplanation", *Journal of Economic Perspectives*, Vol. 2, Nº 4, pp. 9-21.

Griliches, Z. (1995), "R&D and productivity: econometric results and measurements issues" in *Handbook of the economics of innovation and technological change*, Ed. by P.Stonemen: Blackwall.

Grossman, G.M. and Helpman, E. (1990), "Comparative advantage and long-run growth", *The American Economic Review*, Vol. 80, Nº 4, pp. 796-815.

Grossman, G.M. and Helpman, E. (1991), “Quality ladders in the theory of growth”, *Review of Economic Studies*, 58, pp. 43-61.

Grossman, G.M. and Helpman, E. (1992), *Innovation and growth in the global economy*, Cambridge, Mass.; and London England: MIT Press, 2nd edition.

Johansen, S. (1988), “Statistical analysis of cointegration vector”, *Journal of Economic Dynamics and Control*, 12, pp. 231-254.

Jones, C.I. (1993), “Time series tests of endogenous growth models”, *Preliminary Version*, Department of Economics, MIT, Cambridge, MA 02139.

Knight, F. H. (1994), “Diminishing returns from investment”, *Journal of Political Economy*, Vol. 52, pp. 26-47.

Kortum, S. (1994), “A model of research, patenting, and productivity growth”, *National Bureau of Economic Research,* Working Paper Nº 4646.

Kyriacou, G.A. (1991), *Level and growth effects of human capital: a cross-country study of the convergence hypothesis*, C.V. Starr Center for Applied Economics, New York University, New York.

Lee, M.-L., Liu, B.-C. and Wang, P. (1994), “Education, human capital enhancement and economic development: comparison between Korea and Taiwan”, *Economics of Education Review*, Vol. 13, Nº 4, pp. 275-288.

Levine, R. and Renelt, D. (1992), “A sensitivity analysis of cross-country growth regressions”, *The American Economic Review*, Vol. 82, Nº 4, pp. 942-963.

Lucas, R.E. (1988), “On the mechanics of economic development”, *Journal of Monetary Economics*, 22, pp. 3-42.

Lucas, R.E. (1993), “Making a miracle”, *Econometrica*, Vol.61, Nº2, pp. 251-272.

Malthus, T. R. (1798), *An essay on the principle of population*, London: W. Pickering, 1986 edition.

Mankiw, N.G., Romer, D. and Weil, D.N. (1992), “A contribution to the empirics of economic growth”, *The Quarterly Journal of Economics*, Vol. CVI, 2, pp. 407-437.

Mulligan, C. and Sala-i-Martin, X. (1993), “Transitional dynamics in two-sector models of endogenous growth”, *The Quarterly Journal of Economics*, pp. 739-773.

Nelson, R. R. and Phelps, E. S. (1966), “Investment in humans, technological diffusion and economic growth”, *The American Economic Review*, Vol. LVI, Nº2, pp. 69-75.

Nunes, A. (1993), “Education and economic growth in Portugal: a simple regression approach”, *Estudos de Economia*, XIII (2), pp. 181-205.

Nunes, A., Mata, E. and Valério, N. (1989), "Portuguese economic growth 1833-1985", *The Journal of European Economic History*, Vol. 18, Nº 2, pp. 291-330.

Pack, H. (1994), "Endogenous growth theory: intellectual appeal and empirical shortcomings", *Journal of Economic Perspectives*, Vol. 8, Nº 1, pp. 55-72.

Pina, A. and St. Aubyn, M. (2002), "Public capital, human capital and economic growth: Portugal 1977-2001", *Departamento de Prospectiva e Planeamento, Ministério das Finanças*, Outubro 2002.

Psacharopoulos, G. and Arriagada, A.M. (1986), "La composition de la population active par niveau d`instruction: une comparaison internationale", *Revue Internationale du Travail*, Vol. 125, Septembre-Octobre 1986, pp. 617-631.

Ramsey, F. (1928), "A mathematical theory of saving", *Economic Journal,* 38, pp. 543-559. Also in *Readings in the Modern Theory of Economic Growth*, Edited by J. E. Stiglitz and H. Uzawa, The MIT Press, 5th Ed., 1979.

Rao, B. B. (1994), *Cointegration: for the applied economist*, Basingstoke: Macmillan.

Ricardo, D. (1817), *Princípios de economia política e de tributação*, Lisboa: Fundação Calouste Gulbenkian, 1975.

Romer, P. (1986), "Increasing returns and long-run growth", *Journal of Political economy,* 94 (5), pp. 1002-1037.

Romer, P.M. (1990a), "Endogenous technological change", *Journal of Political Economy*, Vol.98, Nº 5, pt. 2, pp. S71-S101.

Romer, P.M. (1990b), "Human capital and growth: theory and evidence", *Carnegie-Rochester Conference Series on Public Policy*, 32, pp. 251-286.

Schumpeter, J. A. (1912), *The theory of economic development: an inquiry into profits, capital, credit, interest, and business cycle*, Harvard University Press, Cambridge, Mass., 1968 edition.

Segerstrom, P.S. (1991), "Innovation, imitation, and economic growth", *Journal of Political Economy*, Vol. 99, Nº 4, pp. 807-827.

Smith, A. (1776), *Inquérito sobre a natureza e as causas da riqueza das nações*, Vol. I, II e III, Lisboa: Fundação Calouste Gulbenkian, 1981.

Solow, R.M. (1956), "A contribution to the theory of economic growth", *The Quarterly Journal of Economics*, 70, pp. 65-94.

Solow, R.M. (1959), Investment and technical progress, in K. arrow, S. Karbin & P. Suppes, eds., *Mathematical models in the Social Sciences*, Stanford University Press. Also in *Readings in the modern theory of economic growth*, Edited by J.E. Stiglitz and H.Uzawa, The MIT Press, 5th Ed., 1979.

Stiglitz, J. E. and Uzawa, H. U. (1979), *Readings in the modern theory of economic growth,* The MIT Press, 5th Ed.

Teixeira, A. (1997), Capacidade de inovação e capital humano. Contributos para o estudo do crescimento económico português, 1960-1991, Master Thesis, Faculdade de Economia, Universidade do Porto.

Teixeira, A. (1998), "Human capital stock: an estimation of a time series for Portugal", *Estudos de Economia,* Vol. XVIII, No. 4, pp. 423-441.

Upadhyay, M. P. (1994), "Accumulation of human capital in LDCs in the presence of unemployment", *Economica*, 61, pp. 355-378.

Verspagen, B. (1993), *Uneven growth between interdependent economies: A evolutionary view on technology gaps, trade and growth*, Aldershot: Avebury 1993.

Villanueva, D.(1994), "Openness, human development, and fiscal policies: effects on economic growth and speed of adjustment", *IMF Staff Papers*, Vol. 41, Nº 1, pp. 1-29.

Young, A. (1928), "increasing returns and economic progress", *Economic Journal*, 38, pp. 527-542.

APPENDIXES

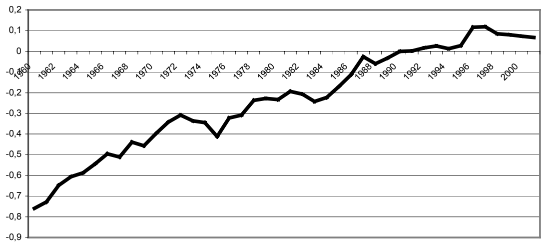
1. Time series used to compute the relevant variables

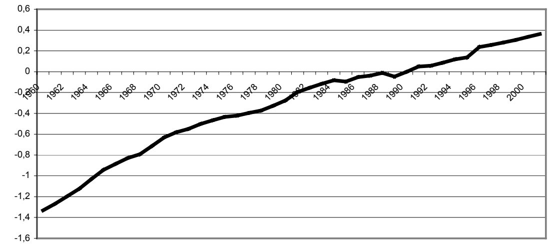
	GDP	Labor	Physical Capital Stock	TFP Index	R&D stock or internal stock of Kkowledge	Human capital stock
1960	2464368	3309	4919	0,468003	1966,0	1,36
1961	2566396	3295	5047	0,482590	2007,8	1,45
1962	2807537	3299	5137	0,523197	2078,2	1,56
1963	2975382	3318	5287	0,545379	2154,3	1,68
1964	3067390	3359	5350	0,555466	2315,4	1,84
1965	3230505	3440	5286	0,580951	2423,6	2,01
1966	3518268	3518	5576	0,609727	2549,1	2,13
1967	3477995	3535	5591	0,600417	2613,4	2,25
1968	3818754	3550	5837	0,644640	2799,8	2,33
1969	3843836	3599	6051	0,633249	2973,2	2,53
1970	4199176	3637	6338	0,673102	3197,4	2,74
1971	4606770	3682	6795	0,709999	3477,3	2,88
1972	4983097	3748	7310	0,735084	3840,3	2,98
1973	4959212	3796	7562	0,715076	4171,9	3,12
1974	5000901	3781	7891	0,708289	4463,5	3,23
1975	4474037	3696	7369	0,662372	4686,0	3,34
1976	4774313	3624	7145	0,724586	4770,6	3,38
1977	4882417	3672	7171	0,734666	5021,2	3,47
1978	5393675	3770	7392	0,788996	5054,2	3,55
1979	5669101	3862	7837	0,796516	5394,9	3,72
1980	5683577	3944	7791	0,791993	5836,3	3,91
1981	6126696	3939	8417	0,823638	6260,3	4,24
1982	6218352	3965	8872	0,812669	6795,0	4,41
1983	5873156	3879	8675	0,784835	7111,5	4,59
1984	5926447	3937	8349	0,799996	7739,0	4,74
1985	6188363	3932	8185	0,843802	8061,6	4,69
1986	6529012	3900	8188	0,893951	8713,4	4,90
1987	7593006	4007	9106	0,974828	9247,6	4,96
1988	7727170	4096	9907	0,942369	9942,4	5,10
1989	8429756	4236	10823	0,968716	10606,8	4,91
1990	9047713	4279	11622	1,000000	11661,6	5,15
1991	9385634	4335	12329	1,001975	12367,4	5,41
1992	9849644	4360	13151	1,016960	13344,3	5,46
1993	10126309	4295	13904	1,026491	14269,8	5,62
1994	10130336	4293	14310	1,013318	15152,0	5,80
1995	10480499	4315	14837	1,027795	15815,4	5,90
1996	11724515	4251	15853	1,123343	17128,1	6,53
1997	12263903	4332	17011	1,125343	18005,1	6,67
1998	12823638	4739	18166	1,087946	19680,2	6,82
1999	13305785	4825	19444	1,082854	21090,0	7,00
2000	13793738	4909	20839	1,076714	22991,8	7,19
2001	14058502	4989	21638	1,068853	25720,0	7,41

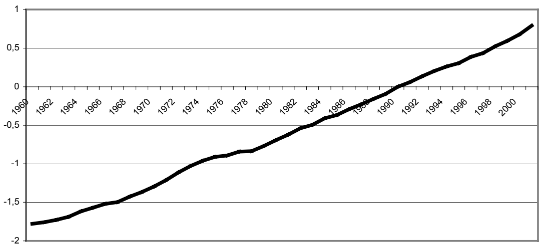
Notes: GDP at constant prices of 1990 in million contos (1000 PTE); Labor - people employed (thousand); Physical capital stock in thousand contos was estimated by permanent inventory method using Gross Fixed Capital Formation (GFCF) and a depreciation rate of 10%; TFP index (1990=100) was computed using the formula $F=Y/[L^{\wedge}(\alpha)K^{\wedge}(1-\alpha)]$, 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 and more).

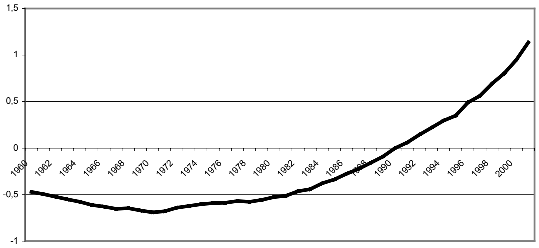
Sources: GDP; GFCF; Labor - "Séries Longas do Banco de Portugal"; GDP deflator - Barreto, A. (Org.) (1999), *A Situação Social em Portugal* , 1960-1999; Physical capital stock in 1960 - César das Neves (1994), *The Portuguese Economy in Figures* ; R&D expenditures - JNICT, Observatório para a Ciência e Tecnologia and Observatório para a Ciência e Ensino Superior.

2. Plots of the variables in levels









3. Tests for nonstationarity or unit roots

Table 1: Unit roots tests - variables in second differences

Series	Mean	*Teste DF*	*Teste PP*	*Teste ADF (lags)*
F	-0.000950	-11.474*	-14.262*	-4.805* (7)
H	-0.000821	-10.792*	-13.507*	-10.792* (0)
ISK	0.002277	-12.766*	-12.309*	-12.766* (0)
HISK	0.005346	-12.358*	-11.934*	-12.358* (0)

Notes: For these series we specify a random walk (i.e., the AR model); *MacKinnon* critical values for rejection of hypothesis of a unit root, that is *nonstationarity* at * 1%, ** 5% and *** 10%.

Legend: *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; *ISK*: natural logarithm of the index of Portuguese internal stock of knowledge, 1960-2001; *HISK = h*ISK:* where *h* is the index of the average years of schooling of Portuguese adult population.

Table 2: Unit roots tests - variables in first differences

Series	Mean	*Teste DF*	*Teste PP*	*Teste ADF (lags)*
F	0.020143	-6.410*	-6.419*	-6.410* (0)
H	0.041294	-4.505*	-4.557*	-4.505* (0)
ISK	0.062714	-4.674*	-4.746*	-2.353 (1)
HISK	0.039209	-5.213*	-5.500*	-1.576 (1)

Notes: For these series, excluding *HISK*, we specify a random walk with drift (i.e., the AR model with constant). In the case of *HISK* the AR model with constant and time trend was used instead; *MacKinnon* critical values for rejection of hypothesis of a unit root, that is *nonstationarity* at * 1%, ** 5% and *** 10%.

Legend: *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; *ISK*: natural logarithm of the index of Portuguese internal stock of knowledge, 1960-2001; *HISK = h*ISK:* where *h* is the index of the average years of schooling of Portuguese adult population.

Table 3: Unit roots tests - variables in levels

Series	Mean	*DF Test*	*Teste PP*	*Teste ADF (lags)*
F	-0.235272	-2.741	-2.677	-2.741 (0)
H	-0.324377	-2.747	-2.775	-2.747 (0)
ISK	-0.603531	-1.802	-2.129	-1.867 (2)
HISK	-0.229400	2.907	2.925	2.907 (0)

Notes: For these series we specify a trend stationary form (i.e., the AR model with constant and time trend); *MacKinnon* critical values for rejection of hypothesis of a unit root, that is *nonstationarity* at * 1%, ** 5% and *** 10%.

Legend: *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; *ISK*: natural logarithm of the index of Portuguese internal stock of knowledge, 1960-2001; *HISK = h*ISK:* where *h* is the index of the average years of schooling of Portuguese adult population.