EDUCATION and GROWTH in a panel of 21 OECD countries

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Abstract

We analyze the econometric link between human capital (measured as the average years of schooling of the working-age population) and growth in 21 OECD countries. We follow the neo-classical growth theory and estimate a medium-term growth-accounting equation on panel data spanning the 1971-1998 period. An Error Correction framework allows for differences in short-term dynamics between countries. We focus on cointegration and collinearity issues in order to obtain a robust estimation. The estimated cointegration vector between the logarithm of production per capita, the logarithm of physical capital (replaced by a simple function of the rate of investment to avoid multicollinearity problems), the average years of schooling of the working-age population and a linear time trend (gains in productivity) is stationary on average for OECD countries. Returns to education are significant and positive and are estimated equal to 7%.

Themes: Education, Economic growth and aggregate productivity

JEL-Code: I20, I21, I23, I28, O40, O47

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Introduction

With an average growth rate of 2% over the past ten years, the main continental European countries are lagging behind the United States, whose growth rate has stayed around 3% for the past decade.

How can we explain such differences in growth between large OECD countries, over a relatively long period? The appearance and rapid diffusion of the ICT (information and communication technologies) in the United States can be evoked. The capacity to assimilate and exploit these new technologies is strongly linked to national efforts in education, and in particular to the importance given to tertiary education. Moreover, the current context of globalization encourages developed countries to create a "reservoir" of highly qualified labor, thereby taking advantage of their comparative advantage over developing countries. It is therefore not surprising that education is at the center of the debate surrounding aggregate productivity in OECD countries.

In this paper, we analyze the econometric link between human capital (measured as the average years of schooling of the working-age population) and growth in 21 OECD countries. We estimate a growth-accounting equation on panel data spanning the 1971-1998 period. We focus on cointegration and collinearity issues in order to obtain a robust estimation. The macroeconomic returns to education are significant and positive.

In the first section, we review the arguments of the theoretical debate surrounding macroeconomics of growth. This leads us to introduce a medium-term growth-accounting equation, based of the Mankiw, Romer and Weil (1992) neo-classical model. In the second section, we give the results of the econometric estimation. In the last section, we give an example of a regression for a single OECD country, France.

1. Effects of education on growth: a review of economic theory.

Education represents an important share of the resources invested in OECD countries (7% of the wealth produced in the OECD). It is therefore crucial to quantify the economic benefits derived from a better education, and the impact of education policy on growth.

Many theoretical papers, both microeconomic and macroeconomic, analyze the economic returns to education. The microeconomic approach of education focuses on the impact of the years of schooling on the future earnings of individuals. However, since an individual's years of education can also serve as a signal on the labor market, measuring the returns of an additional year of schooling can be biased upward. Conversely, the microeconomic returns to education do not include different types of human capital externalities, those that exist between individuals of the same generation or between different generations, or those operating through technical progress. A more macroeconomic approach allows us to take into account these externalities.

The macroeconomic literature on the returns to education is mainly based on the neo-classical Solow model. It however comprises two broad sets of studies. The first moves away from the neo-classical model and introduce endogenous growth models. The second tends to build upon the Solow model in order to take into account human capital as a third production factor.

1.1. From the neo-classical Solow model to endogenous growth theories.

Robert Solow (1956) introduced the neo-classical growth model in its simplest form. Production of a good requires two factors, capital and labor, and is based on a constant returns to scale production function. Returns to each production factor are decreasing. The economy tends towards a long-term equilibrium growth path where capital and production per efficient unit of labor are constant. The source of growth is exogenous technical progress. Thus, the choices of agents, in particular with respect to education, have no impact on the long-term growth rate of output. Increasing the factors of production has no long-term effect on growth.

Endogenous growth models contest this traditional vision. The main contribution of these models is that they display sustainable long-term growth that does not require exogenous technical progress. They are based on the existence of non-decreasing returns to scale for an accumulated factor, such as physical or human capital.

1.1.1. The Nelson Phelps approach (1966)

Nelson and Phelps (1966) postulate that education determines the capacity of nations to innovate, adopt and implement new technology, thereby quickening the diffusion of ideas in the economy. In their model, the Solow residual (technical progress) depends on the difference between the technological level of the country considered, A(t), and the level of the leading country, T(t).

$$\frac{\dot{A}}{A} = c(H)\left[\frac{T(t) - A(t)}{A(t)}\right]$$

The speed at which this gap is breached (at which nations 'catch-up' to the leading country) depends on the level of human capital H. The growth of aggregate factor productivity depends on the level of human capital.

More recent endogenous growth models directly define the growth rate of A as a function of human capital (see Romer (1990a) for example). Thus, production growth is a function of the level (stock) of human capital. In these types of models, a one-time increase in human capital can lead to a durable increase of growth, if human capital exceeds a certain limit.

Benhabib and Spiegel's empirical paper (1994) confirms these theoretical results. They show a significant effect of the level of human capital (measured as the average education attainment of the active population in the beginning of the 1965-1985 period), on the average growth rate of production per capita.

1.1.2. The limits of endogenous growth theories

Endogenous growth models are based on the fact that returns to an accumulated growth factor (physical or human capital) are not decreasing, whereas the neo-classical model states that decreasing returns to scale appear quite rapidly. Many empirical studies agree that returns to capital, both physical and human, are decreasing (see in particular Baumol, Maddison and Abramovitz, quoted in the Congressional Budget Office 1994).

It is possible to include human capital in a neo-classical framework, thereby increasing the share of earnings allocated to « enlarged » capital. This slows down the effect of decreasing returns to scales, allowing for persistence in national production levels. There is convergence towards an equilibrium growth path (in line with many empirical studies[2] (CBO 1994)), but it is slower than in the Solow model. This convergence is however only observed for developed countries.

1.2. Extension of the neo-classical model to include human capital

Endogenous growth theories stress the importance of human capital in growth dynamics. A second set of studies tries to rehabilitate the neo-classical Solow growth model, extending it to include human capital, which remains an accumulated production factor.

1.2.1. The Lucas-Uzawa approach (1988)

One of the main contributions to these studies is that of Lucas (1988), built upon by later studies by Uzawa (1965). In these papers, human capital plays the same role in production as physical capital. However, it generates externalities due to the positive interaction of individuals in a strong human capital environment. Private returns to human capital are constant, but social returns to human capital are increasing, thanks to these externalities.

The production function is based on that of the neo-classical model, extended to include private human capital h as well as the social externalities of human capital h_{ext}. u represents the time devoted to production.

$$Y = AK^{\alpha}(uhL)^{1-\alpha} h_{ext}^{\gamma}$$

[2]Mankiw, Romer et Weil (1992) show that the absence of convergence in previous empirical studies comes from the fact that the long-term growth paths differ from one country to another. The OECD countries have similar savings rates, population growth rates and technical progress. However, when the sample is increased to include developing countries, the long-term growth specification is no longer homogenous. Mankiw, Romer and Weil thus refer to "conditional convergence" (conditional on savings rates, population growth rates and technical progress), and remark that, in this particular case, estimations confirm the predictions of the neo-classical models.

The time *1-u* devoted to the accumulation of human capital is related to h via the equation :

$$\dot{h} = \delta h(1-u)$$

This equation is linear and stems from the hypothesis that returns to human capital h are constant. The growth rate of production becomes:

$$g = \delta(1-u)$$

The growth in production is therefore mainly a function of the accumulation of human capital. Thus, in the long run, growth can only last if human capital grows without limit.

However, the constant returns hypothesis for human capital is difficult to accept. It is generally refuted by econometric estimations. In the Lucas-Uzawa approach, interpreting the notion of human capital with respect to the traditional variables considered, such as education attainment, is difficult. The Lucas-Uzawa approach requires for example that the quality of education improve with time, or that successive generations inherit the human capital accumulated by their parents.

1.2.2. The neo-classical theories: Mankiw, Romer, Weil (1992)

Mankiw, Romer and Weil's (1992) seminal paper also postulates that human capital is an additional accumulated production factor. According to them, accumulating years of schooling amounts to reinforcing labor, thereby increasing productive efficiency, even when technology is constant. But the returns to the two types of capital are not assumed constant or increasing.

The authors include human capital in the aggregate neo-classical Cobb-Douglas production function. Total output, Y, now depends on three input factors: physical capital, K, labor, L and human capital H. Harrod-neutral technical progress, A, remains exogenous.

$$Y_t = K_t^{\alpha} H_t^{\beta} \left(A.L_t\right)^{1-\alpha-\beta} \quad \text{with} \quad \alpha+\beta < 1$$

Unlike Lucas, Mankiw, Romer and Weil consider that human capital depreciates at the same rate as physical capital, that its growth rate is determined by the same accumulation function[3], and that returns to scale for "enlarged" capital are decreasing. On the long-term equilibrium growth path, the level of total output per capital depends on the rate of investment in physical and human capital (or, equivalently, on the savings rate and the long-term equilibrium level of human capital), on the population growth rate and on exogenous technological progress. On the equilibrium growth path, the growth rate of production per capita depends on the accumulation of education over the period. In the absence of technological progress, to maintain positive growth in the long run, the educational attainment of the population must increase continuously.

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[3] In other words, , $\begin{matrix} \dot{k} = s_k y - (n+g+\delta)k \\ \dot{h} = s_h y - (n+g+\delta)h \end{matrix}$ with $k = K/AL$, $h = H/AL$ and $y = Y/AL$ the quantities of physical capital, human capital and production per efficient unit of labor, and s_k , s_h ,*n, g* and δ respectively the share of output invested in physical and human capital, the growth rate of the population, that of technological progress A and the depreciation rate of capital.

The empirical results of this influential paper are conclusive. Mankiw, Romer and Weil show a significant impact of the schooling rate of the 12-17 year olds on output per capita between 1960 and 1985.

2. Estimating a growth-accounting equation for 21 OECD countries.

The macroeconometric estimation of a growth-accounting equation is at the center of the debate surrounding the returns to education. Empirical evidence on this subject is not clear-cut. Many studies fail to show a positive correlation between total output per capita and educational attainment, puzzling economists. Benhabib and Spiegel (1994) volunteer the explanation that education is not an ordinary accumulated factor of production but a determinant of aggregate factor productivity. Pritchett (2001), claims that the weakness of institutions and the low quality and excess supply of education in developing countries are responsible for this absence of correlation between education and growth. However, this remark does not apply to OECD countries. More recently, Krueger and Lindhal (2001) maintain that the quality of the data on educational attainment is primordial.

Our estimation gives a positive correlation between the average years of schooling and the level of total output per capita. The choice of the theoretical model establishing the relationship between these two variables (growth rate/growth rate or growth rate/level) is crucial. We use a growth-accounting equation based on the neo-classical growth model. Our econometric estimation is performed on annual panel data for OECD countries, spanning 1971-1998 period..

Following Bassanini and Scarpetta (2001), we use an Error Correction Model to capture the differences in short-run dynamics between the countries of the panel, and thus use the "Pooled Mean Group" estimation technique. Finally, we calculate multicollinearity statistics and carry out cointegration tests, with all the caution required for time series spanning 27 points.

2.1. The theoretical model

We use the neo-classical model described by Mankiw, Romer and Weil (1992). Many empirical studies show that returns to physical and human capital are decreasing, as postulated by Mankiw, Romer and Weil. Furthermore, their model predicts convergence between developed countries towards a long-term equilibrium growth path, but convergence is slower than in the Solow model (since returns to the "enlarged" capital are higher). This specification seems well adapted to our econometric estimation.

Assuming Cobb-Douglas technology and constant returns to scale, per capita income depends on three input factors, paid at their marginal productivity:

$$Y(t) = K(t)^{\alpha} H(t)^{\beta} \left(A(t)L(t)\right)^{1-\alpha-\beta} \qquad \textit{with } \alpha + \beta < 1$$

with Y, K, H, L respectively total output, physical capital, human capital and labor, α and β the partial elasticities of production with respect to the two forms of capital, A Harrod-augmenting technical progress and t time.

Labor grows at the variable rate n(t) and exogenous technical progress A grows at the constant rate g.

Taking logarithms and dividing by labor, the equation becomes:

$$\ln y(t) = \alpha \ln k(t) + \beta \ln h(t) + (1-\alpha-\beta)\left(\ln A(0) + gt\right) + \varepsilon_t$$

with $y = \frac{Y}{L}$, $k = \frac{K}{L}$ and $h = \frac{H}{L}$.

What macroeconomic indicators should then be used to represent human and physical capital in this specification?

2.1.1. Measuring human capital

The theoretical models concur that human capital is related to national educational efforts. However, defining, and especially identifying the best macroeconomic indicator for human capital, remains subject to debate. A standard indicator is required to carry out rigorous international comparisons. In economic literature, human capital is generally proxied by the average years of education, by enrolment rates in school and university, or by the results obtained in international aptitude tests.

The average number of years of education of the working-age population is thus considered to be an acceptable measure of human capital. Following Bils and Klenow (2000), we use the Mincerian (1974) specification, based on estimations performed on microeconomic data for 56 countries, and which predicts that the logarithm of future earnings is a linear function of the number of years of education. At the macroeconomic level, we assume that the logarithm of human capital is a linear function of the number of years of education[4]. Using this specification, we can compare our results to those estimated in microeconomic studies. The private returns to education are generally between 6% and 10% (see box 1).

$\ln h(t)$, the logarithm of the human capital stock in the production function, follows $\ln h(t) = rS(t)$, with S the average years of education of the working-age population (15-64).

Box 1: the Mincerian (1974) model

The standard microeconomic human capital model introduced by Mincer in 1974 states that workers are paid at their marginal productivity, which increases with accumulated human capital. The net benefit of an additional year of education is estimated on data for private earnings.

$$\ln Y_i = a + bS_i + cE_i + dE_i^2 + u$$

with Y_i private earnings, S_i the number of years of education, E_i professional experience (the quadratic form capture the decrease in returns to post-education investment in human capital), and u a stochastic term of unobservable factors. Mincer also assumes that the costs of an additional year of education only consist in opportunity costs, in other words the earnings that the individual gives up by going to university. The direct costs of education paid by the individual are not considered.

[4] This hypothesis raises the delicate problem of the transition between microeconomics and macroeconomics, which we do not develop in this paper.

Mincer shows that the semi-logarithmic expression is well adapted to the relation between private earnings and education. Standard errors in empirical estimations are generally low and returns to education are estimated between 6% et 10%, depending on the period and the countries considered (Temple 2001).

However, the drawback of this method is that it does not take into account the positive effect of other factors (home environment for example) on the economic value of time spent in school. Overlooking this 'selection effect' can lead to an upward bias in the estimation of the returns to education. Results should be interpreted with caution.

2.1.2. Measuring physical capital

It is difficult to obtain, for the 21 countries considered, complete physical capital data. Furthermore, directly using the stock of physical capital in the production function can lead to multicollinearity problems. Marcelo Soto (2002) analyses these problems in greater detail. In many papers, the coefficient relating the logarithm of output per capita ln(y) to the average number of years of education S is significant only when physical capital is withdrawn from the estimations. When Krueger and Lindhal include physical capital for example, human capital is no longer significant and the α estimated is too high (0,8). This may reflect a strong collinearity between physical capital and human capital. The authors constrain the coefficient α to 0,35[5] in order to get satisfying results. Soto finds similar results with the Cohen Soto (2001) database.

We compute the multicollinearity statistics introduced by Belsley, Kuh and Welsch (1980) to assess the collinearity between the years of education S and physical capital per capita (both on OECD data). The variables S and $\ln k(t)$ are indeed subject to multicollinearity (maximum condition index of 37.5 (see appendix 1) .

We attempt to solve this problem by replacing physical capital by a simple function of the investment rate. Our equation is a medium-term relationship that does not represent the long-term steady state. However, we can proxy physical capital by its steady-state expression, which depends on the investment rate[6]. Let i be the rate of investment $i = Inv/Y$. In the long-term steady state, i is constant. Setting $k = \frac{K}{L}$ the stock of physical capital per unit of labor, $y = \frac{Y}{L}$ output per unit of labor and δ the depreciation rate of physical capital, we find $k^* = \left(\frac{iy}{n + g + \delta} \right)$. In the medium-term equation, we then proxy the stock of physical capital k(t) by the function $\frac{i(t)y(t)}{n(t) + g + \delta}$. Replacing, taking logarithms and dividing by labor gives:

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[5] α is, in theory, the share of the remuneration of physical capital in value added.

[6] In this respect, we move away from Caselli (2004), who adopts a perpetual-inventory calculation for physical capital. However, his method is more adapted to his panel of 93 countries, both developed and developing. Our sample consists only of OECD countries, that are much closer to the steady state

$$\ln y(t) = \frac{\alpha}{1-\alpha}\ln(\frac{i(t)}{n(t)+g+\delta}) + \frac{\beta}{1-\alpha} rS(t) + \frac{1-\alpha-\beta}{1-\alpha}\left(\ln A(0)+gt\right) + \frac{\varepsilon_t}{1-\alpha}$$

Over the period considered (1971-1998), for OECD countries, we can assume, following Mankiw, Romer and Weil (1992), that the constant $g+\delta$ is worth 0,10=0,02+0,08[7]. Production thus depends on the investment rate, on the growth rate of labor, and on human capital.

The collinearity statistics found for the variables $\ln y(t), S, t, \ln\left({i(t)}/{n(t)+g+\delta} \right)$ confirms that there is no multicollinearity between the explanatory variables in the regression (maximum conditional index of 16.1).

2.1.3. The final short-term equation

The relation above is a valid specification for the growth equation only if the countries are in their medium-term steady state, or if the deviations from these medium-term steady states are independent and identically distributed. In the short term, a given country can nevertheless deviate from the medium-term steady state, for example due to fluctuations in the productivity cycle. The data do not accept the hypothesis that these transitional dynamics are identical for all of the countries in the panel. Therefore, following Bassanini and Scarpetta (2001)[8], we explicitly model these dynamics for each individual country.

Using an Error Correction Form, we capture the different transitional dynamics of each country. The estimation of this equation includes the difference between the logarithm of production per capita and the explanatory variables in the medium-term specification, all in levels. The functional form of the equation is as follows:

$$\Delta \ln y_{i,t} = -\phi\left[\ln y_{i,t-1} - (\theta_i \ln\left(\frac{i}{n+g+\delta}\right)_{i,t-1} + \theta_h rS_{i,t-1} + \theta_{trend}(t-1) + \sum_{i=1}^{21} d_i 1_{(country_i)})\right]$$

$$+\left(\sum_{i=1}^{21} a_i 1_{(country_i)}\right)\Delta \ln y_{i,t-1} + \left(\sum_{i=1}^{21} b_i 1_{(country_i)}\right)\Delta \ln\left(\frac{i}{n+g+\delta}\right)_{i,t} + \left(\sum_{i=1}^{21} c_i 1_{(country_i)}\right)\Delta \ln h_{i,t}$$

with $\theta_i = \left({\alpha}/{1-\alpha}\right)$, $\theta_h = \left({\beta}/{1-\alpha}\right)$, $\theta_{trend} = \left({1-\alpha-\beta}/{1-\alpha}\right) g$ [9]

[7] The growth rate of technical progress is that fixed by Mankiw, Romer and Weil (1992) for OECD countries. The depreciation rate of physical capital, 8%, corresponds to that chosen by Sylvain (2001) in a paper on Japan, the United States, France, Germany, the Netherlands and the United Kingdom (life-span of 12 years).

[8] Bassanini and Scarpetta allow for differences in medium-term trends. In this paper, we assume that the coefficients for the variables in levels are common for the 21 countries.

[9] In order to keep the number of parameters low, we do not include the auto-regressive lags $\Delta \ln y_{i,t}$.

The working hypothesis is that the medium-term production function is identical for all 21 countries considered (except for the $\frac{1-\alpha-\beta}{1-\alpha}\ln A(0)$ term, which is proxied by a sum $\sum_{i=1}^{21} d_i 1_{(country_i)}$ of country-specific constant terms). This hypothesis is that generally used in empirical studies in this field. It is plausible in the sense that these 21 OECD countries have relatively homogenous economic structures (access to common technologies, intensive intra-trade and foreign direct investment). For our panel data analysis, we therefore use the « Pooled Mean Group » (PMG) estimator. It allows for variations from one country to the other in the medium-term constant and in the short-term coefficients a_i, b_i and c_i, but it imposes the homogeneity of the medium-term θ parameters.

Analyzing the results from a "cointegration" point of view gives an additional tool for interpretation. The working hypothesis concerning the homogeneity of the production function for the 21 OECD countries considered must be viewed with caution. The panel data analysis gives good indications on the average behavior of OECD countries, but a finer analysis for individual countries will require estimating the production function for each country considered separately.

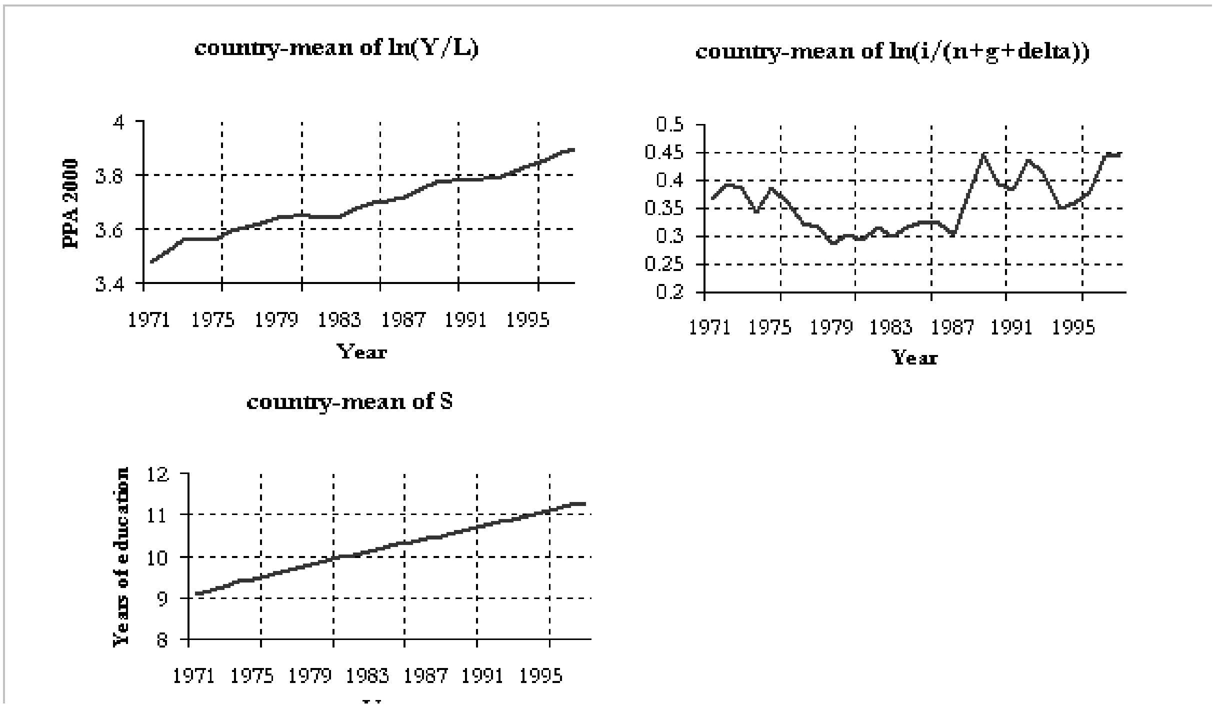
2.2. The data

We have a panel of 21 OECD countries, for which the data for all of the variables used are available for the 1971-1998 period. The data comes from online OECD databases (*OECD online education database 2004, OECD online economic outlook 2004*)

GDP is given as a ratio to labor and is expressed in PPP (2000)[10]. Over the period considered, GDP per capita for all the countries considered increased by 1.7% per year on average. The investment rate i is the ratio of real private non-residential fixed capital formation to real private GDP. Over the estimation period, the investment rate increased by 0.5 points per year on average. The growth rate n(t) is that of labor.

Choosing the right database for S, the average years of education of the working-age population, is difficult. Krueger and Lindhal (2001) suggest that the observed absence of correlation between education and growth in output per capita comes from measurement errors in the databases used. Bosca, de la Fuente and Domenech (1996) stress the extent of the differences between the methods used from one database to the other. They compare two frequently used databases, that of Barro and Lee (1993) and that of Nehru, Swanson and Dubey (1995) and show that the correlation between the average levels of education in both bases is worth 0.81, which is relatively low. In this paper, we follow Bassanini and Scarpetta (2001) and use the OECD database (*the sources of economic growth in OECD countries,* 2003), based on de la Fuente and Domenech (2000) as well as the subsequent editions of OECD *Education at a Glance,* that present the advantage of providing complete annual data for 21 OECD countries on a relatively long time-span (1971-1998). In this database, S increased by 0.85 per year on average between 1971 and 1998.

[10] Since the average years of education of the working-age population are (relatively) comparable between different OECD countries, we prefer to use PPP GDPs, which are also comparable between OECD countries. Furthermore, since the investment rate is a ratio, the production function is homogenous.



Source : OECD online education database 2004, OECD online economic outlook 2004, Bassanini, Scarpetta (2001)

2.3. The empirical results

2.3.1. Past empirical results

Many studies provide support for a significant positive impact of human capital on the growth rate of developed economies. Empirical results in Barro and Sala-i-Martin (1994) and Benhabib and Spiegel (1994) suggest a significant effect of the number of people with a degree in secondary or tertiary education in levels on the growth rate of output per capita. On the other hand, many papers choose the neo-classical Mankiw, Romer and Weil framework and show significant positive effects of the level of human capital on the level of output per capita.

The following table summarizes the empirical results of some papers using this approach.

Paper	Database	Human capital	Sample	α	$\theta_h r$
Mankiw, Romer, Weil (92)	UNESCO	Log(years of school)	OCDE 60-85	0.38	0.23
Topel (99)	Barro Lee (93)	years of school	OCDE 60-90	Constrained to 0.35	0.06
Kruger Lindhal (01)	Barro Lee (93)	years of school	OCDE 60-90	Constrained to 0.35	0.09
De la Fuente Domenech (02)	De la Fuente Domenech (02)	Log(years of school)	OCDE 60-95	0.49-0.52	0.12-0.27
Cohen Soto (01)	Cohen Soto (01)	years of school	OCDE 60-90 *(OLS)*	0.32	0.09
			(GMM)	0.29	0.10
Bassanini Scarpetta (01)	De la Fuente Domenech (00)	years of school	OCDE 71-98	0.20	0.33
Soto (02)	Cohen Soto (01) OCDE 60-90	years of school	*(OLS)*	0.18	0.18
			(GMM)	0.45	0.07
			(GMM2step)	0.36	0.10

OLS : ordinary least squares, GMM : generalized method of moments, GMM2Step : 2-step generalized method of moments.

2.3.2. Unit root tests and cointegration

The medium-term growth-accounting equation is a relation between variables in levels, which may not be stationary. In this case, if cointegration is not taken into account, regressions can be spurious. The statistics generally used (such as the R^2) no longer apply. We must therefore directly estimate a cointegration equation and test its stationarity. Empirical literature on human capital and growth generally overlook this issue.

However, with the limited number of observations available (27 observations between 1971 and 1998), we cannot draw final conclusions on the degree of integration of the variables considered. Cointegration statistics are asymptotic and are therefore robust from about 45 observations. In the appendix, we give the unit root tests and the ranks of the cointegration spaces found for our smaller sample, and only mention the results obtained in the text. They can help justify the precautions required when interpreting the results.

On the 1971-1998 period, the two unit root tests used (Augmented Dickey Fuller (ADF) and Phillips Perron (PP), for which the null hypothesis is the presence of a unit root, and the KPSS test, for which the null hypothesis is stationary), tend to indicate that the variables $\ln y(t),\ \ln\left(i(t) / n(t)+g+\delta \right)\ and\ S$ are I(1).

Thus, the production equation relating these variables in the medium-term must be a cointegrating vector (stationary). The estimation of the error correction form with tradition methods (in particular ordinary least squares) will then not be spurious.

We use the Johansen (1988) method to find the rank of the cointegration space formed by the three variables, country by country, and by the country-mean of these variables[11] for each year (we give details of the method in Appendix 4). For each country, the cointegration space between the three variables, including a trend and a constant, is of rank one. Thus, the growth-accounting equation relating the variables in levels can be a cointegrating vector, provided we check the stationarity of the residual when carrying out estimations.

2.3.3. Panel data analysis

An analysis of the country-means overlooks valuable information. We therefore carry out a panel data analysis with a PMG estimator (« pooled-mean-group », a common medium-term relation in levels), and then test the stationarity of the cointegrating vector for the country-mean of the variables and for each country taken separately.

The econometric estimation of the PMG specification gives, with ordinary least squares:

$$\Delta \ln y_{i,t} = -\underset{(4.98)}{0.05}\left[\ln y_{i,t-1} - (\underset{(3.67)}{0.36}\ln\left(\frac{i}{n+g+\delta}\right)_{i,t-1} + \underset{(3.30)}{0.07} S_{i,t-1} + \underset{(1.04)}{0.003}(t-1) + \sum_{i=1}^{21}\hat{d}_i 1_{(country_i)}) \right]$$
$$+\left(\sum_{i=1}^{21}\hat{a}_i 1_{(country_i)}\right)\Delta \ln y_{i,t-1} + \left(\sum_{i=1}^{21}\hat{b}_i 1_{(country_i)}\right)\Delta \ln\left(\frac{i}{n+g+\delta}\right)_{i,t} + \left(\sum_{i=1}^{21}\hat{c}_i 1_{(country_i)}\right)\Delta S_{i,t}$$

We do not give the values of the coefficients for the short-term dynamics and for the medium-term constants. The Student statistics are in parentheses.

Robustness of results

We can test the robustness of the results by successively eliminating one country from the sample used. Results are quite satisfactory. The estimated coefficients are stable. We summarize the results obtained in Appendix 2.

Interpretation

The coefficient of the medium-term relation, ϕ, is significant at the 1% level. Its value of 0.05 is lower than that obtained by Bassanini and Scarpetta (2001) (around 0.15).

The coefficients of the medium-term relation are significant at the 1% level.

---

[11] We take the country-mean of the variables $\ln y(t), \ln\left(i(t) \big/ n(t)+g+\delta \right)$ *and* S. Since the growth-accounting equation relating them is linear, if this equation is valid for each country, it is also valid for the country-mean.

- A θ_i estimated at 0.36 gives an estimation of $\frac{0.36}{1+0.36}=0.26$ for α[12]. θ_i is not significantly different from its theoretical value, 0.5, which corresponds to α=1/3 (standard error of 0.10). The result is satisfactory.

- $\theta_h * r = 7\%$ are the macroeconomic returns to the average years of education of the working-age population. This value is consistent with estimations for the microeconomic returns to education (between 6% and 10%: see Cohen Soto 2001) as well as those commonly found for the macroeconomic returns to education.

- $\theta_{trend} = 0.003$. If the growth rate of technical progress, g, is taken constant for the estimation period, and if we assume that g=0.02 (MRW 1992), with the relation $\left(1-\alpha-\beta / 1-\alpha\right) g = \theta_{trend}$, we find $\beta = 0.63$. The returns to "enlarged" capital are therefore $\alpha + \beta = 0.26 + 0.63 = 0.89$. Under these hypotheses, returns to scale are decreasing, but are high for the enlarged capital. This corroborates the relatively slow speed of convergence observed in developed countries (see above).

Cointegration tests

The PMG estimation technique gives us a medium-term equation in levels relating $\ln y(t),\ \ln\left(i(t) / n(t)+g+\delta\right)$ *and* S. We must however check that it is a cointegration relation, in other words that the resulting vector is stationary, for the country-mean as well as for each individual country.

We carry out unit root tests (Augmented Dickey-Fuller and Phillips Perron) for the vector $\left[\ln y(t) - (0.36\ln\left(\frac{i(t)}{n(t)+g+\delta}\right) + 0.07S(t) + 0.003t + d_i)\right]$. Results are the following:

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[12] It is generally considered that α corresponds to the share of the remuneration of physical capital in value added. However, estimations do not necessarily give the corresponding value for α, 1/3. This difference can have several explanations:

- Returns to the stock of capital do not in fact correspond to the « gross » stock of capital but to the sum of the different types of physical capital, weighted by the returns to each type.

- α can differ from 1/3 since 1/3 only corresponds to the private returns to physical capital and does not take into account possible externalities.

Country	ADF test	Phillips Perron test	Result
Country-mean	-2,59	-2,74*	Stationary at the 10-11% level
Australia	-2,98**	-3,07**	Stationary
Austria	-2,85*	-3,59**	Stationary
Belgium	-5,26**	-4,92***	Stationary
Canada	-1,81	-1,50	I(1)
Denmark	-2,05	-2,13	I(1)
Finland	-0,83	-1,42	I(1)
France	-2,99**	-3,04**	Stationary
Germany	-3,08**	-3,60**	Stationary
Greece	-1,68	-2,64*	I(1)
Ireland	-0,35	-0,19	I(1)
Italy	-3,03**	-3,20**	Stationary
Japan	-2,67*	-3,62**	Stationary
Netherlands	-1,46	-1,70	I(1)
New-Zealand	-1,47	-0,79	I(1)
Norway	-1,26	-1,30	I(1)
Portugal	-2,09	-2,36	I(1)
Spain	-2,36	-2,80*	I(1)
Sweden	-3,83***	-2,90*	Stationary
Switzerland	-1,68	-1,78	I(1)
United-Kingdom	-3,72***	-2,75*	Stationary
United States	-1,89	-1,84	I(1)

*The 1%, 5% and 10% critical values are respectively -3.71, -2.98, -2.63 for the ADF test and -3.69, -2.97 et -2.62 for the Phillips-Perron test. ***, **, *respectively denote the rejection of the unit root hypothesis at the 1%, 5% and 10% levels.*

We carry out unit root tests for first differences to check that the variables are only I(1).

With our limited number of observations, we cannot draw final conclusions on the stationarity of the vector considered. Results nevertheless indicate that the growth-accounting equation estimated is relatively correct for OECD countries on average. However, it does not give perfectly reliable coefficients for a given country, since the hypothesis according to which all countries have the same medium-term production function can be questioned. We give the example of the estimation for France in the last section.

2.3.4. Endogeneity of human capital

This type of regression can lead to an endogeneity problem for the physical and human capital variables. We choose to address the issue of the returns to human capital. A country with a high level of productivity will spend more on education and the average number of years of education will increase. An upward bias can therefore appear in the estimated macroeconomic returns to education.

To solve this problem, we look for instruments for human capital. Following Cohen Soto (2001), we suppose that the level of human capital at the beginning of the sample period is exogenous with respect to output per capita. Conversely, the growth in human capital depends on the increase in production per capita. Thus, the average years of education of the working-age population can be instrumented by the sum of the initial value for S in 1971 and by an exogenous linear trend. However, this hypothesis is very strong and results must be interpreted with caution.

The regression for the panel of 21 OECD countries gives the following results:

$$\Delta \ln y_{i,t} = \underset{(5.14)}{-0.05}\left[\ln y_{i,t-1} - (\underset{(3.75)}{0.36}\ln\left(\frac{i}{n+g+\delta}\right)_{i,t-1} + \underset{(3.64)}{0.07}\, s_0 + \underset{(3.50)}{0.01}(t-1) + \sum_{i=1}^{21} \hat{d}_i 1_{(country_i)}) \right]$$
$$+ \left(\sum_{i=1}^{21} \hat{a}_i 1_{(country_i)} \right) \Delta \ln y_{i,t-1} + \left(\sum_{i=1}^{21} \hat{b}_i 1_{(pcountry_i)} \right) \Delta \ln\left(\frac{i}{n+g+\delta}\right)_{i,t} + \left(\sum_{i=1}^{21} \hat{c}_i 1_{(country_i)} \right) \Delta S_{i,t}$$

The coefficient for the medium-term relation, ϕ, is still small but significant at the 1% level. The coefficients of the medium-term production equation are very stable (except, of course, for the coefficient for the time trend, which now captures the variations in human capital). The unit root tests are also quite stable. The endogeneity of human capital, under these strong hypotheses, does not seem to affect the value of the estimated coefficients.

3. Example for a single country: France

3.1. Estimating the equation

We insist above upon the importance of carrying out estimations for a single country in order to obtain reliable coefficients for that country. In particular, we estimate a growth-accounting equation on French data.

The Belsley, Kuh and Welsch statistics computed for French data reflect the presence of multicollinearity between the variables S and t and the constant. In order to eliminate a source of this collinearity, the coefficient for the time trend is constrained.

In order to come close to the characteristic value for France, the coefficient is constrained equal to that found in the estimation for a reduced number of countries, relatively close to France, for which no multicollinearity appears. We carry out the regression for the following ten countries: France, Belgium, Netherlands, Germany, Austria, Italy, Spain, Norway, Sweden and Finland. The constraint suppresses multicollinearity for the estimation on French data (see Appendix 1).

Results are the following:

$$\Delta \ln y_t = \underset{(3.57)}{-0.38}\left[\ln y_{t-1} - (\underset{(4.80)}{0.42}\ln\left(\frac{i}{n+g+\delta}\right)_{t-1} + \underset{(7.52)}{0.106}\, S_{t-1} + \underset{c}{0.005}(t-1) + \underset{(18.28)}{2.50}) \right]$$
$$+ \underset{(2.53)}{0.13}\,\Delta \ln\left(\frac{i}{n+g+\delta}\right)_t \underset{(-1..86)}{-0.06}\,\Delta S_t \underset{(-2.77)}{-0.11}\,\Delta \ln S_{t-1}$$

The lagged terms of $\Delta \ln y_t$ *are not significant.*

R^2=0.63 DW=1.76, Root MSE =0.009.

The unit root tests carried out on the vector $\left[\ln y_{t-1} - (\underset{(4.80)}{0.42}\ln(i)_{t-1} + \underset{(7.52)}{0.106}\,S_{t-1} + \underset{c}{0.005}\,t + \underset{(18.28)}{2.50})\right]$ tend to show that the medium-term equation is stationary. The residual of the complete short-term equation is also stationary.

Variable	ADF test	Phillips Perron test	Result
Residual of the medium-term equation	-3.14**	-3.23**	Stationary
Residual of the error correction form	-3.97***	-4.31***	Stationary

*The 1%, 5% and 10% critical values are respectively -3.71, -2.98, -2.63 for the ADF test and -3.69, -2.97 et -2.62 for the Phillips-Perron test. ***, **, *respectively denote the rejection of the unit root hypothesis at the 1%, 5% and 10% levels.*

The results are relatively robust to the constraint chosen for the coefficient of the time trend. Spanning the values close to 0.005 slightly changes the value of the coefficient for the average number of years of education S, but qualitative conclusions do not vary (see below).

3.2. Interpretation

- The elasticity of total output per capita to physical capital is not statistically different from that for the country-mean in the previous section.

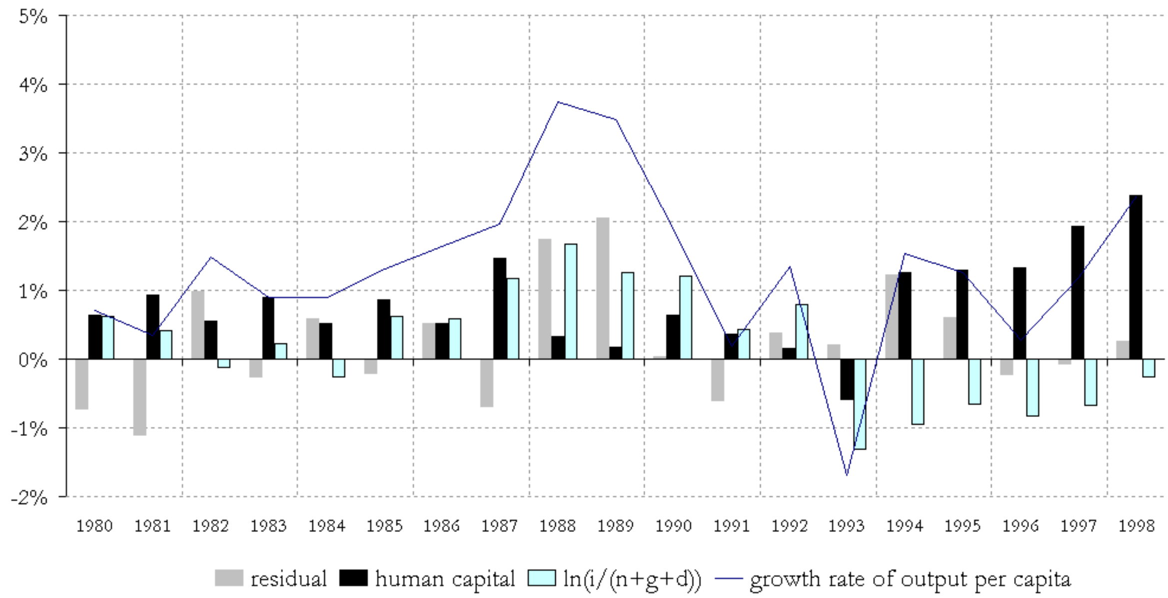
- However, the elasticity of total output per capita to human capital is statistically different in France (0.11 with a standard error of 0.02) and for OECD countries on average (0.07 with a standard error of 0.02). An additional year of education for the working-age population would increase production per capita by 11% in France, against 7% for OECD countries on average. Thus, France seems to have stronger macroeconomic returns to education than the average of OECD countries.

Once again, due to possible endogeneity problems, these results must be interpreted with caution. Macroeconomic returns to education in France may be upwardly biased.

3.3. Dynamic contributions

The analysis of the dynamic contributions of the different factors to the growth of output per capita in France between 1980 and 1998 based on the estimated equation gives the following results:

Contribution to the growth of output per capita



The growth of human capital seems to have mostly contributed to the growth in output per capita near the end of the period, due to the stronger increase in the average number of years of education of the working-age population at that time.

The contribution of the $\ln(i/n+g+\delta)$ term is negative during this period, in particular due to the increase in the growth rate of labor.

Conclusion

Endogenous growth models as well as "enlarged" neo-classical models insist upon the importance of accumulating human capital for growth in developed countries. We estimate a medium-term growth accounting equation, based on a Cobb-Douglas production function with three production factors (labor, physical and human capital), using a Mincerian specification. Following Bassanini and Scarpetta (2001), we carry out a panel data analysis for 21 OECD countries using an Error Correction Framework to capture the differences in short-run dynamics between the countries of the panel.

Our estimation for the sample period 1971-1998 is satisfactory. Replacing the stock of physical capital by a simple function of the rate of investment solves the problem of multicollinearity in our sample. We observe a significant positive effect of the average number of years of education of the working-age population on total output per capita. The macroeconomic returns to an additional year of school are estimated equal to 7%. Cointegration tests confirm the stationarity of the medium-term vector for the country-mean of the sample. However, reliable coefficient estimates for a particular country require carrying out estimations for that country alone. We give the example of the estimation for France. We find macroeconomic returns of 11% for France, which is higher than for OECD countries on average.

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Appendix 1: multicollinearity diagnostics

A1.1. For 21 OECD countries

We compute Belsley, Kuh and Welsch (1980) statistics for our panel data for 21 OECD countries. We attempt to identify the presence of multicollinearity between the variables explaining $\ln y(t)$. Results give:

Collinearity between the variables $\ln y(t), \ln k(t), S, t$

Collinearity Diagnostics

			Proportion of Variation			
Number	Eigenvalue	Condition Index	Intercept	S	temps	log_cap_ tete
1	3.92365	1.00000	0.00025730	0.00084991	0.00246	0.00081417
2	0.05447	8.48689	0.00283	0.01004	0.32774	0.10955
3	0.01909	14.33618	0.00224	0.40659	0.59417	0.07683
4	0.00279	37.52718	0.99466	0.58252	0.07563	0.81281

When the maximum condition index is greater that 30, there is multicollinearity between the variables. Thus, the variables S , $\ln k(t)$ and the constant seem to be collinear.

Collinearity between the variables $\ln y(t), \ln \frac{s_k(t)}{n(t)+g+\delta}, S, t$

Collinearity Diagnostics

			Proportion of Variation			
Number	Eigenvalue	Condition Index	Intercept	S	temps	log_sk_nd10
1	3.47457	1.00000	0.00188	0.00181	0.00345	0.02767
2	0.48233	2.68397	0.00266	0.00326	0.00457	0.95132
3	0.02975	10.80627	0.15134	0.10460	0.98579	0.00462
4	0.01334	16.13731	0.84412	0.89034	0.00618	0.01639

When the variable $\ln k(t)$ is replaced by $\ln \frac{s_k(t)}{n(t)+g+\delta}$, the collinearity problem is solved.

A1.2. For France

Collinearity between the variables $\ln y(t), \ln \frac{s_k(t)}{n(t)+g+\delta}, S, t$

Collinearity Diagnostics

Number	Eigenvalue	Condition Index	Proportion of Variation: Intercept	S	temps	log_sk_nd10
1	3.94550	1.00000	0.00000352	0.00000230	0.00004141	0.00102
2	0.03265	10.99233	0.00013957	7.156177E-7	0.01347	0.12418
3	0.02183	13.44479	0.00072281	0.00026363	0.00165	0.37096
4	0.00002110	432.45704	0.99913	0.99973	0.98485	0.50384

We observe collinearity between the variable S and the time trend. In order to eliminate a source of this collinearity, the coefficient for the time trend is constrained. In order to come close to the characteristic value for France, the coefficient is constrained equal to that found in the estimation for a reduced number of countries, relatively close to France, for which no multicollinearity appears. We carry out the regression for the following ten countries: France, Belgium, Netherlands, Germany, Austria, Italy, Spain, Norway, Sweden and Finland.

Collinearity between the variables $\ln y(t) - 0.005t$, $\ln \frac{s_k(t)}{n(t)+g+\delta}$ *et* S

Collinearity Diagnostics

Number	Eigenvalue	Condition Index	Proportion of Variation: Intercept	s_1b	log_sk_nd10
1	2.84050	1.00000	0.00412	0.02261	0.00390
2	0.14209	4.47109	0.04311	0.96840	0.03212
3	0.01740	12.77505	0.95277	0.00899	0.96398

The maximum condition index is less than 30. The constraint can therefore eliminate multicollinearity for the French data.

Appendix 2: Robustness tests for the panel data analysis.

In order to test the robustness of our regression for a sample of 21 OECD countries, we carry out 21 other regressions, removing one country after the other from the sample. The results are particularly stable.

The following table summarizes the results obtained for each regression.

Size of the sample	θ_{sk}	$\theta_h r$	θ_{trend}	ϕ
Complet sample	0.36 (3.67)	0.07 (3.30)	0.003 (1.04)	0.05 (4.98)
Without Australia	0.37 (3.59)	0.07 (3.28)	0.003 (0.80)	0.05 (4.86)
Without Austria	0.36 (3.51)	0.07 (3.15)	0.004 (1.11)	0.05 (4.77)
Without Belgium	0.37 (3.39)	0.07 (3.17)	0.003 (0.94)	0.05 (4.68)
Without Canada	0.38 (4.92)	0.07 (3.30)	0.003 (1.02)	0.05 (4.92)
Without Denmark	0.36 (3.57)	0.07 (3.25)	0.003 (0.92)	0.05 (4.85)
Without Finland	0.40 (3.73)	0.07 (3.24)	0.002 (0.65)	0.05 (4.80)
Without France	0.39 (3.48)	0.07 (3.23)	0.003 (0.80)	0.05 (4.68)
Without Greece	0.40 (2.28)	0.07 (2.91)	0.004 (1.02)	0.04 (4.43)
Without Germany	0.33 (3.39)	0.07 (3.37)	0.004 (1.25)	0.05 (4.94)
Without Ireland	0.33 (4.93)	0.07 (4.93)	0.003 (1.31)	0.07 (5.56)
Without Italy	0.30 (3.34)	0.08 (4.07)	0.003 (1.13)	0.05 (4.98)
Without Japan	0.38 (3.50)	0.07 (3.14)	0.004 (1.05)	0.05 (4.63)
Without Portugal	0.36 (3.54)	0.07 (3.29)	0.003 (0.76)	0.05 (4.78)
Without the Netherlands	0.35 (3.56)	0.07 (3.35)	0.004 (1.19)	0.05 (4.89)
Without New-Zealand	0.34 (3.67)	0.07 (3.31)	0.005 (1.43)	0.05 (5.02)
Without Norway	0.37 (3.69)	0.07 (3.34)	0.003 (0.86)	0.05 (4.92)
Without Spain	0.38 (3.58)	0.06 (2.12)	0.005 (1.31)	0.05 (4.74)
Without Sweden	0.37 (3.59)	0.07 (3.23)	0.003 (0.89)	0.05 (4.85)
Without Switzerland	0.35 (3.67)	0.07 (3.49)	0.004 (1.35)	0.05 (5.02)
Without the UK	0.37 (3.60)	0.07 (3.18)	0.003 (0.89)	0.05 (4.86)
Without the USA	0.37 (3.72)	0.04 (1.15)	0.005 (1.37)	0.05 (4.96)

Appendix 3: Unit root tests

Over the 1971-1998 period, unit roots give the order of integration of the country-mean of the variables Ln(y), Ln(i/n+g+δ) and S. We use Augmented Dickey Fuller tests (ADF) and Phillips Perron tests (PP) for which the null hypothesis is the presence of a unit root, and the KPSS test for which the null hypothesis is stationarity.

We give the results of the test for the country-mean with a specification with a constant and a linear trend. The tests for each particular country give quite similar results.

Test	Ln(y)	Ln(i/n+g+δ)	S	Critical values for the rejection of H0	
Level: ADF	0.07	-1.94	-1.10	1%	-3.71
				5%	-2.99
				10%	-2.63
Level : PP	-0.83	-2.64*	-1.29	1%	-3.70
				5%	-2.98
				10%	-2.63
Level : KPSS	0.82+++	0.46++	0.81+++	1%	0.74
				5%	0.46
				10%	0.35
First difference: ADF	-5.69***	-6.16***	-3.53**	1%	-3.72
				5%	-2.99
				10%	-2.63
First difference: PP	-3.99***	-7.99***	-7.47***	1%	-3.71
				5%	-2.98
				10%	-2.63
First difference: KPSS	0.15	0.12	0.21	1%	0.74
				5%	0.46
				10%	0.35

*, **, *** respectively denote the rejection of the unit root hypothesis at the 1%, 5% and 10% levels.
+,++,+++ respectively denote the rejection of the stationarity hypothesis at the 1%, 5% and 10% levels.
Thus, for example, according to the PP test, for the variable ln(i/(n+g+δ)), we cannot reject the unit root hypothesis at the 1% and 5% level..

According to the three tests, the variables considered are at most I(1). Thus, we can attempt to identify a cointegration relation between the variables.

Appendix 4: Computing the rank of the cointegration space using the Johansen method

Let *y* be a matrix of I(1) vectors. Johansen takes the following error correction form VAR model: $\Delta y_t = \alpha \beta'' \ y_{t-1} + \sum \Gamma_i \Delta y_{t-i} + u_t$, with α the parameters of adjustment to the long-term relation and β the coefficients of the long-term relation between the columns of the matrix *y*. If β has $r \leq (n-1)$ cointegrating vectors, all of the terms of the above expression are stationary. The rank *r* of the cointegration space is obtained using trace tests on the eigenvalues of matrix $\alpha \beta''$.

We analyze cointegration between the variables ln(y). ln(i/(n+g+δ)) and s. The number of lags in the VAR is chosen so as to minimize the Akaike and Schwarz criteria. Many specifications can be chosen. We postulate that the long-term relations present a constant and a linear time trend, consistently with the theoretical form of the production function.

We carry out the test for each country of the panel, as well as for the country-mean of the variables. The results are quite similar. For France for example, we obtain the following results.

Date: 10/07/04 Time: 08:33
Sample: 1971 1998
Included observations: 25
Series: FRANCE_LOG_GDP_C FRANCE_LOG_SK_ND FRANCE_S
Lags interval: 1 to 2

Data Trend: Rank or No. of CEs	None No Intercept No Trend	None Intercept No Trend	Linear Intercept No Trend	Linear Intercept Trend	Quadratic Intercept Trend
	Log Likelihood by Model and Rank				
0	161.6098	161.6098	167.8176	167.8176	168.4850
1	168.7111	169.9942	175.4880	178.5427	178.5792
2	174.8666	177.0037	180.9468	185.1827	185.2180
3	174.8851	181.0455	181.0455	189.7072	189.7072
	Akaike Information Criteria by Model and Rank				
0	-11.48878	-11.48878	-11.74541	-11.74541	-11.55880
1	-11.57689	-11.59954	-11.87904	-12.04342	-11.88634
2	-11.58933	-11.60029	-11.83574	-12.01462	-11.93744
3	-11.11081	-11.36364	-11.36364	-11.81657	-11.81657
	Schwarz Criteria by Model and Rank				
0	-10.61119	-10.61119	-10.72155	-10.72155	-10.38868
1	-10.40676	-10.38066	-10.56266	-10.67828	-10.42369
2	-10.12668	-10.04013	-10.22683	-10.30819	-10.18226
3	-9.355627	-9.462191	-9.462191	-9.768863	-9.768863
L.R. Test:	Rank = 1	Rank = 2	Rank = 0	Rank = 1	Rank = 3

The rank of the cointegration space between the three variables and a trend and a constant is worth 1. Results are similar for the other countries and for the country-mean.