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*Suggested Citation:* de la Fuente, Angel (2000) : Convergence across countries and regions: Theory and empirics, EIB Papers, ISSN 0257-7755, European Investment Bank (EIB), Luxembourg, Vol. 5, Iss. 2, pp. 25-45

This Version is available at:

<https://hdl.handle.net/10419/44793>

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# Convergence across countries and regions: Theory and empirics



Angel de la Fuente

## 1. Introduction

In the last decade or so, growth has come to occupy an increasingly important place among the interests of macroeconomists, displacing to some extent their previous preoccupation with the business cycle. This change is largely due to two factors. The first one is the realisation that, in terms of medium and long-term welfare, the trend is more important than the cycle - provided the volatility of income remains as low as it has been during the last few decades (Lucas, 1987). The second factor is the increasing dissatisfaction with the traditional neo-classical models that summarised the pre-existing consensus on the determinants of growth - essentially because of their perceived inability to account for such key features of the data as the observed increase in international inequality or the absence of capital flows toward less developed countries.

Dissatisfaction with the received theory has motivated the search for alternatives to the traditional neo-classical model that has driven the recent literature on endogenous growth. At the theoretical level, numerous authors have developed models in which departures from traditional assumptions about the properties of the production technology or the determinants of technical progress generate predictions about the evolution of the international income distribution that stand in sharp contrast with those of neo-classical theory. Some of these models emphasise the role of growth factors that were ignored by previous theories and generate policy implications that are considerably more activist than those derived from the traditional models. At the empirical level, there is also a rich literature that attempts to test the validity of the different theoretical models that have been proposed, and to quantify the impact of various factors of interest on growth and on the evolution of international or interregional income disparities.

This essay provides an introduction to the theoretical and empirical literature on growth and convergence across countries and regions. It is organised as follows. Section 2 contains some general considerations on the convergence and divergence mechanisms identified in the growth literature. In Section 3 develops a simple descriptive model that attempts to capture the main immediate determinants of the growth of output and illustrates how some key properties of technology determine the evolution of the international or interregional income distribution. Section 4 focuses on the empirical implementation of growth models through convergence equations and illustrates their theoretical implications. Finally, Section 5 discusses some loose ends as well as recent empirical developments, and concludes with a brief summary.

## 2. Convergence and divergence in growth theory

As the reader will soon discover, the concept of convergence plays a crucial role in the literature we will survey. Although we will eventually provide a more precise definition of this term, we can provisionally interpret it as shorthand for the tendency towards the reduction over

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time of income disparities across countries or regions. Hence, we will say that there is convergence in a given sample when the poorer economies in it tend to grow faster than their richer neighbours, thereby reducing the income differential between them. When we observe the opposite pattern (i.e. when the rich grow faster and increase their lead) we will say that there is divergence in the sample.

*Economic theory does not provide unambiguous predictions about the convergence of income levels across regions, but it does identify factors that may generate this.*

Economic theory does not provide unambiguous predictions about the convergence or divergence of per capita income levels across countries or regions. It does, however, identify a series of factors or mechanisms that are capable in principle of generating either convergence or divergence. At some risk of oversimplifying, we can classify growth models into two families according to their convergence predictions.

According to those in the first group, being poor is, to some extent, an advantage. In these models, other things equal, poor countries grow faster than rich ones. This does not necessarily imply the eventual elimination of inequality (other things may not be equal), but it does mean that the distribution of relative income per capita across territories will tend to stabilise in the long run, provided some key “structural” characteristics of the different economies remain unchanged over time. In the second set of models, in contrast, rich countries grow faster and inequality increases without any bound.

The source of these contrasting predictions must be sought in very basic assumptions about the properties of the production technology at a given point in time and about the dynamics of technological progress. A first necessary condition for convergence is the existence of decreasing returns to scale in capital (or, more generally, in the various types of capital considered in the model). This assumption means that output grows less than proportionally with the stock of capital. This implies that marginal productivity will decrease with capital accumulation, reducing both the incentive to save and the contribution to growth of a given volume of investment, and creating a tendency for growth to slow down over time. The same mechanism generates a convergence prediction in the cross-section: poor countries (in which capital is scarcer) will grow faster than rich ones. Under the opposite assumption (of increasing returns in capital), the preceding neo-classical logic is inverted and we obtain a divergence prediction. In this case, the return on investment increases with the stock of capital per worker, favouring rich countries that tend to grow faster than poor ones, thereby increasing inequality further.

The second factor to consider has to do with the determinants of technological progress. If countries differ in the intensity of their efforts to generate or adopt new technologies, their long-term growth rates will be different. One possible objection is that the persistence of such differences is not plausible. For instance, it may be argued that the return on technological capital should decrease with its accumulation, just as we would expect to find for other types of capital. In this case, large differences across countries in rates of technological investment would not be sustainable, and there would be a tendency towards the gradual equalisation of technical efficiency levels. It is far from clear, however, that the accumulation of knowledge should be subject to the law of diminishing returns. If the cost of additional innovations falls with scientific or production experience, for instance, the return on technological investment may not be a decreasing function of the stock of

accumulated knowledge, and cross-country differences in levels of technological effort could persist indefinitely.

**Technical progress could be an important divergence factor, but there are also forces that point in the opposite direction.**

Hence, technical progress could be an important divergence factor. But there are also forces that point in the opposite direction. As Abramovitz (1979, 1986) and other authors have pointed out, the public good properties of technical knowledge have an international dimension that tends to favour less advanced countries, provided they have the capability to absorb foreign technologies and adapt them to their own needs. The idea is simple: not having to reinvent each wheel, followers will be in a better position to grow quickly than the technological leader, who will have to assume the costs and lags associated with the development of new leading-edge technologies (1). The resulting process of technological catch up could contribute significantly to convergence, particularly within the group of industrialised countries that are in a position to exploit the advantages derived from technological imitation.

In addition to decreasing returns and technological diffusion, the literature identifies a third convergence mechanism that, although featured less prominently in theoretical models, is likely to be of great practical importance. This mechanism works through structural change, or the reallocation of productive factors across sectors. Poorer countries and regions tend to have relatively large agricultural sectors. Given that output per worker is typically much lower in agriculture than in manufacturing or in the service sector, the flow of resources out of agriculture and into these other activities tends to increase average productivity. Since this process, moreover, has generally been more intense in poor economies than in rich ones in the last few decades, it may have contributed significantly to the observed reduction in productivity differentials across territories.

In conclusion, economic theory identifies forces with contrasting implications for income dynamics. Convergence mechanisms feature prominently in the neo-classical and catch-up models that dominated the literature until recently. The perceived failure of the optimistic convergence predictions of these models, however, has motivated the search for alternatives and contributed to the development of new theories that incorporate various divergence factors. Some of the pioneers of the "endogenous growth" literature (especially Romer 1986, 1987a, b) focused on the possibility of non-decreasing returns to scale in capital alone, while other authors, such as Lucas (1988), Romer (1990) and Grossman and Helpman (1991), developed models in which the rate of technical progress was determined endogenously and could differ permanently across countries, reflecting differences in structural characteristics. In both cases, the theory allows for the possibility of a sustained increase in the level of international or interregional inequality. The Box, which draws on de la Fuente (1995), provides a formal framework that illustrates these two classes of growth theories.

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1) The idea seems to be due originally to Gershenkron (1952) and has been developed among others by Abramovitz (1979, 1986), Baumol (1986), Dowrick and Nguyen (1989), Nelson and Wright (1992) and Wolff (1991).

### Box 1: A formal model

#### Immediate determinants of the rate of growth

Let us consider a world in which there are only two factors of production and one final good. Capital ( $K$ ) and labour ( $L$ ) are combined to produce a homogeneous output ( $Y$ ) that can be consumed directly or used as capital in the production process. We will assume that the production technology can be adequately described by an aggregate production function of the form

$$(1) \quad Y = \Phi K^a (AL)^{1-a} = \Phi ALZ^a$$

where  $A$  is an index of labour-augmenting technical efficiency and  $K$  denotes a broad capital aggregate that includes both human and physical capital. The variable  $Z = K/AL$  denotes the capital/labour ratio in efficiency units and the coefficients  $a$  and  $1-a$  measure the elasticity of output with respect to factor stocks.

To allow the possibility of increasing returns in the simplest possible way, we will assume that the term  $\Phi$ , although perceived as an exogenous constant by individual agents, is in fact a function of the form  $\Phi = Z^b$  that captures the external effects associated with investment. This specification is basically the one proposed by Romer (1986) building on Arrow (1962) to capture the possibility that capital accumulation may generate positive spillovers. Under these assumptions, output per worker,  $Q$ , is given by

$$(2) \quad Q = AZ^\alpha$$

where  $\alpha = a + b$  measures the degree of returns to scale in capital taking into account this factor's indirect contribution to productivity through possible externalities.

Given equation (2), the growth of output per worker must be the result of the accumulation of productive factors or the outcome of technical progress. Taking logarithms of (2) and differentiating with respect to time, we see that the rate of growth of output per capita  $Q/Q = g_Q$ , where  $Q = dQ/dt$ , can be written as the sum of two terms that reflect, respectively, the rate of technical progress and the accumulation of productive factors:

$$(3) \quad g_Q = g_a + \alpha g_Z.$$

Let us explore the immediate determinants of  $g_a$  and  $g_Z$ , starting with the second factor. Denoting by  $s$  the share of investment in GDP and by  $\delta$  the rate of depreciation, the increase in the aggregate capital stock is given by the difference between investment and depreciation, i.e.

$$(4) \quad \dot{K} = sY - \delta K = sLQ - \delta K$$

where  $\dot{K} = dK/dt$  is the instantaneous increase in the capital stock. Since  $Z = K/AL$ , the growth rate of the stock of capital per efficiency unit of labour,  $g_Z$ , is the difference between  $g_k = \dot{K}/K$  and the sum of the rates of technical progress ( $g_a$ ) and labour force growth ( $n$ ). Using (2) and (4), it is easy to see that

$$(5) \quad g_Z = g_k - g_a - n = sZ^{\alpha-1} - (n + g_a + \delta),$$

where the term  $Z^{\alpha-1}$  ( $=Q/(K/L)$ ) is the average product of capital. Substituting this expression into (3), we have:

$$(6) \quad g_Q = (1 - \alpha)g_a + \alpha s Z^{\alpha-1} - \alpha(n + \delta).$$

Finally, we have to specify the determinants of the rate of technical progress,  $g_a$ . We will assume that  $g_a$  is an increasing function of the fraction of GDP invested in R&D,  $\theta$ , and of the opportunities for technological catch-up, measured by the log difference ( $b = \ln X - \ln A$ ) between a "technological frontier" denoted by  $X$  and the country's own technological index,  $A$ , or:

$$(7) \quad g_a = \gamma\theta + \varepsilon b.$$

The parameters  $\varepsilon$  and  $\gamma$  measure, respectively, the speed of diffusion of new technologies across countries and the productivity of R&D. We will also assume that best-practice technology improves at a rate  $g_x$  which we will take as exogenous from the perspective of each given country and assume constant for simplicity.

Substituting (7) into (6) we finally arrive at an expression,

$$(8) \quad g_Q = (1 - \alpha)(\gamma\theta + \varepsilon b) + \alpha s Z^{\alpha-1} - \alpha(n + \delta),$$

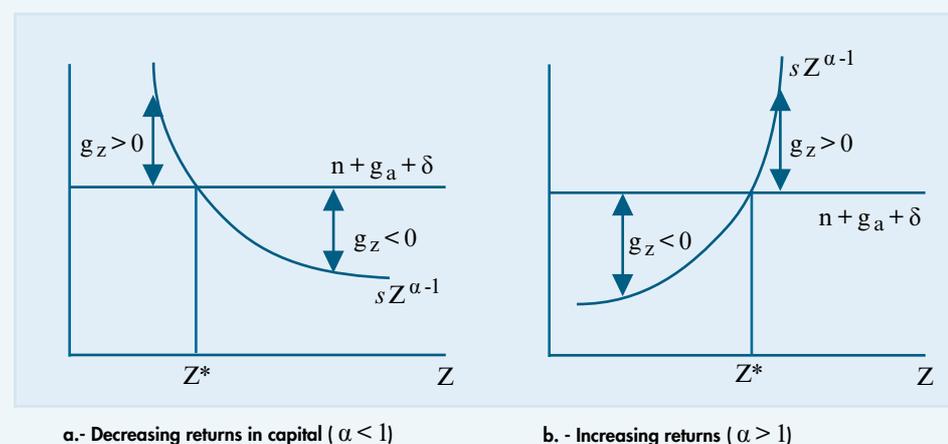
that gives the rate of growth of output per worker,  $g_Q$ , as a weighted sum of two terms that capture the immediate determinants of the rates of technical progress and capital accumulation.

### Dynamics

To study the dynamics of the system, given by equation (5), it will be convenient to organise the analysis according to the impact on growth of two separate processes - capital accumulation and technical progress - for two countries (the "leader" and the "follower").

Assuming that the rate of technical progress,  $g_a$ , is an exogenous constant, we can draw both terms on the right-hand side of (5) as functions of  $Z$ . As shown in Figure 1, the rate of factor accumulation,  $g_z$ , is the difference between the product of the investment rate and the average product of capital,  $sZ^{\alpha-1}$ , and the constant  $(n + g_a + \delta)$ , and corresponds, therefore, to the vertical distance between the two lines, as shown in the figure.

**Figure 1.** Dynamics of capital accumulation



The two panels of Figure 1 show that the behaviour of the dynamical system depends crucially on the value of  $\alpha$ . When  $\alpha < 1$ , that is, when the neo-classical assumption of decreasing returns holds, the return on investment decreases with the stock of capital. Hence, the term  $Z^{\alpha-1}$ , is a decreasing function of  $Z$  and cuts the horizontal line given by the constant  $(n + g_a + \delta)$  at the point  $Z^*$  characterised by  $g_Z = 0$ . This implies:

$$(9) \quad Z^* = \left[ \frac{s}{n + g_a + \delta} \right]^{\frac{1}{1-\alpha}}$$

From a dynamic point of view, the key finding is that under the assumption of decreasing returns the curve  $sZ^{\alpha-1}$  cuts the horizontal line from above, making the growth rate of  $Z$  a decreasing function of its level. This implies that the steady state or long-term equilibrium described by  $Z^*$  is stable. Notice that  $g_Z$  is positive (that is,  $Z$  increases over time) when the stock of capital per worker is small (and therefore the return on investment is high), and negative ( $Z$  decreases over time) when  $Z$  is "large" (larger than  $Z^*$ ), for in this case the volume of investment is not enough to cover depreciation and equip newborn workers with the average stock of capital. Hence, we can interpret the steady-state value of the stock of capital per unit of labour,  $Z^*$ , as the one corresponding to a long-term equilibrium to which the economy gradually converges for any given initial value of  $Z$ .

When the external effects associated with the accumulation of capital are sufficiently strong that  $\alpha > 1$ , the situation is very different, as shown in panel b of Figure 1. Since the return on investment, measured by  $Z^{\alpha-1}$ , is now an increasing function of the stock of capital per efficiency unit of labour, the rate of accumulation increases with  $Z$  instead of falling. Hence,  $Z$  grows when it is larger than  $Z^*$  and falls when it is smaller, moving farther and farther away from the steady state, which must now be interpreted as a threshold for growth rather than as a long-run equilibrium.

To analyse the impact of technical progress on growth and convergence it will be convenient to work explicitly with two countries,  $f$  and  $l$ , (follower and leader). Let us define the technological distance between leader and follower by:

$$b_{lf} = a_l - a_f = (a_l - x) - (a_f - x) = b_l - b_f$$

where  $b_l$  and  $b_f$  denote the technological distance between each of these countries and the best-practice frontier. Observe that the evolution of the technological gap between leader and follower,  $b_{lf}$ , satisfies the following equation:

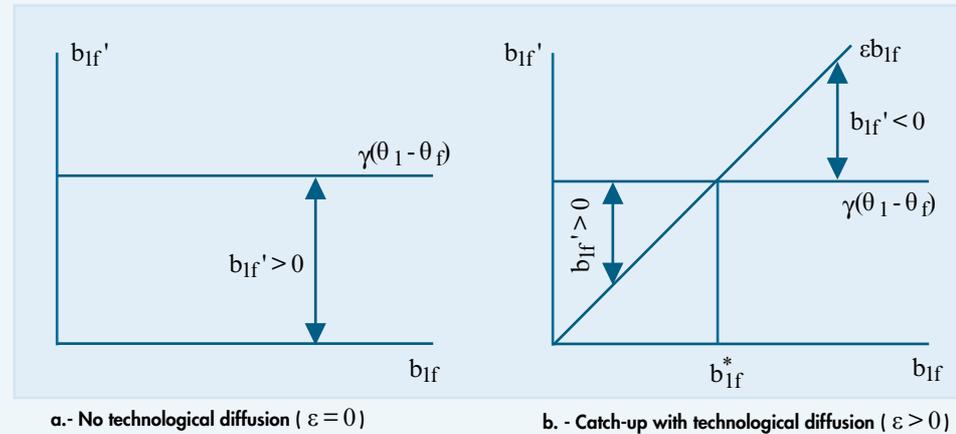
$$(10) \quad \dot{b}_{lf} = \dot{a}_l - \dot{a}_f = \gamma(\theta_l - \theta_f) - \varepsilon(b_l - b_f) = \gamma(\theta_l - \theta_f) - \varepsilon b_{lf}$$

Figure 2 displays the dynamics of this equation under two assumptions on the value of  $\varepsilon$ . When there is no technological diffusion ( $\varepsilon = 0$ ), the leading country (which by assumption invests more in R&D) always has a higher rate of productivity growth. As a result,  $b_{lf}$  is always positive and the technological distance between leader and follower,  $b_{lf}$ , grows without bound as shown in Figure 2a.

When  $\varepsilon > 0$ , on the other hand, the line  $\varepsilon b_{lf}$  is positively-sloped and cuts the horizontal line  $\gamma(\theta_l - \theta_f)$  at a finite value of  $b_{lf}$  we will denote by  $b_{lf}^*$ . Under this assumption, the model is stable:  $b_{lf}$  is positive (that is, the technological gap increases over time) when  $b_{lf}$  is below its stationary value,  $b_{lf}^*$ , and negative ( $b_{lf}$  decreases) otherwise (see Figure 2b). Hence, the technological gap converges to a finite value,  $b_{lf}^*$ , defined by  $\dot{b}_{lf} = 0$ , which reads:

$$(11) \quad b_{lf}^* = \frac{\gamma(\theta_l - \theta_f)}{\varepsilon} .$$

**Figure 2.** Evolution of the technological distance between leader and follower



In the long run, the (logarithm of the) ratio of the technical efficiency indices of the two countries converges to a constant value that is directly proportional to the difference between their rates of investment in R&D, and inversely proportional to the speed of technological diffusion.

Combining the results of the partial analyses undertaken so far, we can distinguish between two cases. When the technology exhibits increasing returns in capital ( $\alpha > 1$ ) or there is no technological diffusion ( $\varepsilon = 0$ ), the model is unstable and the growth paths of the two countries diverge. If there are decreasing returns and technological diffusion ( $\alpha < 1$  and  $\varepsilon > 0$ ), however, the model is stable. In the long run, the rates of growth of the two countries converge to the world rate of technical progress,  $g_x$ , and the ratio of their per capita incomes approaches a strictly positive constant value. Thus, long-run income disparities can be attributed to differences in levels of investment in physical and technological capital and in rates of population growth. Notice, however, that the extent to which such differences in “fundamentals” translate into long-term productivity differentials depends on the strength of the two convergence mechanisms present in the model. For given values of  $\theta$ ,  $s$  and  $n$ , the income differential across countries will be a decreasing function of the rate of technological diffusion ( $\varepsilon$ ) and the degree of returns to scale in capital ( $\alpha$ ). Hence, both convergence mechanisms tend to mitigate the level of international inequality induced by cross-country differences in fundamentals, but do not eliminate it.

### 3. From theory to empirics: A framework for empirical analysis

When it comes to trying to distinguish empirically between these two families of models, set out above, a starting point is the observation that the main testable difference between them is the sign of the partial correlation between the growth rate and the initial level of income per capita. While this correlation should be negative according to standard neo-classical models (that is, other things equal poorer countries should grow faster), in some models of endogenous growth the expected sign would be the opposite one. This suggests that a natural way to try to determine which group of models provides a better explanation of the growth experience involves estimating a *convergence equation*, that is, a regression model in which the dependent variable is the growth rate of income per capita or output per worker and the explanatory variable is the initial value of the same income indicator.

The correct formulation of the empirical model, however, requires that we control for other variables that may affect the growth rate of the economies in the sample. As we have seen in a previous section, neo-classical and catch-up models predict that poor countries will grow faster than rich ones only under certain conditions. In Solow's (1956) neo-classical model, for instance, the long-term level of income is a function of the rates of investment and population growth and can, therefore, differ across countries. In a similar vein, Abramovitz (1979, 1986) emphasises that the process of technological catch-up is far from automatic. Although relative backwardness carries with it the potential for rapid growth, the degree to which this potential is realised in a given country depends on its "social capability" to adopt advanced foreign technologies (i.e. on factors such as the level of schooling of its population and the availability of qualified scientific and technical personnel) and on the existence of a political and macroeconomic environment conducive to investment and structural change.

*Even in models where convergence forces prevail, long-term income levels can vary across territories, reflecting underlying differences in "fundamentals".*

In short, even in models where convergence forces prevail, long-term income levels can vary across territories, reflecting underlying differences in "fundamentals". If we do not control for such differences, the estimated relationship between growth and initial income could be very misleading. Imagine, for instance, that the Solow model (with decreasing returns and access by all economies to a common technology) is the correct one, and that richer countries display on average higher rates of investment and lower rates of population growth than poorer countries (which is why they are richer in the first place). According to the model, these two factors would have a positive effect on the growth rate (during the transition to the long-run equilibrium) that could conceivably dominate the convergence effect that makes growth a decreasing function of income with other things constant. It is clear that if we do not include the rates of investment and population growth in the equation, we could find that the estimated coefficient of initial income is positive and conclude, erroneously, from this fact that the predictions of the Solow model fail to hold. To put it in a slightly different way, the problem would be that when we do not control for the determinants of the steady state, we are actually testing the hypothesis that all economies converge to the same long-run equilibrium. The rejection of this hypothesis, however, has no implications for the validity of the Solow model, since this model makes no such prediction except when the economies in the sample are exactly alike.

On the basis of the preceding discussion, we can conclude that a "minimal" model for the empirical analysis of convergence would be an equation of the form

$$(1) \Delta y_{i,t} = x_{it} - y_{i,t} + \varepsilon_{it},$$

where  $y_{i,t}$  is income per capita or per worker in territory  $i$  at the beginning of period  $t$ ,  $\Delta y_{i,t}$  the growth rate of the same variable over the period,  $\varepsilon_{it}$  a random disturbance, and  $x_{it}$  a variable or set of variables that captures the "fundamentals" of economy  $i$ , that is, all those characteristics of this territory that have a permanent effect on its growth rate.

### 3.1 Structural convergence equations

Many empirical studies of growth and convergence have proceeded by estimating some variant of equation (1). In early studies the empirical specification was frequently *ad hoc* and only loosely tied

with the theory (2). In recent years, however, researchers have increasingly focused on the estimation of “structural” convergence equations derived explicitly from formal models. One of the most popular specifications in the literature is the one derived by Mankiw, Romer and Weil (1992; henceforth MRW) from an extended neo-classical model à la Solow that would be equivalent to the one developed in the Box under the assumption that the rate of technical progress is an exogenous constant common to all countries (3). Working with a log-linear approximation to the model around its steady state, MRW show that the growth rate of output per worker in territory  $i$  during the period that starts at time  $t$  is given approximately by the following equation (4):

$$(2) \quad \Delta y_{i,t} = g + (a_{i0} + gt) + \frac{\alpha}{1-\alpha} \ln \frac{s_{it}}{\delta + g + n_{it}} - y_{i,t}$$

where

$$(3) \quad = (1 - \alpha) (\delta + g + n),$$

and where  $g$  is the rate of technical progress,  $\delta$  the depreciation rate,  $\alpha$  the coefficient of capital in the aggregate production function,  $t$  the time elapsed since the beginning of the sample period,  $a_{i0}$  the logarithm of the index of technical efficiency at time zero,  $s$  the share of investment in GDP and  $n$  is the rate of growth of the labour force.

It is important to understand that the estimation of equation (2) does not imply that we are literally accepting the assumptions of the underlying Solow-type model (i.e. we do not need to assume that the investment rate is exogenous or constant over time). What we are doing is simply assigning to some of the parameters of the Solow model (in particular, to  $s$  and  $n$ ) the observed average values of their empirical counterparts during a given period. During this period, the economy will behave approximately as if it were approaching the steady state of the Solow model that corresponds to the contemporaneous parameter values. In the next period, of course, we are likely to observe different values of the investment and population growth rates and therefore, a different steady state, but this poses no real difficulty. In essence, all we are doing is constructing a convenient approximation to the production function that allows us to recover its parameters using data on investment flows rather than factor stocks. This is very convenient because such data are easier to come by and can be expected to be both more reliable and more comparable over time and across countries than most existing estimates of factor stocks. It must be kept in mind, however, that the only information we can extract from the estimation of a convergence equation of the form (2)

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2) See for instance Kormendi and McGuire (1985), Grier and Tullock (1989) and Barro (1991).

3) That is, the specification of the rate of technical progress as a function of R&D expenditure and the technological gap is abandoned, being replaced by the simple assumption that the rate of technological progress is an exogenous constant,  $g$ , equal for all countries. The part of the model that describes capital accumulation, on the other hand, would be exactly as developed in Section 2.

4) Barro and Sala-i-Martin (1990, 1992a) derive a similar expression from a variant of the optimal growth model of Cass (1965) and Koopmans (1965) with exogenous technical progress. The resulting equation is similar to (2) except that the investment rate (which is now endogenous) is replaced by the rate of time discount among the determinants of the steady state. The convergence coefficient,  $\beta$ , is now a more complicated function of the parameters of the model, but it still depends on the degree of decreasing returns to capital and on the rates of population growth, depreciation and technical progress. A second difference between the two models is that, whereas the MRW model can be easily extended to incorporate investment in human capital, Barro and Sala do not include this factor as an argument of the production function, although they do bring it into their empirical specification, in an ad hoc way, as a determinant of the steady state.

concerns the properties of the production technology. As Cohen (1992) emphasises, the estimated equation does not, in particular, tell us anything about the actual dynamics of the economy or the position of a hypothetical long-run equilibrium - although it does allow us to make predictions about long-term income levels conditional on assumptions about the future behaviour of investment and population growth rates.

The empirical implementation of equation (1) or (2) does not, in principle, raise special problems. Given time series data on income, population and investment for a sample of countries or regions, we can use (2) to recover estimates of the rate of convergence and the parameters of the production function. The convergence equation can be estimated using either cross-section or pooled data. Most of the earlier convergence studies took the first route, averaging the variables over the entire sample period and working with a single observation for each country or region. The second possibility, which has become increasingly popular, involves averaging over shorter sub-periods in order to obtain several observations per country.

In either case, one difficulty which immediately becomes apparent is that three of the variables on the right-hand side of the equation ( $g$ ,  $\delta$  and  $a_{i0}$ ) are not directly observable. In the first two cases, the problem is probably not very important. Although these coefficients can be estimated inside the equation (and this has been done occasionally), the usual procedure in the literature is to impose "reasonable" values of these parameters prior to estimation. The standard assumption is that  $g = 0.02$  and  $\delta = 0.03$ , but researchers report that estimation results are not very sensitive to changes in these values.

***The possibility that initial levels of technical efficiency may differ across countries raises a difficult problem that requires panel data techniques.***

The possibility that initial levels of technical efficiency ( $a_{i0}$ ) may differ across countries does raise a more difficult problem. Although some authors have argued that it may be reasonable to assume a common value of  $a_{i0}$  because most technical knowledge is in principle accessible from everywhere, casual observation suggests that levels of technological development differ widely across countries. If this is so, failure to control for such differences (or for any other omitted variables) will bias the estimates of the remaining parameters whenever the other regressors in the equation are correlated with the missing ones. In other words, we can only legitimately subsume technological differences across countries in the error term if they are uncorrelated with investment rates and population growth. This seems unlikely, however, as the level of total factor productivity is one of the key determinants of the rate of return on investment.

The standard solution for this problem is to turn to panel data techniques in order to control for unobserved national or regional fixed effects. The simplest procedure involves introducing country or regional dummies in order to estimate a different regression constant for each territory. It should be noted, however, that this is equivalent to estimating the equation with the dependent and independent variables measured in deviations from their average values (computed over time for each country or region in the sample). Hence, this procedure (as practically all panel techniques designed for removing fixed effects), ignores the information contained in observed cross-country differences and produces parameter estimates which are based only on the time variation of the data within each territory over relatively short periods. Since what we are trying to do is characterising the long-term dynamics of a sample of economies, this may be rather dangerous, particularly when the data contain an important cyclical component or other short-term noise.

The structural convergence equation methodology has some important advantages and limitations, both of which are derived from the close linkage between theory and empirics that characterise this approach. Its most attractive feature is that it allows us to use the relevant theory to explicitly guide the formulation of the empirical model - that is, the formal model is used to determine what variables must be included in the regression and how they must enter in order to obtain direct estimates of the structural parameters of the model. It is clear, however, that such guidance comes at a price, as our estimates will be, at best, only as good as the underlying theoretical model. Hence, an inadequate specification of this model can yield very misleading conclusions.

*An inadequate specification of the model can yield very misleading conclusions.*

Although this problem arises to some extent whenever we run a regression, there are reasons to think that it may be particularly important in the present context. In most of the recent empirical work on growth and convergence, the theoretical model of reference is some version of the one-sector neo-classical model with exogenous technical progress that underlies equation (2). Since the only convergence force present in this model is what we may call the neo-classical mechanism, the usual finding of a negative partial correlation between growth and initial income must be interpreted in this framework as evidence that the aggregate production function displays decreasing returns to scale in reproducible factors. In fact, this assumption is precisely what allows us to draw inferences about the degree of returns to scale from the estimated value of the convergence coefficient. The problem, of course, is that if there are any other operative convergence mechanisms, the inference will not be valid, as the estimated value of the convergence parameter will also capture their effects.

As we have seen, the literature identifies at least two factors other than decreasing returns that can generate a negative partial correlation between income levels and growth rates holding investment and population growth constant: technological diffusion and structural change. Although none of these convergence mechanisms is incompatible with the neo-classical story, the observation that this is not the only possible source of convergence suggests that it may be dangerous to accept without question an interpretation of the convergence coefficient based too literally on the preceding model. For instance, if income per capita is highly correlated with the level of technological development, the coefficient of initial income in a convergence regression could capture, at least in part, a technological catch-up effect. To avoid the danger of drawing the wrong conclusions about the properties of the technology, it may be preferable to interpret existing estimates of the convergence parameter,  $\beta$ , (particularly in the case of unconditional convergence equations) as summary measures of the joint effect of several possible convergence mechanisms. The value of this parameter (i.e. the partial correlation between the growth rate and initial income) will depend on the coefficient of capital in the production function, the speed of technological diffusion, the impact of sectoral change and on the response of investment rates to rising income, and will be positive (i.e. growth will be negatively correlated with initial income) whenever the forces making for convergence dominate those working in the opposite direction.

### **3.2 Some convergence concepts**

Before we proceed to review the empirical evidence, it is convenient to introduce some concepts of convergence that will feature prominently in the discussion below. Perhaps the first question that arises concerning the evolution of the distribution of income per capita is whether the dispersion of this variable (measured for instance by the standard deviation of its logarithm) tends to decrease

over time. The concept of convergence implicit in this question, called  $\sigma$ -convergence by Barro and Sala-i-Martin (1990, 1992a,b), is probably the one closest to the intuitive notion of convergence. It is not, however, the only possible one. We may also ask, for instance, whether poorer countries tend to catch up with richer ones, or whether the relative position of each country within the income distribution tends to stabilise over time. The concepts of *absolute* and conditional  $\beta$ -convergence proposed by Barro and Sala-i-Martin correspond roughly to these two questions.

To make more precise these two notions of convergence, we can use a variant of equation (1) in which we assume that each economy's fundamentals remain constant over time (that is, that  $x_{it} = x_i$  for all  $t$ ) and we interpret the variable  $y_{it}$  as relative income per capita, that is, income per capita normalised by the contemporaneous sample average. Omitting the disturbance term, the evolution of relative income in territory  $i$  is described by

$$\Delta y_{i,t} = x_i - y_{i,t}.$$

Setting  $\Delta y_{i,t}$  equal to zero in this expression, we can solve for the steady-state value of relative income,

$$y_i^* = \frac{x_i}{\alpha}$$

It is easy to check that if  $\alpha$  lies between zero and one, the system described by the above equation is stable. This implies that the relative income of territory  $i$  converges in the long run to the equilibrium value given by  $y_i^*$ . Notice that the equilibrium can differ across countries as a function of the "fundamentals" described by  $x_i$ .

In terms of this simple model, we will say that there is conditional  $\beta$ -convergence when  $\alpha$  lies between zero and one, and absolute  $\beta$ -convergence when this is true and, in addition,  $y_i^*$  is the same for all economies - i.e. when all countries or regions in the sample converge to the same income per capita.

Even though they are closely related, the three concepts of convergence are far from being equivalent. Some type of  $\beta$ -convergence is a necessary condition for sustained  $\sigma$ -convergence, for the level of inequality will grow without bound when  $\alpha$  is negative (i.e. when the rich grow faster than the poor). It is not sufficient, however, because a positive value of  $\alpha$  is compatible with a transitory increase of income dispersion due either to random shocks or to the fact that the initial level of inequality is below its steady-state value (as determined by the dispersion of fundamentals and the variance of the disturbance). The two types of  $\beta$ -convergence, moreover, have very different implications. Absolute  $\beta$  convergence implies a tendency towards the equalisation of per capita incomes within the sample. Initially poor economies tend to grow faster until they catch up with the richer ones. In the long run, expected per capita income is the same for all members of the group, independently of its initial value. As we know, this does not mean that inequality will disappear completely, for there will be random shocks with uneven effects on the different territories. Such disturbances, however, will have only transitory effects, implying that, in the long run, we should observe a fluid distribution in which the relative positions of the different regions change rapidly.

With conditional  $\beta$ -convergence, on the other hand, each territory converges only to its own steady state but these can be very different from each other. Hence, a high degree of inequality could persist, even in the long run, and we would also observe high persistence in the relative positions of the different economies. In other words, rich economies will generally remain rich while the poor continue to lag behind.

It is important to observe that, although the difference between absolute and conditional convergence is very sharp in principle, things are often much less clear in practice. In empirical studies we generally find that a number of variables other than initial income enter significantly in convergence equations. This finding suggests that steady states differ across countries or regions and, therefore, that convergence is only conditional. It is typically the case, however, that these conditioning variables change over time and often tend to converge themselves across countries or regions. Hence, income may still converge unconditionally in the long run, and this convergence may reflect in part the gradual equalisation of the underlying fundamentals. In this situation, a conditional and an unconditional convergence equation will yield different estimates of the convergence rate. There is, however, no contradiction between these estimates once we recognise that they are measuring different things: while the unconditional parameter measures the overall intensity of a process of income convergence which may work in part through changes over time in various structural characteristics, the conditional parameter captures the speed at which the economy would be approaching a “pseudo steady state” whose location is determined by the current values of the conditioning variables.

#### **4. Convergence across countries and regions: Empirical evidence and theoretical implications**

Having reviewed the theoretical and empirical framework used in the convergence literature, we are now in a position to examine the empirical evidence and discuss its implications. Contributions to the empirics of economic growth highlight three interesting empirical regularities. First, evidence of some sort of  $\beta$ -convergence is found in practically all available samples. While convergence is only conditional at the national level, in most regional samples a negative correlation between initial income and subsequent growth emerges without controlling for other variables. This second result is consistent with the existence of absolute convergence at the regional level - but most of the studies we have reviewed do not explicitly test this hypothesis (5). Secondly, the process of convergence seems to be extremely slow. Many of the existing estimates of the convergence parameter cluster around a value of 2 percent per year which implies that it takes around 35 years for a typical region to reduce its income gap with the national average by one half. Hence, the expected duration of the convergence process must be measured in decades. Finally, it is interesting to observe that the estimated convergence coefficient is remarkably stable across samples. This

*The process of convergence seems to be extremely slow.*

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5) Those that do test it by including different sets of conditioning variables generally reject it, as the significance of many of these variables implies important cross-regional differences in steady states. See for instance Dolado et al., (1994) and Mas et al., (1995) for the Spanish provinces, Herz and Röger (1996) for the German Raumordnungsregionen, Neven and Gouyette (1995) and Faberberg and Verspagen (1996) for various samples of European regions, Holtz-Eakin (1993) for the states of the US and Paci and Pigliaru (1995), and Fabiani and Pellegrini (1996). As we have noted in Section 3, however, this evidence does not conclusively reject the hypothesis of absolute convergence, as conditioning variables (and hence steady states) may themselves be converging over time. Note that the study by Vanhoudt et al., this volume, tackles this issue for Europe in more detail. The authors report strong support of conditional convergence within Europe - even at the regional level - with a speed of convergence of about half the size found for the United States.

stability suggests that the mechanisms that drive convergence in income per capita across different economies seem to operate in a regular fashion. Hence, we can at least hope to provide a unified structural explanation of the convergence process in terms of a “general” theoretical model.

*A good candidate for a “general” model is a simple extension of the neo-classical one. All that is needed is to extend the concept of capital to intangibles.*

Perhaps the dominant view in the literature is that a good candidate for this “general” model is a simple extension of the one-sector neo-classical model with exogenous technical progress. Just about the only departure from the traditional assumptions required in order to explain the empirical evidence is a broadening of the relevant concept of capital in order to include investment in intangibles such as human and technological capital. This conclusion is reached essentially by interpreting the results we have just reviewed within the framework of the growth model given in (2). According to our previous discussion, the finding of (at least conditional)  $\sigma$ -convergence in most national or regional samples can be interpreted as evidence in favour of the neo-classical assumption of decreasing returns to capital, as this result would not be consistent with increasing returns models that predict an explosive behaviour of income and its distribution. On the other hand, the apparent slowness of the convergence process does suggest that we are not that far from having constant returns in reproducible factors - a result that seems considerably more plausible if we think in terms of a broad capital aggregate, rather than the rather restrictive concept of capital we find in old-fashioned neo-classical models.

Since this broader concept of capital is probably one of the most significant contributions of the recent literature to our understanding of the mechanics of growth, the issue deserves a fairly detailed discussion. The reader will recall that within the framework of the Solow model the convergence coefficient ( $\sigma$ ) depends on the degree of returns to scale, measured by  $\rho$  (the coefficient of capital in the aggregate production function with, as discussed in the Box,  $\rho = a + b$ , where  $a$  is the coefficient of capital in the “private” production function and  $b$  captures the possible externalities), and on the rates of technical progress ( $g$ ), population growth ( $n$ ) and depreciation ( $\delta$ ). More specifically, we have seen that the relationship among these variables is given by equation (3):  $\sigma = (1 - a - b) (\delta + g + n)$ .

Using this expression and making reasonable guesses about the values of some of the parameters, we can extract information about key properties of the production technology from empirical estimates of the convergence rate. To start, let us consider the expected value of  $\sigma$  under conventional assumptions about the values of the remaining parameters. Within the framework of a traditional neo-classical model (with constant returns to scale in capital and labour, perfect competition and no externalities) we would have  $b = 0$  and the coefficient  $a$  would be equal to capital's share of national income, which is around one third. The average rate of population growth in the industrial countries during the post-WWII period is approximately 1%. Available estimates of the rate of technical progress are around 2% per year. Finally, estimates of the rate of depreciation vary considerably. In the convergence literature it is commonly assumed that  $\delta = 0.03$ , but a higher value (around 5 or 6% per year) may be more reasonable. Given these assumptions, the expected value of  $\sigma$  lies between 0.04 and 0.06.

The empirical results of Barro and Sala-i-Martin (1990, 1992a,b), Mankiw, Romer and Weil (1992) and other authors point towards a much lower convergence rate. Since the estimated value

of the parameter is still positive, the evidence is consistent with decreasing returns to capital (i.e.  $a + b < 1$ ). The low value of  $\beta$ , however, suggests that we are relatively close to having constant returns to capital. Maintaining our previous assumptions about the values of the remaining parameters, a convergence coefficient of 0.02 would imply a value of  $\beta$  between 0.67 and 0.78 - more than twice the share of capital in national income.

One possible explanation (Romer, 1987b) is that this result may reflect the existence of important externalities associated with the accumulation of physical capital. While these external effects would not be sufficiently strong to generate increasing returns in capital alone, they might still account for the apparent slowness of convergence. Other authors, however, argue that a more plausible explanation is that the omission of variables which are positively correlated with investment in physical capital may bias upward the coefficient of this variable. Barro and Sala-i-Martin (1990, 1992a) argue that a value of capital's coefficient around 0.7 only makes sense if we count accumulated educational investment as part of the stock of capital.

Mankiw, Romer and Weil (1992) advance the same hypothesis and test it explicitly by estimating a structural convergence equation similar to equation (2) that explicitly incorporates a proxy for the rate of investment in human capital as a regressor. Their results, and those obtained by other authors who estimate similar specifications, tend to confirm the hypothesis that investment in human (and technological) capital plays an important role in the growth process (6). As Mankiw (1995) points out, once human capital is included as an input in the production function, the resulting model is consistent with some of the key features of the data. Countries that invest more in physical capital and education tend to grow faster and therefore eventually attain high levels of relative income. Cross-country differences in rates of accumulation, moreover, are sufficiently high to explain the bulk of the observed dispersion of income levels and growth rates.

## 5. Loose ends and recent developments

It is probably fair to say that just a few years ago the extended neo-classical model we have just described summarised a consensus view on the mechanics of growth. In recent years, however, this consensus has been challenged by a series of papers that, relying on panel data techniques, obtain results that are difficult to reconcile with the prevailing theoretical framework. In this section we will summarise some of the key findings of these studies and discuss the theoretical difficulties they raise.

One of the key findings of the "classical" convergence studies is that convergence to the steady state is an extremely slow process. It has recently been argued, however, that this result may be due to a bias arising from the use of econometric specifications that do not adequately allow for unobserved differences across countries or regions. To get around this problem, a number of authors have proposed the use of panel techniques that allow for unobserved fixed effects. As we will see in this section, their results raise some puzzling questions.

For example, Marcet (1994), Raymond and García (1994), Canova and Marcet (1995), de la Fuente (1996a,b), Tondl (1997) and Gorostiaga (1998), estimate fixed-effects convergence models

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6) See for instance Lichtenberg (1992), Holtz-Eakin (1993), Nonneman and Vanhoudt (1996) and de la Fuente, (1998b). de la Fuente (1997) provides a detailed review of this literature.

using panel data for a variety of regional samples. Their results suggest a view of the regional convergence process that stands in sharp contrast with the one advanced before: instead of slow convergence to a common income level, regional economies within a given country seem to be converging extremely fast (at rates of up to 20 percent per year) but to very different steady states. Cross-national studies provide a roughly similar picture: Knight *et al.*, (1993), Canova and Marcet (1995), Islam (1995) and Caselli *et al.*, (1996), among others, find evidence of rapid convergence across countries (at rates of up to 12% per annum) toward very different steady states whose dispersion can be explained only in part by observed cross-national differences in population growth and investment rates. In both cases, many of the standard conditioning variables (such as human capital indicators) lose their statistical significance, the estimated coefficient of physical capital adopts rather low values, and the size and significance of the regional or national fixed effects suggests that persistent differences in levels of technical efficiency play a crucial role in explaining the dispersion of income levels.

**We can reject the assumption that increasing returns generate an explosive behaviour in the distribution of income across economies.**

Should we take these results at face value? Before we do so and abandon the only workable models we have so far, it seems sensible to search for some way to reconcile these empirical findings with some kind of plausible theory. I believe that this can be done - at least to some extent. My argument is essentially that a more reasonable interpretation of the extremely high convergence rates obtained in recent studies is that, if we have correctly estimated the relevant parameter (and we may not), then convergence is much too fast to be simply the result of diminishing returns to scale. This observation points to two complementary lines of research. The first one asks whether panel specifications of growth equations do in fact yield estimates of the relevant parameter. The second proceeds by identifying plausible mechanisms that may help account for rapid convergence and incorporating them into theoretical and empirical models.

On the first issue, Shioji (1997a, b) and de la Fuente (1998a) provide some evidence that panel estimates of the convergence rate may tell us very little about the speed at which economies approach their steady states (and therefore about the degree of returns to scale in reproducible factors) - essentially because these estimates are likely to capture short-term adjustments around trend rather than the long-term growth dynamics we are really interested in. Both authors show that correcting for the resulting bias in various ways brings us back to convergence rates that are broadly compatible with sensible theoretical models.

On the second issue, de la Fuente (1995, 1996b) and de la Fuente and Doménech (2000) estimate a further extension of the neo-classical model that allows for cross-country differences in total factor productivity and for a process of technological catch-up and show that technological diffusion can go a long way towards explaining rapid convergence across countries and regions (7). It follows that fast convergence does not require us to abandon the broad concept of capital we have so laboriously developed over the last decades. In fact, the parameters of the aggregate production functions estimated by these authors at the regional and national level are not far from those

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7) Dowrick and Nguyen (1989) also investigate the quantitative importance of technological catch-up as a convergence factor, but their empirical specification makes it difficult to disentangle this effect from the neo-classical convergence mechanism. Helliwell (1992), Coe and Helpman (1995) and Engelbrecht (1997) provide additional evidence on technological diffusion. There is also some evidence that a significant part of what appears to be TFP convergence at the aggregate level is in fact due to factor reallocation across sectors. See for instance Paci and Pigliaru (1995), de la Fuente (1996b), Caselli and Coleman (1999) and de la Fuente and Freire (1999).

obtained by Mankiw, Romer and Weil (1992) and suggest, in particular that educational investment plays a crucial role in growth that may not be apparent in previous studies in part because of data deficiencies. On the other hand, these studies do show that total factor productivity (TFP) differences across countries and regions are substantial and account for around half of observed productivity differences in the OECD in recent years, a result that is broadly consistent with the findings of Klenow and Rodríguez (1997) on the explanatory power of the extended neo-classical model. These results highlight the importance TFP dynamics as a crucial determinant of the evolution of productivity, a subject brought up recently by Prescott (1998), while retaining a significant role for differences in factor stocks as sources of income differentials across economies.

*Recent results have still been useful in shaking-up an exaggerated confidence in our ability to explain why some countries are richer than others.*

If we try to summarise, the key points that stand out in the theory and empirics on economic growth are as follows. In the current state of the literature, the conclusions we can draw must necessarily remain rather tentative. Practically all existing studies on the subject find clear evidence of some sort of long-run convergence both across countries and across regions over the post-war period. These findings allow us to reject with a fair degree of confidence a series of recent models in which the assumption of increasing returns generates an explosive behaviour of the distribution of income across economies that cannot be found in the data. Many of the results we have reviewed are consistent with an extended neo-classical model built around an aggregate production function that includes human capital as a productive input.

Recently, results using panel data techniques have suggested that educational investment was not productive and that the bulk of productivity differences across countries or regions has little to do with differences in stocks of productive factors. In my opinion, this has been largely a false alarm, but it has been useful in shaking up what was probably an exaggerated confidence in our ability to explain why some countries or regions are richer than others with an extremely simple model, and in directing researchers' attention to the determinants of technological progress and to some of the difficult econometric issues involved in the estimation of growth models.

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