Comparing Macroeconomic Returns on Human and Public Capital:

An Empirical Analysis of the Portuguese Case (1960-2001)

June 2004

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Abstract:

The impact of human and public capital on growth is a major issue in economic theory and in policy evaluation. Using a cointegrated VAR, we estimate a Cobb-Douglas production function for Portugal with public and human capital. Return rates are then computed with and without dynamic feedbacks. Without these, human capital yields a return comparable to private investment, and smaller than public investment. Considering dynamic feedbacks, private capital responds positively to a shock in public capital, but negatively to a shock in human capital. Consequently, the dynamic feedbacks return on human capital is much lower than on public capital.

1. Introduction

Policies to promote growth, in the European Union (EU) and elsewhere, are usually based on the belief that human capital formation and public investment have a long-lasting effect on aggregate production. In the EU, less developed economies have been on the receiving end of structural funding in order to foster real convergence, meaning an approximation to richer countries income levels. Recipient economies have included Greece, Ireland, Italy, Spain, Portugal and several regions of other countries. Also, all ten countries that entered the EU in May 2004 will be beneficiaries of this European regional policy. Community funds directed to converging economies co-finance an important number of government programs in what concerns public investment (roads, railways, airports and ports, schools and hospitals and other public infrastructure) and also human capital formation, in both the formal education system and training. It becomes therefore essential, from a policy evaluation point of view, to have a quantified measure of the impact of both human capital and public investment on the growth performance of receiving economies.

A second motivation for this paper stems from the current debate on fiscal rules in Europe, especially as regards the treatment of public investment. Some economists argue that this kind of spending is discouraged under the rules of the Stability and Growth Pact (SGP), and that public investment should therefore be excluded from the deficit definition to which ceilings apply. Blanchard and Giavazzi (2004), for instance, propose a golden rule applying to net public investment. Critics of the golden rule, among other arguments, point out its vulnerability to creative accounting, warn that a preferential treatment of physical investment could bias expenditure decisions against spending on education and R&D, and stress that what matters is the overall capital stock, be it private or public (see e.g. Buti, Eijffinger and Franco, 2003). Against this background, it is clearly important to assess how "productive" public capital really is, especially by comparison with private capital and human capital. It is also relevant to study the impact of public investment on the overall (physical) capital stock.

In the light of the above motivations, this paper computes rates of return on public capital and on human capital for the Portuguese economy, using a new data set with annual data (from 1960 to 2001) on GDP and four production factors: labor, private (physical) capital, public capital and human capital. Most inputs for deriving such rates follow from the estimation of a cointegrated vector autoregression (VAR), where the cointegrating vector can be interpreted

as an aggregate four-factor Cobb-Douglas production function. While this vector forms the basis to compute returns on a given factor holding all the others constant (which we term the *ceteris paribus* rate of return), the estimated VAR also allows us to consider the dynamic responses of all the variables in the system to a structural shock to public or human capital, giving rise to what we call the dynamic feedbacks rate of return.

From a methodological point of view, our work contains two main innovative features. First and foremost, we study the importance of public capital and human capital in a unified, coherent framework, rather than separately, as is common in the literature. In this way we are in a position to compute rates of return on each of those two inputs which are comparable and which control for the contribution of the other input. Second, we consider alternative definitions of rates of return, clarifying the underlying assumptions. Again, this enables us to compare magnitudes that previous studies had computed in isolation.

The issues motivating this study concern a wide range of countries, to which our methodology would also be applicable. The empirical focus on Portugal was mainly dictated by reasons of data availability for human capital: Pereira (2003) provides a carefully constructed annual series for the average years of schooling of the Portuguese adult population, something which is not available (with annual periodicity) for most other economies. Care has also been taken to ensure that our measures of private and public capital reflect the best available statistical information.

The remainder of this study is organized as follows. Section 2 surveys the literature on the contribution of public capital and human capital to economic growth. In section 3 we present the production function to be estimated, and discuss in detail the computation of rates of return under alternative assumptions. Our data set is described in section 4, with an emphasis on the construction of physical capital stocks, as well as on the chosen proxy for human capital. Section 5 contains the empirical results regarding the specification and estimation of a cointegrated VAR and the ensuing rates of return on public and human capital. Section 6 concludes.

2. Literature overview

Public capital and growth

In the economic literature, it is not taken for granted that public investment has a significant impact on growth[1]. The works of Aschauer (1989a, 1989b, 1990) on the US economy suggested that the elasticity of output with respect to the public capital stock was about 0.39, and that returns to public investment were higher than returns to private investment. These results were supportive of a particular explanation of the productivity slowdown felt at the time – that it was due to a decline in public investment. Aschauer's findings were criticized on several methodological grounds, and these critiques have led to the application of different econometric techniques to the public capital issue. At the same time, several studies were made to other countries than the US.

Aschauer results relied on static OLS regressions performed with series that are not usually stationary. As it is now well understood, least squares regression may lead to spurious results if there is no cointegration among the variables. Tatom (1991) showed that using first differences led to a much smaller and statistically insignificant effect of public investment on growth. Also, the estimation of a static equation is not immune to the reverse causality problem – public capital may well be caused by output, and not the contrary. Aaron (1990) first made this point.

Subsequent researchers have taken these points seriously. VAR analysis has become a more usual tool, as it allows for the endogeneity of both production and public capital and for dynamic effects between the variables. The finding that series are cointegrated has made some researchers consider a cointegrated VAR, or a VAR with an error-correction mechanism. Crowder and Himarios (1997), Lau and Sin (1997) and Pereira (2000) applied VAR analysis to the US case. In a similar vein, Batina (1999) deals with cointegration and dynamic causality issues by resorting to dynamic ordinary least squares (DOLS). Recent studies that follow a VAR approach applied to European countries include Flores de Frutos, Gracia-Díez and Pérez-Amaral (1998) and Pereira and Roca (2001, 2003) for Spain, Evareart (2003) for Belgium, and Ligthart (2000) and Pereira and Andraz (2002, 2004) for Portugal. In general terms, Batina's (2001) inferences from the empirical literature – that public capital

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[1]Surveys on the "public capital hypothesis" include Batina (2001), Congressional Budget Office (1998), Gramlich (1994) and Pereira and Andraz (2004), chapter 2.

has a positive but not tremendous effect on economic growth, that some types of public investment have more impact than others, and that, in statistical terms, it is perfectly possible to find little or no effect of public investment, "even after careful statistical work has been done" (p. 125) – seem an adequate synthesis[2].

Results specific to the Portuguese economy do not abound. Ligthart (2000) estimates a production function associated to a cointegrating vector in a VAR. The estimated public capital elasticity of output is high, between 0.37 and 0.39, and close to the US value estimated by Aschauer (1989a, 1989b). The same author reports results from an unrestricted VAR analysis that confirm public capital as a significant long-term determinant of output growth, and a disaggregation showing that transport infrastructures are more productive than other types of public investment. Pereira and Andraz (2002) analyze the effects of public investment in transportation infrastructures on Portuguese economic performance. Using a VAR methodology, they find important positive long run effects of aggregate public investment on production, employment and private investment. The rate of return to public investment is close to 16%. Their data set allows them to perform a discrimination of these effects by types of investment. In Pereira and Andraz (2004), they present results in more detail together with sectoral and regional disaggregations.

Human capital and growth

Country-specific studies concerning human capital and growth are scarce, probably because human capital data is seldom available on an annual basis. Consequently, effects on growth have often been estimated by resorting to cross-sectional regressions[3]. The dependent variable is usually GDP, either in levels or in growth rate terms, sometimes divided by population or by the number of workers. A proxy for "human capital" is included among the explanatory variables. The most common proxies are school enrolment rates and the average number of schooling years, or other variables closely related to the educational attainment of the adult population.

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[2] Another line of applied research in this field follows a cost function minimisation approach. As we do not pursue this approach, we refer the interested reader to Batina (2001) and to Pereira and Andraz (2004) for an exposition and references.
[3] Krueger and Lindahl (2001) Sianesi and Van Reenen (2002) and De la Fuente and Ciccone (2002) survey the empirical literature on the influence of human capital formation on growth.

Specification options strongly condition empirical results. As emphasized by De la Fuente and Ciccone (2002) and Sianesi and Van Reenen (2002), there is a dichotomy between a levels and a growth rate specification. In the former, human capital affects the level of GDP per head, or productivity. This type of specification is usually associated to an augmented neo-classical growth model, like the one proposed by Mankiw, Romer and Weil (1992). In a growth rate specification, the human capital stock affects changes in GDP per head or productivity. This latter option is usually related to "new" or "endogenous" growth models[4]. When a growth rate specification is adopted, the impact of human capital investment is potentially greater, especially in a long run perspective.

Several studies find that there is a significant and positive relationship between human capital and growth. Nevertheless, there remains considerable uncertainty concerning the magnitudes involved. De la Fuente (2003), who follows a production function approach comparable to ours, uses a parameter range for his human capital elasticity based on a literature survey and on own estimates. According to this author, and considering EU countries, a 1 percent increase in average years of schooling implies a percentage increase in the GDP level between 0.394 and 0.587.

In what concerns Portugal, Teixeira (1996), Teixeira and Fortuna (2003) and Pina and St. Aubyn (2002) were the sole country-specific studies known to us that provide estimates of the human capital contribution to economic growth. Teixeira and Fortuna obtain a GDP level elasticity with respect to human capital (measured as average years of schooling) close to 0.42. Pina and St. Aubyn estimates are similar – between 0.36 and 0.48.

3. The aggregate production function and the returns to investment

To study in a common framework the importance of human capital and public capital for Portuguese economic growth, we specify a Cobb-Douglas production function,

$$Y(t) = A[\exp(H(t))]^{\gamma} (KP(t))^{\alpha} (KG(t))^{\beta} L(t)^{1-\alpha-\beta} , \qquad (1)$$

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[4] For example, in Lucas (1988) model of learning by studying, the output growth rate is closely related to the human capital rate of change.

where *Y* is GDP, *KP* is the private capital stock, *KG* is the public capital stock (all in real terms), *H* is our measure of human capital (average years of schooling), *L* denotes employment and *A* is a constant scale parameter. All variables will be defined in detail in section 4.

Dividing by $L(t)$ and taking logs in equation (1), the production function can be written in condensed form:

$$y(t) = c + \gamma H(t) + \alpha kp(t) + \beta kg(t), \qquad (2)$$

where a lower case variable denotes values per worker (i.e., divided by *L*) in log terms.

We impose constant returns to scale across physical capital (both private and public) and labor, but leaving out human capital. Many other studies have made a similar assumption[5], which can be justified on grounds of a standard replication argument[6]. One should also notice that, due to the way human capital enters the production function, parameter γ is a semi-elasticity, indicating the percentage increase in output that would result from one more year of schooling for the average worker. This formulation is reminiscent of the well-known Mincerian wage equations (percentage increase in wages due to one more year of schooling), and has been previously adopted in some macroeconomic studies as well (e.g. Jones, 2002).

Both for investment in public capital and in human capital, we compute rates of return (r.o.r.) in two different ways, which we call the "*ceteris paribus* r.o.r." and the "dynamic feedbacks r.o.r.". Each will be now presented and discussed, starting with the case of public capital.

Public capital rates of return

The *ceteris paribus* r.o.r. corresponds to the usual definition of a rate of return, based on the discounted value of the stream of increases in output due to a unit investment in the present (time 0), *holding all other inputs constant*. Formally, this r.o.r. is the value of *r* that solves the equation

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[5] See, for example, De la Fuente (2003), De la Fuente and Doménech (2000), Cohen and Soto (2001), Everaert (2003) and Teixeira and Fortuna (2003).
[6] Doubling the physical capital stocks and the number of workers, and keeping unchanged the average level of education, should yield twice as much output.

$$\int_{o}^{\infty}(\partial Y(t)/\partial KG(t))e^{-\delta t}e^{-rt}dt=1,\qquad\qquad(3)$$

where the marginal productivity is computed on the basis of the production function, and the rate of depreciation δ takes account of the fact that the initial unit increase in the stock of public capital will gradually fade away.

Using the production function elasticity β, one can write $\partial Y(t)/\partial KG(t)=\beta\,(Y(t)/KG(t))$, and assuming, as an approximation, that the capital/output ratio stays constant[7], the r.o.r. becomes

$$r=\beta\,\frac{Y}{KG}-\delta\ .\qquad\qquad(4)$$

The dynamic feedbacks r.o.r. drops the *ceteris paribus* assumption, and considers how the other inputs respond to an increase in public capital. Such a response is an important factor to be taken on board when assessing the merits of public investment, particularly as regards whether public capital crowds in or out private capital. VAR models provide the standard framework to quantify the dynamic responses of several variables to a (structural) shock in one of them; hence, following Pereira (2000) and Pereira and Andraz (2002, 2004), our dynamic feedbacks r.o.r. draws on the impulse response functions (IRFs) of a VAR model with output and the several inputs.

Formally, we compute the value of r that solves the equation

$$\int_{o}^{\infty}d^{b}Y(t)e^{-rt}dt=\int_{o}^{\infty}d^{b}IG(t)e^{-rt}dt\ ,\qquad\qquad(5)$$

where *IG* denotes public investment and d^{b} stands for the differences relative to baseline, given by the IRFs[8].

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[7] This will hold in a steady state, and can be regarded as an acceptable simplification even in the case of catching-up economies, where the *Y/KG* ratio has not displayed a clear-cut trend (see section 4 and Kamps, 2003).

[8] By "baseline" we mean a scenario where no shock to public investment would occur. While deferring to section 5 the details on the computation of $d^{b}Y$ and $d^{b}IG$, we add at this point that equation (5) differs from Pereira (2000) and Pereira and Andraz (2002, 2004), since they only consider the long-term values of $d^{b}Y$ and $d^{b}IG$ (our notation) – i.e., the values when the IRFs converge.

The only difference between equations (3) and (5) lies in the way of calculating the increases in output and public investment[9], which in turn hinges upon whether the *ceteris paribus* assumption is appropriate. Pereira (2000) strongly defends that induced changes in private inputs should be taken into account, and that the ensuing "total marginal product" of public investment ($d^b Y/d^b IG$, in our notation) is "the relevant concept from the standpoint of policy-making" (ibid., p. 517). While agreeing that dynamic feedbacks are of indisputable relevance, our view is that there are valid arguments both for and against their inclusion into the r.o.r.. Against the dynamic feedbacks r.o.r., one may point out that if private investment is crowded in (out), its cost should be included in (deducted from) the right-hand side of equation (5), rather than ignored, as is the case. On the other hand, the output effects of such crowding in (or out) should be, to some extent, credited to public investment, as they would not take place in its absence – a shortcoming of the *ceteris paribus* r.o.r.. Taking an agnostic approach, we will compute both rates of return[10].

Human capital rates of return

Again, we start with the *ceteris paribus* r.o.r.. We assume that human capital formation falls on the young, and consider the macroeconomic costs and benefits stemming from the decision of a 16-year-old to stay one more year at school, instead of joining the workforce.

The literature (e.g. De la Fuente, 2003) considers two main costs of schooling – the opportunity cost of studying and the direct costs of education (mainly teachers' wages). Instead of trying to quantify these costs in money terms through off-model computations, we measure them by the marginal productivity of labor, derived from the production function.

If a 16-year-old attends school for one more year, the total labor costs involved are equal to:

$$\mu = (1 - u_s) + \tau (1 - u_t), \qquad (6)$$

where u_s is the unemployment rate for 16-year-olds, τ is the teacher/student ratio and u_t is the unemployment rate for teachers. Equation (6) takes into account that some students or

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[9] Notice that $(\partial Y(t)/\partial KG(t))e^{-\delta t}dKG(0)$, with $dKG(0) = 1$, is the counterpart of $d^b Y(t)$.

[10] There are cases where we have stronger beliefs: for instance, to assess whether public investment "pays for itself" (by generating fiscal revenues), dynamic feedbacks should definitely be taken into account (see Pereira, 2000, p. 517).

teachers would be otherwise unemployed, schooling entailing in their case no loss of labor for other activities.

Total costs in terms of output are therefore equal to:

$$\mu \frac{\partial Y(0)}{\partial L(0)} = \mu(1 - \alpha - \beta)\frac{Y(0)}{L(0)}, \qquad (7)$$

assuming that investment in human capital takes place at time 0.

As for benefits, we simply consider the present value of output gains brought about by the increase in *H*. In De la Fuente (2003), other benefits are taken into account, such as a decrease in the probability of unemployment (i.e., the unemployment rate) or a technological catch-up effect. The latter requires that at least a second country (the technological leader) is included in the analysis, which is not the case in this paper. As for the former, we decided to keep the unemployment rate independent from *H*: while at a microeconomic level a more educated individual may find it easier to get a job (indeed, De la Fuente documents that, in virtually every country, better educated workers have higher probabilities of employment - ibid., p. 60), at a macroeconomic level there is scant evidence that an increase in the average level of schooling lowers the natural rate of unemployment.

Benefits are therefore equal to:

$$\int_0^\infty \frac{\partial Y(t)}{\partial H(t)} dH(t) e^{-rt} dt, \qquad (8)$$

where $dH(t) = \dfrac{1}{POP(t)}$ and $\dfrac{\partial Y(t)}{\partial H(t)} = \gamma Y(t)$. *POP(t)* is the population aged 15 to 64. Since a youngster has a full working life ahead of him or her, equation (8) ignores any depreciation of the human capital formation (i.e., it is ignored that the 16-year-old will eventually retire).

If we assume that population is constant and that output grows at a constant annual rate, *g*, the *ceteris paribus* r. o. r. is the value of *r* that solves the following equation:

$$\frac{1}{POP(0)} \int_0^\infty \gamma Y(0) e^{(g-r)t} dt = \mu(1-\alpha-\beta)\frac{Y(0)}{L(0)}. \qquad (9)$$

One obtains:

$$r = g + \frac{\gamma L(0)}{\mu(1-\alpha-\beta)POP(0)}. \qquad (10)$$

The rate of return in equation (10) depends on three production function parameters (elasticities or semi-elasticities of inputs, to be estimated), and also on μ, *L(0)* and *POP(0)*. Using values from Table 1, it becomes possible to express the human capital *ceteris paribus* r.o.r. as a function of production function parameters only:

$$r = 0.035 + \frac{0.648\gamma}{1-\alpha-\beta}. \qquad (11)$$

Table 1

Parameter values used to compute the human capital *ceteris paribus* r.o.r.

Parameter	Value	Description	Source
u_s	0.051	Unemployment rate of the population aged 15-19 not having completed upper secondary education, 2001	OECD (2003), p. 297.
u_t	0.05	Unemployment rate, Eurostat definition, 2001	AMECO database[11], May 2004.
τ	0.125	Ratio teachers/students, upper secondary, 2001.	OECD (2003), p. 330.
μ	1.06775	Labor costs (equation (6))	$= (1-u_s) + \tau(1-u_t)$
POP(0)	7 006 022	Population aged 15-64, 2001.	Pereira (2003)
L(0)	4 848 412	Civilian employment, persons, 2001	AMECO database, May 2004
g	0.035	Output per employed person average growth rate, 1961-2001	AMECO database, May 2004

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[11] AMECO - Annual Macro Economic Database, European Commission. Available online at:
http://europa.eu.int/comm/economy_finance/indicators/annual_macro_economic_database/ameco_en.htm

The dynamic feedbacks r.o.r. of human capital formation is computed in a similar way to its counterpart for public investment. It is the value of r that solves the equation

$$\int_{o}^{\infty} d^{b} Y(t) e^{-rt} dt = \int_{o}^{\infty} d^{b} IH(t) e^{-rt} dt \ , \tag{12}$$

where *IH* denotes investment in human capital. As in equation (5), d^{b} denotes differences relative to baseline, inferred from the IRFs. Investment in human capital is recovered from changes in the stock of human capital (*H*), and expressed in real euro terms using equation (7).

4. Data

Physical capital

To construct a measure of physical capital (either private or public), one needs two basic ingredients: a time series of gross fixed capital formation (GFCF) flows, and a method for cumulating them into stocks. As regards the latter, we follow Kamps (2003), who has recently computed capital stocks for several OECD countries. However, instead of drawing on OECD investment data, as Kamps does, we resort to national sources, which we deem more accurate.

Our main source is Banco de Portugal (1997), where an effort was made to remove breaks in series by recalculating older values in the light of more recent statistical concepts and methodologies. Several investment series are provided, from 1953 to 1995[12]. From 1995 onwards we have used ESA 95 data provided by Instituto Nacional de Estatística, removing discontinuities in the common year (1995) by applying backwards the growth rates of the Banco de Portugal series to the ESA 95 levels[13]. Our GFCF series, therefore, cover the period 1953-2001.

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[12] Available on-line at www.bportugal.pt.
[13] Admittedly, this is a shortcut, though of very common use. The ideal solution would be to reconstruct the whole series with ESA 95 criteria.

We have computed investment series at constant 1995 prices for the whole economy and for the public sector (general government)[14], obtaining private investment by difference. As regards the whole economy, the above sources provide data with and without housing. We have chosen to include it, for two reasons: first, for consistency, since no GFCF series net of housing could be computed for the general government; second, because residential assets themselves generate value added (branch 70 in ESA 95), which is included in GDP[15].

Having constructed investment series, we calculate stocks by the perpetual inventory method with geometric depreciation. The law of motion for a given capital stock, either private or public, can be written as

$$K_t = (1 - \delta_{t-1})K_{t-1} + (1 - \frac{\delta_{t-1}}{2})I_{t-1}, \qquad (13)$$

where K_t is the beginning-of-period stock, I_t is the corresponding GFCF variable (again, either private or public), and δ_t is a time-varying depreciation rate.

As in Kamps (2003), the rates of depreciation for non-residential assets remain constant until 1960, and then gradually increase over time[16], according to

$$\delta_t = \delta_{1960}\left((\delta_{2001}/\delta_{1960})^{1/41}\right)^{t-1960}, t = 1960,...,2001. \qquad (14)$$

For public capital, the values of $\delta_{1960} = 0.025$ and $\delta_{2001} = 0.04$ are assumed, while for private capital we posit $\delta_{1960} = 0.0275$ and $\delta_{2001} = 0.07$[17].

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[14] In Banco de Portugal (1997) data for general government GFCF is only reported in nominal terms. However, it includes a breakdown by types of capital goods (e.g. vehicles, construction, etc), and applying to each of these the corresponding price index (computed for the whole economy) has enabled us to produce estimates of public investment at constant prices.

[15] Kamps (2003) estimates the residential capital stock separately for several countries in his sample, but not for Portugal.

[16] Using data from the Bureau of Economic Analysis, Kamps (2003) shows that the implicit scrapping rates in the USA display an upward trend. Though similar data is not available for the Portuguese economy, it is worth mentioning that the depreciation rates accepted by the tax authorities for different types of assets generally increased from 1981 to 1990 (*Decreto Regulamentar* no. 2/90 *versus Portaria* no. 737/81).

[17] These rates for private capital are slightly below those of Kamps, since he considers residential assets (which depreciate much slower) separately, while we include them in the capital stock.

To generate initial values for the capital stock, and again following Kamps (2003), artificial GFCF series starting in 1860 were constructed by assuming 4% real annual growth from that year to the start of our actual investment series (1953).The capital stocks in 1860 were then initialized at zero, and equation (13) run until 2001.

Human capital

We have used Pereira's (2003) series for the average years of schooling of the Portuguese population aged between 15 and 64, a range close to the working force. The author anchored his series in census data and computed figures for years between censuses using data from different national sources on school enrollment, migration, mortality rates and retiring population. The use of interpolations or estimations was kept to a minimum.

It should be emphasized that the human capital series used in this paper is an annual one. Annual series on average years of schooling are not usually found in the empirical literature. However, they are essential for a time series, country-specific study like this one. Researchers on human capital and growth have mostly used series available at a five or ten year frequency, like the ones provided by Barro and Lee (2000), Cohen and Soto (2001) or De la Fuente and Doménech (2000). These data sets are interesting for panel data studies, with different countries as units of observation, but insufficient for use in a VAR.

GDP and employment

Our GDP and employment data come from the AMECO database, updated in May 2004. GDP is the gross domestic product at 1995 market prices and employment is civilian domestic employment.

The time series used in our empirical work are presented in the appendix and plotted in Figures 1 to 4. GDP per worker (Figure 1) grew faster from 1960 to 1974. Growth was somewhat disrupted following the first oil crisis and the democratic revolution in the middle of the 70s. Economic growth was reinforced after Portuguese accession to the European Community in 1986. Human capital, or average years of schooling, grew steadily from a very low value in 1960, less than 3 years, to a still low value in European terms in 2001 – a bit more than 7 years (see Figure 2). Public capital (Figure 3) tended to increase along GDP per worker. Public investment was particularly strong in recent years, in part due to structural funds made available by the EU. Private capital per worker, like GDP, grew at a higher rate in

the first part of the sample (Figure 4). The capital–output ratios displayed no clear trend, even if there was a jump in private capital relative to output in the mid 70s (Figure 5).

5. Empirical results[18]

The graphical analysis of the previous section suggests that all the series entering the production function (2) – GDP per worker, on the one hand, and the three capital inputs, also defined in per worker terms, on the other hand – are not stationary. If their first differences are stationary, then they can all be treated as I(1) series. In this case, there is the possibility that there is at least one linear combination of these four variables that is stationary. If there were a meaningful production function that links inputs to output then one would indeed expect to find such a stationary vector. The vector coefficients, if correctly normalized, would give us the elasticities we are interested in.

Accordingly, our empirical results are presented in the following sequence. Firstly, we show some evidence that the series are I(1). Secondly, we proceed to estimate the number, if any, of cointegrating vectors. Thirdly, once the number of cointegrating vectors has been chosen, we estimate a cointegrated VAR, yielding the parameters of the cointegrating vector(s) and the implied *ceteris paribus* r.o.r. Finally, drawing on the IRFs to structural shocks in human or public capital, we proceed to compute the dynamic feedbacks r.o.r..

Stationarity tests

Table 2 presents results from Augmented Dickey-Fuller (ADF) tests[19]. The first half of the table contains results when a trend was included in the regression. In the second half, no trend was included. The number of dependent variable lags was chosen starting from a relatively high value, nine lags, and sequentially reducing it when the t-statistic associated to the highest lag coefficient was not significant[20].

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[18] Econometric results presented in this section were obtained using GiveWin and PcGive 10. See Doornik and Hendry (2000, 2001) for a complete description of this software.

[19] Augmented Dickey-Fuller tests are described in detail in several manuals of econometrics. See, for example, Hayashi (2000).

[20] The chosen maximum number of lags results from the formula proposed by Shwert (1989):

$$p_{max} = \left[12 \left(\frac{T}{100} \right)^{\frac{1}{4}} \right], \text{ where } T \text{ is the number of observations.}$$

Table 2

Augmented Dickey-Fuller tests

Series in levels

Variable	Lags included	ADF statistic	Critical level 5%	Critical level 1%
Trend and constant included in the regression:				
H	8	-2.177	-3.551	-4.260
kg	1	-3.161	-3.525	-4.202
kp	1	-1.250	-3.525	-4.202
y	8	-2.370	-3.551	-4.260
Constant but no trend included in the regression:				
H	8	1.579	-2.953	-3.642
kg	0	-1.183	-2.934	-3.597
kp	1	-2.605	-2.936	-3.602
y	8	-1.196	-2.953	-3.642

The null hypothesis of no stationarity is not rejected in any case, as the ADF statistic is never inferior to the 5 percent critical level.

When the series are first differenced, the no stationarity hypothesis is dismissed in almost all cases, as can be inferred from Table 3. The number of lags was determined as above, and only a constant was included in the regression.

Table 3

Augmented Dickey-Fuller tests

Series in first differences

Variable	Lags included	ADF (or DF) statistic	Critical level 5%	Critical level 1%
DH	1	-2.191	-2.938	-3.607
Dkg	0	-4.671**	-2.936	-3.602
Dkp	0	-3.035*	-2.936	-3.602
Dy	1	-3.990**	-2.938	-3.607

  * Rejection at the 5 percent level.

  ** Rejection at the 1 percent level.

The ADF test for the first difference of the human capital series was not conclusive in dismissing the non-stationarity hypothesis. This could well result from the fact that our sample is relatively small – it is well known that stationarity tests are not very powerful in small samples. In conceptual terms, it is difficult to believe that *changes* in average years of schooling have random walk properties. These changes result from higher schooling rates in younger cohorts. These schooling rates have clearly increased in Portugal from 1960 onwards, as they were very far from the 100 percent limit. As this limit is gradually approached, it is to be expected that changes in years of schooling become smaller. Visual inspection of Figure 2 suggests this could already be the case for Portugal from 1993 onwards. Accordingly, we take the *H* series as being I(1), the same order of integration as *kg*, *kp* and *y*.

Number of cointegrating vectors

In determining the number of cointegrating vectors, we followed the Johansen (1988) procedure. We started by estimating the following unrestricted VAR:

$$\Delta X_t = c + \Phi D_t + \sum_{i=1}^{p} \Gamma_i \Delta X_{t-i} + \Pi X_{t-1} + \varepsilon_t, \qquad (15)$$

where X_t is a vector of four endogenous variables (*kg*, *kp*, *H* and *y*). This VAR includes an unrestricted constant, *c*, which allows for linear growth in the data. Two unrestricted dummy variables, $D1_t$, taking value 1 from 1960 to 1974 and equaling 0 from 1975 onwards, and $D2_t$, which equals 1 from 1986 onwards, and zero otherwise, were also included. The first artificial variable takes into account the structural break in growth that occurred in the mid-seventies, while $D2_t$ corresponds to the growth resurgence following Portuguese entry to the European Community in 1986. The number of lags in the VAR, p , was chosen to be equal to 1, considering a residuals normality test and three information criteria (Schwarz, Hanann-Quinn and Akaike)[21].

Table 4 summarizes results from four tests used to determine the number of cointegrating vectors (CV)[22]. In every case, the statistic presented and respective probability value correspond to the null hypothesis that the number of cointegration vectors, *r*, equals the figure in the first column. With the trace test, the number of cointegrating vectors exceeds *r*

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[21] See Doornik and Hendry (2000), vol. II.
[22] Doornik and Hendry (2000), vol. II, includes a complete presentation of these tests.

under the alternative hypothesis. When applying the maximum eigenvalue test, the alternative is that the number of cointegrating vectors equals *r+1*. The tests denoted (T-nm) include a small sample correction suggested by Reimers (1992).

Table 4

Cointegration tests

r, number of CVs	Trace test	Maximum eigenvalue test	Trace test (T-nm)	Maximum eigenvalue test (T-nm)
0	64.00 [0.001]**	34.11 [0.004]**	30.78 [0.016]*	57.75 [0.004]**
1	29.89 [0.049]*	16.52 [0.204]	26.97 [0.105]	14.91 [0.308]
2	13.37 [0.102]	9.65 [0.241]	12.06 [0.155]	8.71 [0.319]
3	3.72 [0.054]	3.36 [0.067]	3.72 [0.054]	3.36 [0.067]

Values within brackets are p-values.

* Rejection at the 5 percent level.

** Rejection at the 1 percent level.

Even if one of the trace test results in Table 4 suggest that there could be two CVs, the other three tests clearly indicate that there is one, and one only, cointegrating vector. On the whole, results imply therefore that matrix Π in equation (15) has rank 1. Under this hypothesis, this matrix can be decomposed as:

$$\Pi = ab', \qquad\qquad (16)$$

where *a* is a 4x1 vector of loadings and *b* is a 4x1 cointegrating vector.

Estimation of the cointegration vector and *ceteris paribus* rates of return

Estimation of a cointegrated VAR by full information maximum likelihood imposing one cointegration relationship yielded results for the cointegrating vector parameters and their standard errors presented in Table 5, line 1.

Table 5

Estimated cointegrating vectors

	Likelihood ratio test of restrictions		Y	H (γ)	kg (β)	kp (α)
1. No restrictions		Estimated parameter	-1.0	0.0563	0.148	0.557
		Standard error	0.0	0.0643	0.373	0.198
		Ceteris paribus r.o.r.		0.158	0.267	0.185
2. Imposed elasticity of kp and imposed semi-elasticity of H	$\chi^2(2) = 0.2978$ (P-value: 0.8611)	Estimated parameter	-1.0	0.0660	0.294	0.350
		Standard error	0.0	0.0	0.071	0.0
		Ceteris paribus r.o.r		0.154	0.568	0.090

The cointegrating vector was normalized imposing that the parameter associated with GDP equals -1. A production function interpretation of this vector associates the other parameters to elasticities (or to a semi-elasticity, in the case of *H*). Knowledge of these elasticities allows us to compute the *ceteris paribus* rates of return, also presented in the table[23]. Note that the estimated r.o.r. on private investment, of about 18.5 percent, is quite high. For instance, it is higher than recent estimates for the US economy[24]. The estimated public capital elasticity ensures a *ceteris paribus* r.o.r. for public investments, 26,7%, clearly above the private one. The estimated *ceteris paribus* rate of return on human capital formation results from all three parameters *α*, *β* and *γ* (see equation 11). It implies that this type of investment is fairly profitable – yielding a return of 15.8%, close to, albeit below, the private investment one.

It is interesting to note that an even higher estimated elasticity for public capital is obtained if we jointly impose two restrictions on private and human capital production function parameters (Table 5, line 2). These restrictions are:
   – a *ceteris paribus* r.o.r. on private capital equal to 9 percent (a figure closer to the estimates for the US economy), which, considering the private capital to output ratio in 2001, amounts to imposing $\alpha = 0.35$;
   – a human capital semi-elasticity equal to 0.066. De la Fuente (2003) estimates the elasticity of output to average schooling years (call it ε) to be comprised between 0.394 and 0.587, for a sample of EU countries. We arrived to the 0.066 value by

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[23] Rates of return on public capital were computed using 2001 values for *Y/KG* and *δ* (recall equation (4) and section 4). A similar methodology was applied to the computation of the *ceteris paribus* r.o.r. on private capital.

taking the simple average between those two extremes and dividing it by the Portuguese level of average years of schooling in 2001 (since $\gamma = \dfrac{\varepsilon}{H}$).

The joint hypothesis that $\gamma = 0.066$ and $\alpha = 0.35$ is not rejected at a 86.11 percent level. The estimated elasticity of public capital is equal to 0.294, which gives a *ceteris paribus* public investment r.o.r. equal to 56.8 percent. These impressive values are still smaller than those estimated by Aschauer (1989a, 1989b) for the US economy and by Ligthart (2000) for Portugal. Even so, in further analysis we use the non-restricted cointegrated VAR (Table 5, line 1), which includes a lower estimate of the growth effects of public investment.

Impulse response functions and dynamic feedbacks rates of return

To estimate the dynamic feedbacks rates of return on public and human capital investment, one considers the IRFs generated by shocks to *kg* and *H*, respectively. Following standard practice in VAR analysis, economically interpretable (i.e., structural) shocks to those variables, orthogonal to each other and to other disturbances in the system, are recovered through appropriate identifying hypotheses.

It is assumed that public capital does not respond contemporaneously to any structural disturbances to the remaining variables in the VAR. Pereira (2000) made a similar assumption as regards public investment, on grounds of the lags involved in government decision-making – an argument shared by this paper. This is equivalent to an orthogonalisation of shocks using the well-known Cholesky decomposition, with *kg* ordered first.

As regards investment in human capital, the decision of whether to pursue further studies is viewed as potentially responsive to innovations in any of the remaining variables: for instance, shocks to output or to physical investment (private or public) may influence labor market conditions and thus the trade-offs between taking up a job or staying at school[25]. In turn, *y*, *kp* and *kg* are assumed to be only affected by innovations in *H* with a lag – a possible justification being that the economic benefits from a better-educated population are to be

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[24] Poterba (1997) finds that this rate is close to 8.5 percent and CBO (1998) mentions different studies where it varies between 7 and 11 percent.

[25] An output innovation may affect the overall unemployment rate, whereas shocks to investment may change the relative supply of low-skilled *versus* high-skilled jobs (e.g. more jobs in construction associated to public investment in infrastructures).

reaped when students leave school and start working, rather than when they are still studying. In the context of the above Cholesky decomposition, this amounts to ordering H last. However, since the literature offers no guide for the identification of human capital innovations, a sensitivity analysis will be carried out by considering other possible orderings of variables.

Figure 6 to 9 depict the IRFs generated by a 0.01 shock to kg (i.e., a one percent increase in public capital per worker)[26]. The response of output is positive both in the short and in the long run: forty years into the future, when IRFs have essentially converged, output per worker is about 0.33 percent above the baseline (see figure 9). The original exogenous increase in public capital also induces further changes in other inputs. Apart from the response of public capital itself (see Figure 7), our results show that public capital innovations crowd in private investment (see Figure 8). The IRF of kp indicates that the private capital stock is approximately 0.32 percent above the baseline in the long run. On the other hand, public investment seems to crowd in human capital investment in the short run, but crowd it out in the long run – Figure 6 tells us that in the long run human capital is almost 0.003 years of schooling below the baseline.

The IRF of kg implies a time series of gross public investment deviations from baseline. This time series can be computed by converting the percentage deviations of public capital into absolute, constant euros terms (recall that kg is a log), and then using equation (13) with a depreciation rate of 4 per cent (as in section 4). After also converting the response of y into absolute terms, it becomes possible to compute the value of r that solves equation (5)[27]. This dynamic feedbacks r.o.r. on public investment equals 37.3 percent.

Comparing this result to the 15,9% r.o.r. computed by Pereira and Andraz (2002, 2004) for public investment in transportation infrastructures, it seems at first sight that our estimated return is almost 2.5 times bigger. However, though both figures take dynamic feedbacks into account, they are not comparable for a number of reasons: the VAR specifications are

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[26] In the context of a VAR in error-correction form – see equation (15) – the depicted responses are actually accumulated IRFs. The same holds for the remaining IRFs of this section.

[27] As the empirical analysis is set in discrete time, r is derived from the discrete-time counterpart of equation (5), namely, $\sum_{t=0}^{\infty} \Delta^b Y_t /(1+r)^t = \sum_{t=0}^{\infty} \Delta^b IG_t /(1+r)^t$. A similar discrete-time approximation will be used when computing the dynamic feedbacks r.o.r. on human capital.

different; we consider all public investment, not just transportation infrastructures; most importantly, their r.o.r. is based on long-run impacts, while we consider the full path of dynamic responses (recall equation (5) and note 8). A better, albeit still imperfect, comparison can be made by looking at the "total marginal product" of public investment – the ratio between the long-run responses of the levels of output and public investment, both measured in constant euros. Pereira and Andraz (2002, 2004) report a value of 9.5, whereas we obtain 14.6 – still bigger, but by a much smaller margin.

Presenting a high r.o.r., it is hardly surprising to find that public investment pays for itself by generating additional fiscal revenues. For instance, assuming that in the Portuguese economy output is taxed at a rate of 35% (as in Pereira and Andraz, 2002), and government bonds pay interest at a rate of 6% (a figure close to the implicit rate on public debt in recent years), then public investment pays itself back in only 13 years, generating further revenues afterwards.

Figures 10 to 13 present the impulse responses of H, kg, kp and y to a 0.01 shock in H (an increase of one hundredth of a year in the average years of schooling). One observes that, over time, there is a positive response of output (Figure 13), though of a very small magnitude – an increase of less than 0.03% in the long run. Figure 12 provides the clue to such a reduced impact: human capital investment is found to crowd out private physical investment, private capital per worker becoming almost 0.06% lower in the long run. The overall impact on output is therefore the net effect of the growth in H and in kg (which is crowded in to some extent – see Figure 11), and of the reduction in kp. One also remarks that there is some gradual weakening of the effort in human capital investment, more than 7 percent of the initial impulse being lost in the long run (see Figure 10).

To compute a dynamic feedbacks r.o.r. on human capital, one converts the gains in output per worker into constant euros (as in the case of public capital), generates a series for investment in human capital (simply the first difference of the IRF of H, since depreciation is ignored – see section 3), and translates it into euros per worker using equation (7). For the time span of the IRFs, the outcome is a modest r.o.r. of 2.7%.

As mentioned above, Cholesky decompositions with different orderings of variables were also considered. More specifically, kg was kept first throughout and shocks to H were simulated under all the possible orderings for the remaining variables (y, kp, H). The response of kp

(crowding out) was qualitatively similar to that reported above[28] but generally stronger, leading to slight decreases in output (long run losses between 0.02 and 0.12 percent), and hence making it impossible to compute dynamic feedbacks r.o.r.

6. Conclusions

This paper has quantified the importance of both public capital and human capital for aggregate output in a unified, production function-based framework, rather than separately, as in previous studies. The Portuguese economy has been taken as a case study, due to the availability of annual time series for the several capital stocks involved. Resorting to the estimation of a cointegrated VAR model has made it possible to compute and compare two alternative concepts of rates of return, according to whether the dynamic feedbacks between the different production factors are considered or not.

Investment in public capital was found to yield a *ceteris paribus* return of 26,7%, well above the homologous figures for private capital (18,5%) and human capital (15,8%). Though seemingly uncommon, such a high figure simply stems from the estimated elasticity of output *w.r.t.* public capital – which, in turn, is actually lower than the corresponding estimates of other studies. Fears that public investment may crowd out private investment are not confirmed: instead, crowding in takes place, explaining the even higher return (37,3%) when dynamic feedbacks are accounted for. As for budgetary consequences, this study finds that public investment fully pays itself back in only thirteen years, while its positive influence on output and fiscal revenues is much more long-lasting.

A number of policy implications for the Portuguese economy ensues. First, the emphasis on infrastructural improvement laid since Portugal joined the European Union, and started to benefit from structural funds, seems well justified. Second, in the light of the political vulnerability of public investment in times of fiscal retrenchment, the empirical findings here reported lend support to fiscal frameworks that include a golden rule, and run against the counterargument that private capital is crowded out. Finally, and in a similar vein, fiscal consolidation efforts which fall disproportionally on public investment may severely hamper growth prospects, and are in all likelihood counterproductive even in narrow fiscal terms, due

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[28] All the IRFs concerned are available from the authors upon request.

to lost revenue. A caveat to be born in mind, however, is that in most of our sample period Portugal had a blatant infrastructural deficit, which is probably no longer the case, though insufficiencies persist. It cannot therefore be excluded, as Pereira and Andraz (2004) caution (p. 240), that in the future returns on public capital will become smaller.

Results for human capital were less clear-cut. Though the estimated *ceteris paribus* r.o.r. (15,8%) was fairly high, and close to private capital's, shocks to years of schooling were found to induce a negative dynamic response of private investment, leading to a disappointing 2,7% return with dynamic feedbacks. Worse still, a sensitivity analysis revealed that the dynamic response of output could actually be negative. As in the case of public capital, some prudence is called for when interpreting these results. A first point to make is that one should not conclude that investment in human capital is almost "unproductive", or even detrimental: the crowding out of private investment also means that the associated costs are not incurred[29], an aspect which the dynamic feedbacks r.o.r. fails to capture (recall the discussion in section 3)[30]. A second point, made by Barro (2001), among others, is that the quality of education may be at least as important as its quantity (i.e., the number of years at school). Attempting to capture the former, and not just the latter, seems an important avenue for future work.

It would also be interesting in future research to study other countries. As mentioned in the introduction, our motivations and methodology, unlike our data set, do not concern only Portugal.

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[29] And thus more resources are left available for other uses, such as consumption.
[30] Not to mention the non-economic benefits of education, which are left altogether out of the analysis.

References

Aaron, H. (1990) Discussion. In *Is There a Shortfall in Public Capital Investment? Proceedings of a Conference* (A Munnell, Ed.). Boston: Federal Reserve Bank.

Aschauer, D. (1989a) Is public expenditure productive? *Journal of Monetary Economics* 23: 177- 200.

Aschauer, D. (1989b) Does public capital crowd out private capital? *Journal of Monetary Economics* 24: 171- 188.

Aschauer, D. (1990) Why is Infrastructure Important? In *Is There a Shortfall in Public Capital Investment? Proceedings of a Conference* (A Munnell, Ed.). Boston: Federal Reserve Bank.

Banco de Portugal (1997) *Séries Longas para a Economia Portuguesa Pós II Guerra Mundial.* Lisbon: Banco de Portugal.

Barro, R. (2001) Human Capital and Growth. *American Economic Review* 91(2): 12-17.

Barro, R. and Lee, J. (2000) International Data on Educational Attainment: Updates and Implications. Working paper 7911, National Bureau of Economic Research, Cambridge, Massachusetts.

Batina, R. (1999) On the long run effect of public capital on aggregate output: Estimation and sensitivity analysis. *Empirical Economics* 24: 711-717.

Batina, R. (2001) The Effects of Public Capital on the Economy. *Public Finance and Management* 1(2): 113-134.

Blanchard, O. and F. Giavazzi (2004) Improving the SGP Through a Proper Accounting of Public Investment. CEPR Discussion Paper no. 4220, London.

Buti, M., S. Eijffinger and D. Franco (2003) Revisiting the Stability and Growth Pact: Grand Design or Internal Adjustment? CEPR Discussion Paper 3692, London.

Cohen, D. and M. Soto (2001) Growth and Human Capital: Good Data, Good Results. OECD Development Centre, Technical Papers no. 179. Organisation for Economic Cooperation and Development, Paris.

Congressional Budget Office (1998) The Economic Effects of Federal Spending on Infrastructure and Other Investments. CBO Paper, Congressional Budget Office, Washington.

Crowder, W. and D. Himarios (1997) Balanced growth and public capital: an empirical analysis. *Applied Economics* 29: 1045-1053.

De la Fuente, A (2003) *Human capital in a global and knowledge-based economy, Part II: assessment at the EU country level – final report*. Brussels: European Commission, Directorate-General for Employment and Social Affairs.

De la Fuente, A. and A. Ciccone (2002) *Human capital in a global and knowledge-based economy – final report*. Brussels: European Commission, Directorate-General for Employment and Social Affairs.

De la Fuente, A. and R. Doménech (2000) Human Capital in Growth Regressions: How Much Difference Does Data Quality Make? Working paper nº 262, OECD Economics Department, Organisation for Economic Cooperation and Development, Paris.

Doornik, J. and D. Hendry (2000) *Modelling Dynamic Systems Using PcGive.* London: Timberlake Consultants.

Doornik, J. and D. Hendry (2001) *GiveWin, An Interface to Empirical Modelling.* London: Timberlake Consultants.

Evaraert, G. (2003) Balanced growth and public capital: an empirical analysis with I(2) trends in capital stock data. *Economic Modelling* 20: 741-763.

Flores de Frutos, R., M. Gracia-Díez and T. Pérez-Amaral (1998). Public capital stock and economic growth: an analysis of the Spanish economy. *Applied Economics* 30, 985-994.

Gramlich, E. (1994). Infrastructure Investment: A Review Essay. *Journal of Economic Literature* 32: 1176-1196.

Hayashi, F. (2000). *Econometrics*. Princeton University Press, Princeton.

Johansen, S. (1988). Statistical analysis of cointegration vectors. *Journal of Economic Dynamics and Control* 12: 231-254.

Jones, C. (2002). Sources of U.S. Economic Growth in a World of Ideas. *American Economic Review* 92(1): 220-239.

Kamps, C. (2003). New Estimates of Government Net Capital Stocks for 22 OECD Countries 1960-2001. Working paper. Kiel Institute for World Economics, Kiel, Germany.

Krueger, A.B. and M. Lindahl (2001). Education and growth: why and for whom? *Journal of Economic Literature* 39: 1101-1136.

Lau, S. and P. Sin (1997). Public infrastructure and economic growth: time-series properties and evidence. *Economic Record* 73(221) June: 125-135.

Ligthart, J.E. (2000). Public Capital and Output Growth in Portugal: An Empirical Analysis. Working Paper 00/11, International Monetary Fund, Washington.

Lucas, R. E. (1988). "On the Mechanics of Economic Development". *Journal of Monetary Economics* 22: 3-42.

Mankiw, N. G., D. Romer and D. N. Weil (1992). A Contribution to the Empirics of Economic Growth. *Quarterly Journal of Economics* 2(2): 407-437.

OECD (2003). *Education at a Glance – OECD Indicators*. Paris: Oganisation for Economic Co-Operation and Development.

Pereira, A. M. (2000). Is All Public Capital Created Equal? *The Review of Economics and Statistics*. 82(3): 513-518.

Pereira, A. M. and J. M. Andraz (2002). Public Investment in Transportation Infrastructures and Economic Performance in Portugal. In *Portuguese Economic Development in the European Context: Determinants and Policies. Proceedings*. Lisbon: Banco de Portugal.

Pereira, A. M. and J. M. Andraz (2004). *O Impacto do Investimento Público na Economia Portuguesa*. Lisbon: Fundação Luso-Americana para o Desenvolvimento.

Pereira, A. M. and O. Roca (2001). Public Capital and Private-Sector Performance in Spain: A Sectoral Analysis. *Journal of Policy Modeling* 23: 1-14.

Pereira, A. M. and O. Roca (2003). Spillover Effects of Public Capital Formation: Evidence from the Spanish Regions. *Journal of Urban Economics* 53: 238-256.

Pereira, J. (2003). A Medição do Capital Humano em Portugal. Master Thesis, Instituto Superior de Economia e Gestão, Lisbon.

Pina, A. and M. St. Aubyn (2002). Public Capital, Human Capital and Economic Growth: Portugal, 1977-2001. Working paper. Departamento de Prospectiva e Planeamento, Ministério das Finanças, Lisbon.

Poterba (1997). The Rate of Return to Corporate Capital and factor Shares: New Estimates Using Revised National Income Accounts and Capital Stock Data, Working paper 6263, National Bureau of Economic Research, Cambridge, Massachusetts.

Reimers, H.-E. (1992). Comparisons of tests for multivariate cointegration. *Statistical Papers* 33: 393-397.

Shwert, G.W. (1989). Tests for unit roots: A Monte Carlo investigation. *Journal of Business and Economic Statistics* 7: 147-159.

Sianesi, B. and J. Van Reenen (2002). The Returns to Education: A Review of the Empirical Macro-Economic Literature. Working paper nº 02/05, The Institute for Fiscal Studies, London.

Tatom, J. (1991). Public Capital and Private Sector Performance. *Review of the Federal Reserve Bank of Louis* 78(3): 3-15.

Teixeira, A. (1996). Capacidade de Inovação e Capital Humano. Master Thesis, Faculdade de Economia da Universidade do Porto.

Teixeira, A. and N. Fortuna (2003). Human Capital, Innovation Capability and Economic Growth, working paper no. 131, Faculdade de Economia da Universidade do Porto.

Appendix - Time series used in this paper

Year	Employment	GDP	Human capital	Public capital	Private capital
1960	3743.599	18.194	2.237	8.086	34.842
1961	3726.690	19.142	2.284	8.494	36.699
1962	3716.545	20.406	2.337	8.850	39.052
1963	3705.273	21.605	2.401	9.283	41.213
1964	3695.127	23.175	2.471	9.745	42.807
1965	3683.855	24.928	2.552	10.185	44.683
1966	3661.310	25.889	2.641	10.593	47.056
1967	3638.765	27.980	2.732	11.034	50.178
1968	3616.220	30.547	2.827	11.394	53.191
1969	3593.675	31.576	2.928	11.793	56.345
1970	3789.816	33.973	3.051	12.286	59.981
1971	3778.544	36.209	3.121	12.706	63.780
1972	3754.872	39.122	3.210	13.148	68.714
1973	3723.309	43.513	3.312	13.614	75.070
1974	3694.000	44.000	3.436	14.129	81.928
1975	3724.000	42.100	3.539	14.522	89.219
1976	3789.000	44.998	3.653	15.003	93.686
1977	3784.000	47.482	3.775	15.616	97.181
1978	3772.000	48.819	3.936	16.272	102.028
1979	3854.000	51.572	4.091	17.093	106.021
1980	3940.000	53.939	4.261	18.107	110.807
1981	3918.000	54.812	4.450	19.349	114.422
1982	3928.000	55.982	4.539	21.010	118.812
1983	4128.000	55.885	4.678	22.273	123.450
1984	4075.000	54.835	4.789	23.273	127.634
1985	4057.000	56.374	4.911	24.064	130.263
1986	4059.700	58.708	5.046	24.748	132.601
1987	4148.200	62.455	5.177	25.480	135.197
1988	4252.400	67.132	5.309	26.376	139.665
1989	4346.700	71.456	5.457	27.553	145.422
1990	4438.500	74.279	5.610	28.716	151.172
1991	4562.700	77.523	5.765	29.891	157.449
1992	4468.400	78.368	5.911	31.167	163.814
1993	4389.000	76.767	6.116	32.809	170.547
1994	4381.600	77.507	6.321	34.570	174.772
1995	4358.400	80.827	6.519	36.100	178.749
1996	4388.400	83.690	6.704	37.713	182.804
1997	4477.300	87.007	6.868	39.713	186.901
1998	4597.599	90.992	7.028	41.915	192.794
1999	4683.735	94.450	7.169	43.879	200.609
2000	4784.265	97.933	7.313	46.138	208.738
2001	4848.412	99.540	7.433	48.033	217.197

Employment - Civilian domestic employment, 1000 persons. Source: AMECO, Annual macro-economic database of the European Commission's Directorate General for Economic and Financial Affairs (DG ECFIN), May 2004.

GDP – Gross domestic product at 1995 market prices, 10^9 euros. Source: AMECO, May 2004.

Human capital - Average years of schooling of the Portuguese population aged between 15 and 64. Source: Pereira (2003).

Private capital and **public capital** – Constructed by the authors. Values at 1995 prices, 10^9 euros. See main text for details.
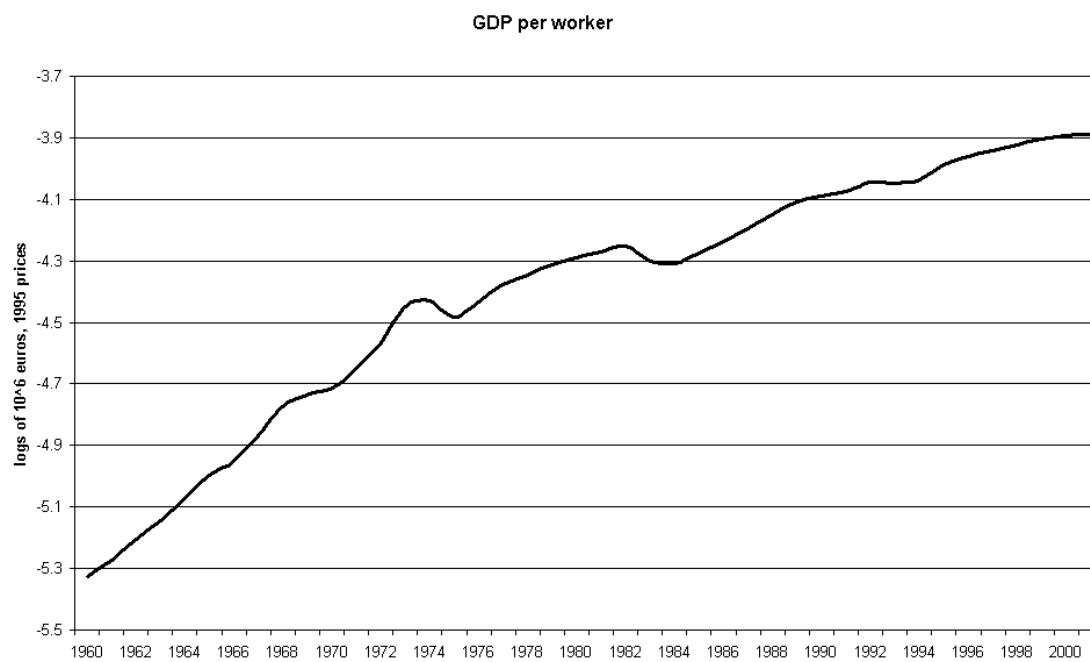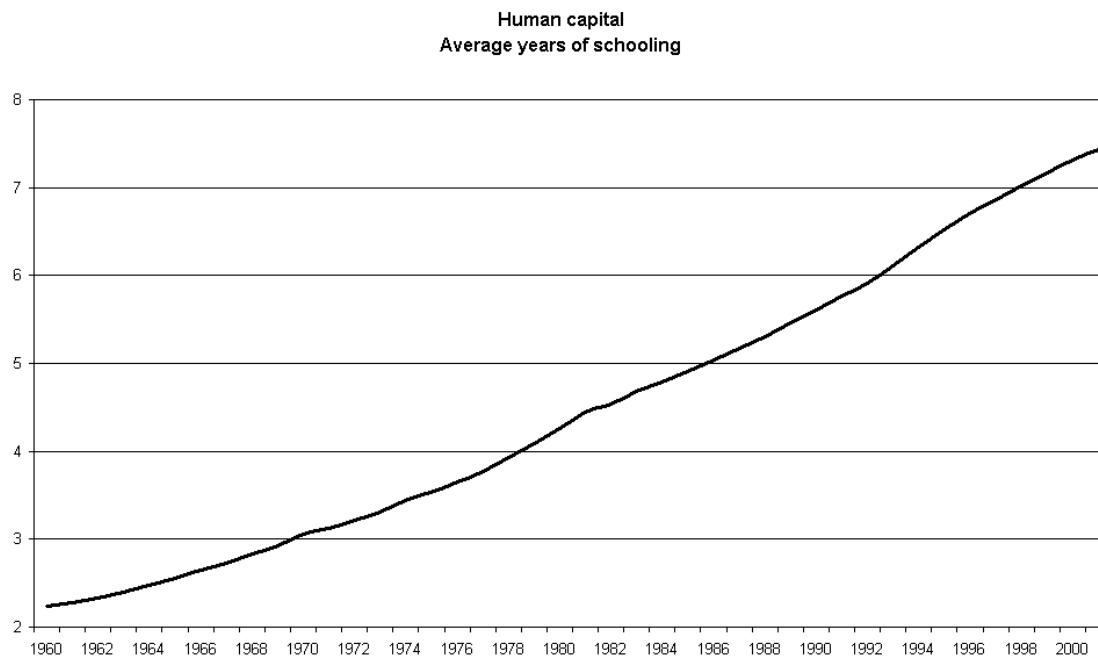
Figure 1

GDP per worker

Figure 2

**Human capital
Average years of schooling**

Figure 3

Public capital per worker

Figure 4

Private capital per worker

Figure 5

Private and public capital to output ratios

Figure 6

Response function of H
Impulse in kg

Figure 7

Response function of kg
Impulse in kg

Figure 8

Response function of kp
Impulse in kg

Figure 9

Response function of y
Impulse in kg

Figure 10

Response function of H
Impulse in H

Figure 11

Response function of kg
Impulse in H

Figure 12

Response function of kp
Impulse in H

Figure 13

Response function of y
Impulse in H