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CONVERGENCE AND DIVERGENCE IN NEOCLASSICAL GROWTH MODELS WITH HUMAN CAPITAL

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CONVERGENZA E DIVERGENZA NEI MODELLI DI CRESCITA NEOCLASSICI CON CAPITALE UMANO

Abstract
Among the determinants of the growth and convergence processes identified by the theoretical literature, human capital is certainly one of the most important. This paper offers a selective survey of the more recent contributions of the theory of human capital and growth. In particular, our aim is to provide the necessary link between the theory on growth, convergence and human capital and the empirics of convergence. Summarising with a play on words, we might conclude that during the last fifteen years there has been a convergence of ideas between endogenous and exogenous models with respect to the convergence hypothesis where human capital plays an important role. Despite the still theoretically important difference between models that assume exogenous versus models that assume endogenous long-run growth rates, both theories predict that a mechanism of convergence is possible, but it will only be so among similar economies. In particular, most theoretical literature assumes that similar levels of human capital are fundamental for catch up to take place. Therefore, both theories are currently able to explain a stylised fact of the empirical literature on growth, namely the observed convergence among groups of homogeneous countries and the absence of convergence when large and heterogeneous data sets are introduced. This observation explains why, with current econometric techniques, it is not possible to discriminate endogenous versus exogenous models by simply using a convergence regression.

JEL classification: O40, O15, O33,

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> "Knowledge and skills are the product of investments and combined with other investments account for the productive superiority of the technically advanced countries. To omit them in studying economic growth is like trying to explain soviet ideology without Marx." Shultz (1962).

1 Introduction

Growth theory has been an active area of research during the last ten years due to the development of the endogenous growth literature[1]. In particular, the theoretical contributions developed by Romer (1986) and Lucas (1988) on endogenous growth have stimulated a resurgence of interest in this field. The debate that followed focused on theoretical and empirical aspects alike. From the point of view of theory, endogenous growth models appeared to be, or rather were simply presented by their authors as being "new" developments of the growth literature; new with respect to the "old" and still unmodified Solow-type growth model. Nevertheless, these models have their roots within the neoclassical solovian growth model. Given the availability in the mid 1980s of large international data sets with comparable GDP measures, these theoretical developments were soon followed by numerous empirical studies focusing primarily on one of the most important implications of the Solow growth model: the convergence hypothesis. By ascribing economic growth to the joint impact of exogenous technological change and capital deepening on an economy with concave short run production opportunities, the neoclassical solovian model makes very strong predictions concerning the behaviour of economies over time. In particular, the Solow (1956) growth model was initially interpreted as predicting that poorer countries should be catching up with the richer ones. This hypothesis is called in the literature the *absolute convergence* hypothesis.

Conversely, early endogenous growth models stress the presence of persistent differences in per capita income across countries: rich

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[1] For a complete survey of the early literature on growth starting from Harrod (1939) to the mid 60s contributions see Hahn and Matthews (1964).

economies may retain a constant gap with poorer regions or may even increase it. Theoretically, these models emphasise mechanisms which generate divergence across economies. Therefore, estimating the convergence equation has become increasingly popular as the convergence hypothesis appeared to be a sort of acid test to discriminate between endogenous and exogenous theories. In other words, the convergence test was considered as the main empirical test of the validity of these modern theories of economic growth and this is why, at first, a lot of efforts have been devoted to trying to estimate the presence of a convergence/divergence mechanism across different economic areas.

In general, stylised facts derived from international data sets showed the absolute convergence prediction to be untrue[2]. Nevertheless, the debate did not conclude in favour of endogenous models for various reasons. First of all, it has been demonstrated that the Solow model predicts *conditional convergence*. That is, roughly speaking, it predicts that only economies with similar fundamentals (preferences, technology as well as institutions, economic structure etc.) actually converge towards the same level of long-run output per person. Moreover, recent endogenous growth models predict the possibility of convergence across economies. In particular, models that stress both the importance of technology in explaining long-run growth and the possibility of transfer of technology among different countries predict that countries lagging behind may catch up towards the more advanced areas.[3]

In particular, recent models focus on technology as the driving force for long run growth and on human capital as one of its main determinants. This is not to say that the role of human capital for growth was neglected by economists prior to 1986[4]. From its earliest beginnings, economic theory has stressed the importance of human capital as a key factor for explaining growth. In general, human capital should indicate the degree of ability of the labour force and is usually measured in terms

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[2] See Barro (1991).

[3] Recent empirical evidence shows that the evolution of technology represents an important element in observed convergence among OECD countries. An interesting reading on the convergence hypothesis debate can be found in the "Controversy" of the *Economic Journal* (vol. 106, 1996) that includes papers by Durlauf, Sala-i-Martin, Bernard and Jones, Quah and Galor.

[4] Romer's (1986) model is considered as the first endogenous growth model.

of formal education levels or on the job training. Accordingly, investment in human capital entails investment (education, training…) geared to sustaining and developing the ability of individuals. The accumulation of human capital is costly (it subtracts time available to production) but it represents a remunerative investment. Arrow (1961) together with the works of Schultz (1962), Uzawa (1965), Nelson and Phelps (1966) are probably the most important early contributions to the theory of human capital and growth. Although Arrow (1961) does not explicitly introduce human capital in his study, his model does include externalities linked to the process of the accumulation of physical capital. It is a learning by doing model where the larger the scale of production, the greater the increase of the labour force's on-the-job productivity. We find a different approach in both Shultz (1962) and Uzawa (1965), where human capital is explicitly introduced in their analysis and is not considered as a mere by-product of production.

In this Paper we introduce *old* and *new* neoclassical models that stress the importance of human capital and focus exclusively on what the different models predict in terms of the convergence hypothesis. As we shall see, different models imply different concepts of convergence. Therefore, it is important to stress how convergence has been differently defined and understood. Thus, our aim is to investigate the role human capital plays in the various growth models and to examine specifically the predictions of different models with regard to the convergence hypothesis[5].

In order to classify the different models we follow Aghion and Howitt (1998) and distinguish two different approaches that analyse the link between growth and education: the Lucas approach and the Nelson and Phelps approach. In the following sections we shall see that these two approaches include both endogenous and exogenous models. What distinguishes the different models is the assumed relationship between human capital and growth. What mainly characterises the Lucas approach is the assumption that human capital enters a growth model simply as an additional input in a standard Cobb-Douglas production function and that capital accumulation is central force in generating growth. In other words, all these models imply there is a positive correlation between human capital accumulation and (long or short-run)

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[5] Other important recent contributions not included in this survey are, for example, Becker, Murphy and Tamura (1990) and Benabou (1996).

growth rates. Therefore, empirically, we should observe that countries with different rates of investment in human capital grow at different rates. Conversely, the Nelson and Phelps approach does not emphasize the role of *capital accumulation* (both physical and human) as an engine of growth and stresses the importance of the process of technological change. Within this framework, human capital is a prerequisite for economic growth where "the growth rate of output will depend on the rate of innovation as well as on the level of human capital"[6]. Thus, (long or short-run) growth rates depend on stocks rather than on rates of accumulation of human capital.

Finally, while models reviewed above describe a catch up mechanism resulting from technology transfers with human capital levels acting as the main determinant, they do not describe any mechanisms that may affect the existence of transfers of technology among countries. In this survey we focus on models that identify trade policies as the main determinant of technology diffusion.

This Paper may be divided into ten different parts. The next three sections briefly reviews how the concept of convergence has evolved in the literature on growth. We define the solovian convergence equation and introduce the notion of conditional convergence, while section four is dedicated to the early development of endogenous growth literature and to the divergence hypothesis. In section 5 we discuss the main points and predictions of the so-called Lucas approach, and the following three sections examine respectively a second class of models whose roots lie in the contribution of Nelson and Phelps (1966) (sections six and seven) and models that stress the importance of trade for technology transfers and catching up (section eight). The final part of this paper (sections nine and ten) is dedicated to a summary of the different concepts of convergence encountered during the survey and a classification of the theoretical models examined in terms of their ability to explain observed convergence or divergence, stressing the role that human capital plays in determining either one or the other result.

2 The Solow model and the convergence hypothesis: absolute convergence

In the Solow model, capital deepening is at the heart of the growth

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[6] Nelson and Phelps (1966).

process. The aim of the model is to explain the link between savings and growth, where savings are exogenous. This link is the process of capital accumulation. The model describes an economy in which the production function of the representative producer is $Y = F(K, AL)$, where Y is the flow of output, K is the stock of capital, L is the labour force and A is knowledge or, in general, "effectiveness of labour". Note that A and L enter multiplicatively, in which case technology is known as *labour augmenting* or *Harrod-neutral.* Both population growth and technological progress are exogenous. It is assumed that $F(\ .\ )$ exhibits positive and diminishing marginal products in each input, as well as constant returns to scale. The assumption of constant returns enables us to work with the production function in intensive form:

$$y = f(k) = k^{\alpha} \qquad (1)$$

where $0 < \alpha < 1$ and, henceforth, the lowercase letters denote a quantity per unit of effective labour, with $k = K/AL$, and $y = Y/AL$. Output can be used for investment or consumption. If depreciation of capital is proportional at rate δ, and a constant proportion of income, s, is invested in this economy, the derivative of k with respect to time evolves in accordance with:

$$\dot{k} = sf(k) - (n + g + \delta)k \qquad (2)$$

Equation (2) is the resource constraint, where n is the exogenous growth rate of the labour force and g is the exogenous technology (or knowledge) growth rate. The exogenous growth rate of the labour force can be considered as being a depreciation rate because it represents the fraction of resources that we need to pass on to the new generation. We can rearrange equation (2) to obtain the growth rate of k as:

$$\dot{k}/k = sf(k)/k - (n + g + \delta) = sk^{-(1-\alpha)} - (n + g + \delta) \qquad (3)$$

If we consider a log-linear approximation of equation (3) around the steady state we obtain:

$$\dot{k}/k = d[\ln(k)]/dt \cong -\beta[\ln(k/k^{*})] \qquad (4)$$

where

$$\beta = (1-\alpha)(n+g+\delta) \qquad (5)$$

That is, β determines the speed of convergence from *k* towards its steady state level, *k**[7]. In general, when a country or region starts with *k* below its level of steady state we should observe positive net investment, which implies positive growth of the stock of capital. If we focus on the development of a single country over time, the model predicts that the growth rate will be high when capital per worker is low and will decline as capital per worker rises. This is due to the fact that a low value of capital per worker implies a high marginal product of capital and therefore a high interest rate and a high level of investment. Therefore, we should observe that the real interest rate declines along with capital marginal product as an economy develops. This movement to higher values of *k* continues as long as $k<k^*$, where *k** is the steady state level of capital. Once the capital stock gets to $k=k^*$, net investment becomes zero and *k* no longer changes over time.

In brief, the Solow model has many important implications. First of all, savings rates do not affect the long-run growth of per capita income. The crucial factor explaining the presence of a sustained long-run growth rate in an economy is the presence of exogenous technological progress. However, the savings rate affects the long-run *level* of per capita income. In particular, the Solow model predicts that economies converge to a steady state, where the key force that underlies the convergence effect is diminishing returns to reproducible capital; the process toward the steady state is called transitional dynamics. The steady state growth rate explained by the model is equal to zero; it is only possible to obtain continued growth in output per head if there is exogenous technical progress.

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[7] A more complex definition of the beta parameter is found when we assume savings to be determined by optimal choices of consumption over time. When the utility function takes the standard isoelastic form, it can be shown that the beta-convergence parameter becomes:

$$2\beta = (\rho-n) - \left\{(\rho-n)^2 + 4\left(\frac{1-\alpha}{\alpha\vartheta}\right)(\rho+\delta+n+g)\left[(\rho+\delta+n+g)-\alpha(\delta+n+g)\right]\right\}^{1/2} \text{ I}$$

n this case a higher θ (reduced willingness to substitute intertemporally) lowers the speed of adjustment towards the steady state, while a higher time-preference rate, ρ, raises it.

Moreover, assuming certain assumptions are satisfied, the process of convergence towards the long-run equilibrium (within country convergence) may result in a tendency towards convergence in per capita income among economies. Note that given the Cobb-Douglas production function we assumed, $Y = K^{\alpha}(AL)^{1-\alpha}$, the growth rate of *(Y/AL)* has the same form as equation (4):

$$\dot{y}/\,y = d\,[ln(\,y\,)]\,/\,dt \cong -\beta[ln(\,y\,) - ln(\,y^{*}\,)] \qquad (6)$$

or

$$\ln y(t) - \ln y(0) = (1 - e^{-\beta t})(\ln y^{*} - \ln y(0)) \qquad (6')$$

Equation (6') represents the convergence equation introduced in empirical studies. This equation indicates that when an economy starts from a level of income in efficiency units lower than its steady state level, we should observe a positive rate of growth of *y* where β, as before, represents the speed of adjustment towards *y**. Thus, there should be a force that promotes convergence in levels of per capita income. Empirically, we should observe that the per capita growth rate tends to be inversely related to the starting level of output per person. This implication of the solovian model is referred to as the absolute or unconditional convergence hypothesis.

3 Conditional convergence and the role of human capital

We have seen that countries would converge in the absolute sense if the only difference between them is the initial level of per capita income. One of the most convincing arguments in endogenous growth literature against the Solow model was that the latter cannot account for international differences in income[8], since there is no evidence of international convergence. However, there are two possibilities for reconciling evidence based on convergence, using the Solow model.

Firstly, equation (5) shows that one of the key force underlying the convergence effect is diminishing returns to reproducible capital. In other words, the extent of these diminishing returns, that is, the size of the capital-share coefficient α in the production function, has a strong

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[8] See Romer (1986) and Lucas (1988).

effect on β. In particular, it has been shown[9] that for small values of α, diminishing returns set in rapidly, β is large and convergence is rapid. As α approaches unity, the convergence becomes less and less rapid and, when $\alpha=1$, diminishing returns to capital disappear, β tends to zero and we do not observe convergence. Thus, for values of α close to one the transitional dynamic turns out to take a long time: as shown by Mankiw, Romer and Weil (1992), if we see the transitional dynamics as protracted, the model becomes potentially capable of explaining sustained cross-country differences in growth rates, thus providing a Solow-type explanation of these differences. Large values of α are usually explained by the introduction in the production function of a broad concept of capital that includes human capital. Secondly, economies may differ not only in their capital labour ratio but also in the level of technology, savings rate, depreciation rate or population growth rate. In particular, it is important to focus attention on the determinants of the steady state. In the *augmented* version of their model Mankiw, Romer and Weil (1992) (henceforth MRW) introduce a standard solovian production function augmented by human capital, *H*:

$$Y = K^{\alpha} H^{\beta} (AL)^{1-\alpha-\beta} \qquad \text{with} \qquad \alpha+\beta<1 \tag{7}$$

The constraints are:

$$\dot{k} = s_k y - (n+g+\delta)k \tag{8}$$

$$\dot{h} = s_h y - (n+g+\delta)h \tag{8'}$$

The lowercase letters denote a quantity per unit of effective labour. Equations (8) and (8') are identical: MRW assume the same dynamics for both physical and human capital, where s_k and s_h represent the exogenous and constant propensities to invest in both types of capital. Thus, MRW assume the same technology for producing human capital as for producing physical capital. This is a controversial assumption and has been criticised by Klenow and Rodriguez-Clare (1997a).[10]. The steady

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[9] King and Rebelo (1993).

[10] They produce evidence showing that the technology for producing human capital is more intensive in labour than is the technology for producing other goods. Their

state values of physical capital, k^*, and human capital, h^*, are determined by:

$$k^* = \left(\frac{s_k^{1-\beta} s_h^{\beta}}{(n+g+\delta)} \right)^{1/1-\alpha-\beta} \tag{9}$$

$$h^* = \left(\frac{s_k^{\alpha} s_h^{1-\alpha}}{(n+g+\delta)} \right)^{1/1-\alpha-\beta} \tag{9'}$$

By augmenting the model with human capital, MRW obtain an expression for the steady state (indicated by the asterisk) of per capita GDP:

$$ln\left[\frac{Y(t)}{L(t)}\right]^* = ln\,A(0) + gt + \frac{\alpha}{1-\alpha-\beta} ln\,s_k + \frac{\beta}{1-\alpha-\beta} ln\,s_h - \frac{\alpha+\beta}{1-\alpha-\beta} ln(n+g+\delta) \tag{10}$$

Equation (10) states that the steady state level of income per effective worker is positively related to the savings (or investment rates) of an economy while it is negatively related to parameters *n, g* and δ. It is also positively determined by the parameter *A(0)* which, as Mankiw Romer and Weil (1992) emphasise, represents not only the initial level of technology or knowledge, as previously suggested, but also institutions, climate and resource endowments. Moreover, the steady state of per capita income, in addition to the factors of the Solow's textbook model described in (14), depends on s_h, the rate of accumulation of human capital. Substituting equation (10) in the usual convergence equation, we obtain a positive relationship between the growth rate of an economy and the rate of accumulation of human capital.

Note that this is not the only possible specification of the convergence regression. MRW also introduce a specification of the convergence regression in which the growth rate of an economy is a function of the level of human capital. Nevertheless, this alternative specification of the growth process involves per capita income growth as a function of the *steady state level* of human capital. In fact, equation (10) can be rewritten as:

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evidence suggests factor shares of 10%, 40% and 50% for physical capital, human capital and raw labour in the production of human capital, as opposed to 30%, 28% and 42% shares used by MRW for both sectors.

$$ln\left[\frac{Y}{L}\right]^{*} = ln\,A(0) + gt + \frac{\alpha}{1-\alpha-\beta} ln\,s_{k} + \frac{\beta}{1-\alpha-\beta} ln\,h^{*} - \frac{\alpha}{1-\alpha-\beta} ln(n+g+\delta) \qquad (10')$$

In this case, by substituting equation (10') within the convergence equation, we also find there to be a positive relationship between the growth rate of per capita income and the steady state level (or stock) of human capital. Note that in their empirical analysis, MRW introduce secondary school enrolment rates as a proxy for human capital. In other words, they probably consider equation (10) as the most appropriate specification of steady state[11]. In fact, h^* should be considered unobservable, since in most countries it is implausible to assume that the observed human capital is at its steady state level. [12]

Thus, if countries differ in one or more of these parameters, it is clear from equation (10) that they will end up in different steady states. In the latter case, only for given y^* can we say that the growth rate is higher the lower $y(0)$, that is, the convergence is conditional in that $y(0)$ enters in relation to y^*, which may differ across regions. Empirically, this means we would expect to observe poor countries growing faster than rich ones only if their respective steady state is similar. Yet if, for example, rich countries have a higher steady state level of per capita income with respect to poorer countries, poor economies will not necessarily grow faster.

The MRW model has been highly influential within the growth-convergence debate. Theoretically, they have clearly illustrated the concept of *conditional convergence*, emphasizing that the Solow model predicts absolute convergence only under very restrictive assumptions. In this way, they provide a better description of cross-country data compared to the previous *unconditional convergence-exogenous growth* empirical literature, and show that it is not necessary to rely on endogenous models to explain the evident divergences among countries in international data sets. In their empirical analysis, they test for the determinants of the steady state including data on population growth

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[11] More precisely, during their empirical analysis they assume that actual values of human capital stocks represent a good proxy of their steady state value. However they never include in their regressions a measure of the stock of human capital arguing for a lack of data on that variable.

[12] On this see Klenow and Rodriguez-Clare (1997a).

rates, savings rates and secondary school enrolment rates[13] and find evidence of conditional convergence. That is, they do not predict there will be convergence in levels of per capita income among countries, since economies converge towards different long-run levels of per capita income but will *converge towards the same long-run exogenous growth rate*. Moreover, by augmenting the Solow growth model with human capital, they predict a larger contribution of total capital to *transitional* growth, and thus predict the existence of a prolonged transitional dynamic process. With the inclusion of a human capital indicator in their empirical analysis, they also find plausible values for the structural parameters of the Solow model[14].

4 Endogenous growth: early divergence, possible convergence

The divergence hypothesis has been explicitly formulated and tested in various studies on endogenous growth. As stated above, one of the main motivations for further studies in endogenous growth literature has certainly been the model's inadequacy in explaining the absence of convergence among countries Endogenous growth models are highly heterogeneous. A simple and unifying definition of the endogenous growth models uses their relationship with the Solow model: what distinguishes the endogenous growth literature from the solovian approach is the possibility of positive long-run growth rates without the presence of exogenous technological progress. Nevertheless, different models within this literature give quite diverse interpretations regarding the engine of long-run growth.

Following Romer (2001), we distinguish two different classes of models within the endogenous growth literature. The first class assumes that the process of capital accumulation and, in particular, human capital accumulation, is central for explaining long-run growth paths. These models differ from Solow's in that they assume the capital share coefficient to be $\alpha \geq 1$, that is, they assume that returns to capital are constant or increasing. As in MRW, non decreasing returns are usually explained by the introduction in the production function of a broad

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[13] As a proxy for the accumulation of human capital, *sh*.

[14] In particular, the value of the elasticity of output with respect to total capital, with an estimated value of approximately 0.8.

concept of capital that may include human capital[15]. In the second class of models, technology is a standard reproducible factor of production. In this case the process of accumulation of A is the key factor for explaining long-run growth. These studies determine how the technology evolves and describe what the possible determinants of innovation will be, seen as a distinct economic activity, i.e., they focus on the input A of the production function and its evolution over time. However, the original contribution of these works is not in their simple emphasis on technology. Undoubtedly, even in Solow's view technological change lies at the heart of economic growth since it is the key factor in explaining long run growth. Nevertheless, while Solow believes that explaining technological progress is still too difficult a task for economic theory, and that the exogeneity assumption is the most reasonable one[16], this is precisely what most endogenous growth models attempt to do. As Romer notes (1990), technology or knowledge is a nonrival good but it is not necessarily nonexcludable as assumed by Solow. In particular, excludability depends on the nature of the knowledge produced and on the legal system governing property rights (or patenting and copyrights laws). Models assuming that technology shares both of these characteristics identify the public support for basic scientific research as the driving force for growth. Thus, government decisions become important for growth as it is necessary to subsidise the R&D sector. As in Solow, technology (or knowledge) is considered to be a purely public good, not something that the private sector can provide. Yet here, unlike in Solow's model, long-run growth needs to be sustained. That is, technology is never *manna from heaven*. On the other hand, when knowledge created by R&D is excludable, it is possible to obtain mechanisms in which expenditure in R&D is motivated by the desire for private gain. In this case the developer of new ideas must have some degree of market power. Innovators can charge a fee for the use of the idea, where the fee is limited by the extent to which others are prepared to devote resources to learning the idea[17].

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[15] See Lucas (1988) and Rebelo (1991).

[16] See Solow (1994).

[17] Other forces which have raised interest because important for governing the allocation of resources to the development of technology include economic incentives and social forces influencing the activity of talented individuals and learning by doing. See Romer D. (2001).

We briefly introduce the Romer's model (1990) in this survey, as it is one of the most influential studies of the *new growth* literature. Romer starts from the premise that technological change lies at the heart of economic growth as it is technological change that engenders continued capital accumulation. More precisely, the crucial input of production necessary for explaining long-run growth is the process of *knowledge creation* in an economy. Although closely linked, knowledge and technological progress are not one and the same thing. In particular, knowledge can be divided into two components: human capital and technology. While the first component cannot grow indefinitely, the second one can. This is an explicit criticism levied at the Lucas (1988) model, which identifies long-run growth (that grows indefinitely) exclusively with the growth of human capital[18]. For Romer (1990), the interesting case is that of a nonrival but not completely excludable good, where excludability depends on both the nature of the knowledge itself and on economic institutions governing property rights[19]. The consequence of a nonrival good when used as an input of production is that output does not have a constant returns to scale function of all inputs taken together. Therefore, technology is characterised by knowledge spillovers: the discovery of a new technology will not capture all the benefits of its investment. As a result, private efforts at technological improvements will be less than socially optimal. As an example of new technologies, Romer introduces the design of a new good: in this case technology is embodied in new capital goods. The idea is simple: this model shows that productivity increases because of ideas embodied in capital and material inputs. We will briefly introduce a few details of the model which describes an economy with four inputs of production: capital (K), labour (L), human capital (H) and index of the level of technology (A). In this model the final good production function may be rewritten as:

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[18] See section 5.

[19] To avoid any confusion, we prefer to distinguish between models that focus on the importance of endogenising technological change distinct from capital accumulation and models that instead focus on processes of capital deepening. However, there is a third class of models that, following Arrow (1961), introduce the possibility that accumulation of knowledge occurs in part not as a result of deliberate efforts, but as a side effect of conventional economic activity; for example, as a side effect of the production of new capital.

$$Y = qA^{\alpha+\beta} H_y^{\alpha} L_0^{\beta} K^{1-\alpha-\beta} \tag{11}$$

where $q = \eta^{-(1-\alpha-\beta)}$, a constant. This production function shows increasing returns (is homogeneous of degree $1+\alpha+\beta$). These are caused by the nonrival nature of knowledge, implying knowledge spillovers will occur. If we examine the model in the balanced growth equilibrium, g^*[20]. It can be shown that the balanced growth rate is determined by:

$$g^* = \lambda H_A = \frac{\lambda(\alpha+\beta)H - \alpha\rho}{\alpha\theta+\beta} \tag{12}$$

Equation (12) says that the balanced growth rate of an economy depends on the amount of human capital allocated in the R&D sector, H_A. Allocation of human capital in the R&D sector is influenced by the interest rate. In this model, the opportunity cost for H to be allocated in the R&D sector is the wage that can be earned in the final good sector, while the returns to investing H_A in the R&D sector are represented by the stream of net revenue generated by a new design. A higher interest rate leads the present discounted value of the stream of net revenue to be lower and thus results in less human capital, H_A, being allocated as well as a lower growth rate. Contrariwise, a reduction in the interest rate should speed up growth. The last equality in (12) represents the parametrically expressed balanced growth rate. It shows that H, total human capital, enters the growth rate equation and that λ, the research success parameter, has a positive effect on g^*, while the discount rate, ρ, has a negative effect. Moreover, in (12), g does not represent the efficient balanced growth rate because of the presence of a positive externality in research. There is a nonexcludable effect of R&D: when a new design is invented it increases the productivity of the R&D sector and this effect is not considered in the new design's price. The social optimum can be obtained by subsidizing the accumulation of A.

In terms of the convergence/divergence hypothesis, it must be noted that there is no convergence mechanism operating here. If we consider two economies, the one with the larger H_A will grow faster

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[20] That is, when $g_C^* = g_K^* = g_Y^* = g_A^*$.

indefinitely and neither GDP per capita levels nor long-run growth rates will converge. Moreover, even if human capital is important in defining the dynamics of the growth process it cannot be considered as the ultimate source of long-run growth. In order for unbounded per capita income to grow indefinitely, we need to identify another unbounded input, i.e technological progress. Nevertheless, in this study the long-run growth rate of an economy ultimately depends on the stock of human capital.

The influence of Romer's (1990) model may be gauged by the many criticisms and extensions it has received. One of the first common criticisms of Romer's (1990) model within endogenous growth literature is that it has a scale effect. Equation (12) implies that a country with a larger skilled labour force should grow faster, since technology evolves according to the rule, $\dot{A} = \lambda H_A A$, where λ is a research success parameter. Human capital is an input into idea production function characterised by knowledge spillovers: researchers generate more varieties of products (more ideas) the greater the stock of knowledge from which to learn. Moreover, there is no uncertainty in the R&D sector: Romer assumes that investments would certainly produce innovation given an exogenous success parameter λ.[21] Thus, this assumption implies that the growth of technology should follow the same path of human capital over time. In practice, though, this prediction is difficult to detect in actual data. This is widely known as the Jones (1995) critique and will be dealt with later. [22]

Overall, despite their heterogeneity, all endogenous growth models are similar to Romer's (1990) in that they do not sustain a solovian convergence mechanism. Nevertheless, even if this literature was at first associated with predicting divergence among economies, further developments showed that endogenous models could actually

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[21] Aghion and Howitt (1992) introduce uncertainty in the R&D sector, where uncertainty in the research process implies that the growth rate becomes stochastic.

[22] Moreover, the model does not account for obsolescence of capital goods because it assumes additive separability of durables in the final goods production function. That is, in Romer, capital goods are horizontally differentiated implying that no one capital good is better than the others. This characterisation of the growth process has been considered unsatisfactory by advocates of the so-called Schumpeterian approach. See Aghion and Howitt (1992) and Grossman and Helpman (1991).

produce convergence with human capital playing an important role in generating this mechanism. This point will be further investigated in the following sections.

5 Human Capital and the Lucas Approach

The so called Lucas approach is characterised by the assumption that the role of human capital in a growth model is simply as an additional input in a standard Cobb-Douglas production function. Therefore, we identify a new input, total capital, which represents the sum of human plus physical capital. As usual, the presence of an endogenous or exogenous growth mechanism crucially depends on how returns to total capital in the production function of this economy are viewed. The presence of non-decreasing returns in this *augmented* form of capital cause, as expected, non-decreasing incentive to its accumulation as the stock of capital increases. Conversely, if total capital (human plus physical) is characterised by decreasing returns, incentives to its accumulation tend to decrease with an increase in its stock. In that case, human capital, even if it does not explain long-run growth, is still crucial for a better understanding of the process of transition towards long-run equilibrium. Note that the MRW model examined in section 3 may certainly be included in this class of models.

However, not all these models introduce augmented forms of capital. For example, Lucas (1988) assumes non-decreasing returns in the accumulation of human capital only, and identifies in this way the mechanism that causes the presence of an endogenous growth process. Unlike the MRW one, this is an endogenous growth model where technological progress and, thus, long-run growth essentially coincides with the process of accumulation of human capital, which is assumed to be unbounded[23], and to determine the long-run growth of an economy. He describes an economy where human capital is the key factor of production and where the production of human capital does not require physical capital:

$$y = k^{\beta} (uh)^{1-\beta} (h_{\alpha})^{\gamma} \tag{13}$$

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[23] And we have seen that this assumption has been criticised by Romer (1990).

Differently from MRW, lowercase letters denote variables in per capita term; *y* is the usual GDP, *h* denotes the human capital stock of the representative agent, *u* is the fraction of time allocated to production and h_a represents the average human capital stock across individuals. Leisure is assumed exogenous and *(1-u)* denotes the time spent on education[24]. The presence of the parameter $\gamma > 0$ implies an externality in the model. In this way, Lucas stresses the possibility of the existence of "internal" and "external" effects on the accumulation of human capital: the former is simply the effect of individual human capital on its own productivity while the latter arises from a simple positive externality that the average level of human capital has on the productivity of all factors. This assumption implies that competitive equilibrium does not equate with efficient equilibrium. Therefore, optimal equilibrium will only be obtained by the social planner equilibrium. However, as we shall see, the presence of an externality in the production function is not essential in order to obtain the main results of this model. In this framework, the representative agent maximises the standard constant relative risk aversion utility function given the constraints:

$$\dot{k} = y - c - nk \tag{14}$$

$$\dot{h} = \xi(1-u)h \tag{14'}$$

Equations (14) and (14') show that, unlike MRW, Lucas does not assume the same accumulation function for *h* and *k*. The parameter ξ in (14') represents the efficiency of the educational system. Equation (14') is the key one: it implies the presence of a process of endogenous growth. Endogenous growth is determined by the presence of constant returns to accumulation of the existing stock of human capital. In this case, the rate of growth of the stock of human capital plays the same role as exogenous technological change does in the Solow model. In fact, the Hamiltonian of this problem is[25]:

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[24] It is possible to relax this assumption. For a version of the Lucas model with leisure introduced endogenously see Solow (1994).

[25] Assuming the standard isoelastic utility function.

$$H(c,u,k,h,\lambda,\mu)=\frac{c^{1-\vartheta}-1}{1-\vartheta}e^{-\rho t}+\lambda(Ak^{\beta}(uh)^{1-\beta}h_a^{\gamma}-c-nk) \qquad (15)$$
$$+\mu(\delta(1-u)h)$$

where the first order conditions are determined as usual. Rearranging the FOC's and using the relationship between *k* and *y* we obtain:

$$g_c^* = g_k^* = g_y^* = \frac{1-\beta+\gamma}{1-\beta}g_h^* \qquad (16)$$

where *g** denotes the steady state growth rates. It can be shown that:

$$g_h^* = \frac{1-\beta}{\vartheta(1-\beta+\gamma)-\gamma}(\delta-\rho) \qquad (17)$$

Equation (16) is what most interests us here. In this model, the per capita income growth rate turns out to be a proportion of the growth rate of human capital. In other words, unlike MRW, Lucas endorses the idea that the *long-run growth* of per capita output is driven by the *accumulation* of human capital. Therefore this model predicts divergence across countries: economies that invest more in human capital (richer economies) should grow faster. That is to say, there is no convergence in levels of per capita income among countries because each country converges to different long-run growth rates.

However, in a more recent work, Lucas (1993) modifies this model including *a convergence in levels* mechanism. More precisely, he explicitly introduces knowledge spillovers among economies that cause the presence of a catching up process.[26] In fact, Lucas (1988) can simply be modified by introducing two countries, and transforming equation (14') as follows:

$$\dot{h}_1 = \delta(1-u_1)h_1^{\mu}h_2^{1-\mu} \qquad \text{with} \qquad 0<\mu<1 \qquad (18)$$

where the subscripts, 1 and 2, represent the two countries. In (18) we still have constant returns on human capital for country 1 as before, but in

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[26] The following example represents a further simplification of the model proposed by Lucas (1993) but it is still able to incorporate the catching up mechanism.

this case note that $\dot{h}_1$ also depends on the level of human capital in country 2. More precisely, this equation captures the idea of possible interdependencies among economies because it accounts for ideas developed in one place affecting the development of new ideas elsewhere. In terms of growth rates:

$$\frac{\dot{h}_1}{h_1} = \delta(1 - u_1)\left(\frac{h_2}{h_1}\right)^{1-\mu} \tag{19}$$

Equation (19) implies that, if $u_1=u_2$, and $h_1>h_2$, country 2 should grow faster until $h_1=h_2$. Therefore, this relationship implies convergence in both per capita income levels and long-run growth rates between the two countries.

Unlike Lucas (1988) and (1993), the Azariadis and Drazen (1990) model introduces the existence of positive threshold externalities in education technology that lead to the existence of a multiplicity of equilibria and, thus, of steady state growth paths. They describe an overlapping generation model that allows economies with identical structures but different levels of investment in education to experience sustained differences in income per capita growth rates[27]. Individuals lives can be divided into two periods: when young, they inherit the aggregate human capital accumulated by previous generations and decide how much time to allocate to investing in education, u[28], and how much time to allocate to production activities, $(1-u)$.

As in Lucas (1988), the long-run growth rate, g^*, is a function of investments in human capital and, more specifically, it turns out to be an increasing function of the productivity of education. We focus on the equation that defines how human capital accumulates during the lifetime of an individual:

$$h_{2,t} = (1 + \gamma(u_{t-1}) \cdot u^{\vartheta})h_{1,t} \tag{20}$$

where the subscript 1, denotes the individual when young, 2

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[27] We will follow a simplified version of this model proposed by Aghion and Howitt (1998).

[28] That is, as in Lucas (1988), u represents the fraction of time allocated to education.

when old, ϑ is a parameter strictly less than one and γ represents the productivity of education and depends on the fraction of time allocated to education by the previous generation.

The existence of multiplicity of equilibria requires that there exists a positive threshold externality such that:

$$\gamma(u_{t-1}) = \begin{cases} \underline{\gamma} & if \quad u_{t-1} \le u_0 \\ \overline{\gamma} & if \quad u_{t-1} > u_0 \end{cases} \quad \text{with } 0<u_0<1 \text{ and } \underline{\gamma} << \overline{\gamma} \qquad (21)$$

where u_0 defines the threshold level of u. Suppose that the previous generation invested a low fraction of his time in education such that $\gamma(u_{t-1}) = \underline{\gamma}$: in this case, investment in education will be unattractive for the current generation as well, because private rates of return on human capital investment depend on the existing average quality of h. Therefore, we will observe "…a tendency to perpetuate the successes and failures of the development process[29]". This analysis of a single economy may be extended to a multiple economies framework. In fact, empirically this model implies the existence of convergence clubs. If two countries, A and B, have different initial human capital endowments where $u_A<u_0$ and $u_B>u_0$, they will experience indefinite growth at different growth rates with $g^*_A<g^*_B$. Without any intervention, economies that have not invested sufficiently in education in the past will find themselves in a "low development trap", that is, they will find themselves in the "poor countries" club. Moreover, we should observe different returns to education for the different clubs, with the rich countries club having the highest returns. There are no convergence mechanisms or knowledge transfers. Here, differences in actual investment rates of human capital should represent the key variable for explaining observed internationally divergent patterns of growth. And the policy implication is a simple one: in order to change club the government should subsidise education so that $u_t \ge u_0$.

Overall, note that, despite the presence of important differences, these models share a common assumption and a common testable prediction. First of all, this framework assumes that the process of accumulation of

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[29] Azariadis and Drazen (1990).

human capital is equivalent to that of physical capital. Secondly, all these models imply that an increase in human capital endowments positively affects an economy's growth rate. In other words, empirically, we should observe that countries with different rates of investment or rates of change in human capital grow at different rates. However, it affects the *long-run growth rate* in Lucas and Azariadis and Drazen, while it influences the short run growth rate or, more precisely, *the growth rate of the transitional dynamics* in Mankiw, Romer and Weil (1992).

6 From rates of change to levels: The Nelson and Phelps approach

An alternative approach to growth and education has its roots in the contribution of Nelson and Phelps (1966). This literature de-emphasises the role of *capital accumulation* (both physical and human) as the engine of growth and highlights the importance of the process of technological change. Within this framework "the growth rate of output will depend on the rate of innovation and, subsequently, on the level of human capital"[30] and not on the rate of change of human capital as in the previous studies[31].

Moreover, the majority of these models stress the importance of a catch-up mechanism in which human capital plays a fundamental role. In particular, it has the dual role of increasing the rate of technological innovations, as well of sustaining the rate of adoption of existing technologies. That is, technological improvement is the combination of two distinct types of activities, innovation and imitation. The first role is generally related to technologically advanced economies or economies that may be considered at the technology frontier, and can be thought as pure research. The second role identifies a convergence mechanism resulting from technology transfers among economies rather than from factors accumulation as in the case of solovian convergence and, thus, should be important for less developed economies. In this case, stocks of human capital increase the capacity to adopt and implement innovations or new technologies from more advanced countries. Thus, the latter describes the capacity to adopt new

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[30] Nelson and Phelps (1966).

[31] This assumption may lead us to include the Romer's (1990) model analysed above within the Nelson and Phelps approach.

technologies from abroad and demonstrates the possibility of a process of beta convergence occurring, that is, of a catch up process, among countries.

Abramovitz (1986) was among the first to develop the idea of technological catch up as described above, though in a non-formal setting. He shares some ideas with endogenous growth models. Firstly, as were early endogenous growth studies, his studies were motivated by the search for a pattern in the observed wide variation in cross-country growth rates of output per man-hour. Secondly, he criticises the solovian approach, since catching up may explain the observed pattern of growth, but it does not represent a movement towards a steady state trend. Those who lag behind have the potential to experience higher growth rates. In particular, as in Nelson and Phelps (1966), the larger the technological and, therefore, the productivity gap between leader and follower, the stronger the follower's potential for growth in productivity. The idea is the often cited one: learning and imitating may be cheaper and faster than the original discovery and testing. Therefore, the distance between the level of development of the leader and that of a follower may be seen in terms of a stock of technological opportunities to exploit. Abramovitz distinguishes between potential and realised catching up. The former is measured by the gap between the leader countries and the backward countries, while realised catching up is the rate of exploitation of potential catching up. Actual exploitation depends on "the diffusion of knowledge, the rate of structural change, the accumulation of capital, and the expansion of the demand"[32]. More precisely, a country should have the *social capability* or the *technological congruence* to catch up with the leader; these concepts can be broadly identified with and explained in terms of technical competence, human capital and political, financial and industrial institutions. Therefore, in describing *social capability* determinants, he identifies many factors other than human capital. Despite his influence within literature on catching up, the limitation of the Abramovitz approach has been the absence of a clear theoretical background. Below we introduce different models that explain in a formal setting how this advantage of backwardness can lead to catch up.

As in the Solow model, Nelson and Phelps (1966) describe a model where it is possible to observe a convergence process. However,

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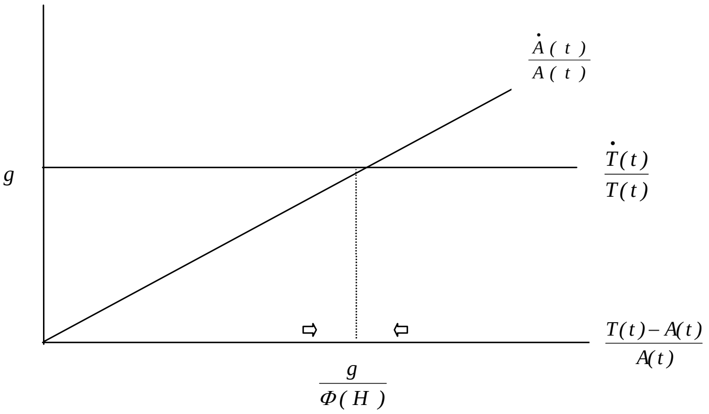
[32] Abramovitz (1986).

unlike in solovian convergence, this process is not produced by the existence of decreasing returns to capital accumulation but rather by the presence of knowledge spillovers or technology transfers. In particular, the higher the level of human capital and the larger the technology gap between the follower and the technology leader, the higher the resulting growth rate will be. They introduce the notion of an exogenously given theoretical level of technology *T*. In particular, *T(t)* can be seen as a measure of the stock of knowledge available to innovators, or as the technological frontier at time *t*, where *T* grows exogenously at a constant exponential rate, *g*. That is, $T(t)=T(0)e^{gt}$, where $g>0$. The major difference between this and the standard Solow model is described by the following equation:

$$\frac{\dot{A}(t)}{A(t)} = \Phi(H)\left[\frac{T(t)-A(t)}{A(t)}\right] \quad \Phi(0)=0, \quad \Phi'(H)>0 \qquad (22)$$

Equation (22) implies that the growth rate of *A*, the actual index of technology, is an increasing function of *H*, the level of educational attainment, and is also proportional to the gap between the theoretical knowledge, *T,* and *A*. Equation (22) also implies that the long-run growth rate of *A* is determined by the growth rate of theoretical knowledge, *g,* and that the long-run gap between *T* and *A* is determined by the level of *H*. In particular, when an economy has a positive level of *H* (exogenously determined) such that $\dot{A}/A > g$, we would observe a decreasing gap between *T* and *A* that causes a decrease in the current growth rate of *A* during the transition towards the common *g*. This process will continue until the growth rate of *A* is equal to *g*. We can interpret these results as implying the existence of a short run and a long-run Solow residual, where the former is influenced by the level of human capital while the latter is, as in Solow, exogenously determined. The Figure above describes this dynamic.



Thus, given H, in steady state the economy will grow at the rate g and will retain a constant gap between the theoretical knowledge and its actual level of technology where the equilibrium gap is given by

$$\frac{T(t)-A_a(t)}{A_a(t)}=\frac{g}{\Phi(H)} \qquad (23)$$

where A_a represents actual technology.

Equation (23) implies that the gap between T and A can be eventually reduced to zero by an increase in H, the human capital stock. Therefore, in terms of the convergence in levels prediction, the Nelson and Phelps model could be collocated within the conditional convergence literature. However, in this case the transitional dynamics at work constitute an explicit catching up process where the level of human capital plays the key role in defining the long-run gap that separates one country from the highest level of per capita income attainable.

7 The Nelson and Phelps approach: endogenous models

Even if, in comparison with Solow, the Nelson and Phelps model represents a richer framework for understanding the role of technology and human capital within the growth process, ultimately, as in Solow, the long-run growth rate of technical progress is still exogenous. Benhabib and Spiegel (1994) extend this framework considering technological progress to be endogenously determined. Therefore, they stress the endogenous nature of growth and technical progress, introducing a model in which a higher level of human capital, *H*, causes a higher long-run growth rate of technical progress, where *H* is exogenously given. In particular, they extend the Nelson and Phelps model (hereafter NP) assuming an explicit process of diffusion of technology among countries. More precisely, following Nelson and Phelps (1966), they explicitly interpret *T*, the theoretical level of knowledge, as the technology level of a leading economy. The main difference with the Nelson and Phelps model is illustrated by the following equation:

$$\frac{\dot{A}_i(t)}{A_i(t)} = f(H_i(t)) + c(H_i(t))\left(\frac{\max\limits_j A_j(t)}{A_i(t)} - 1\right) \qquad i=1,\ldots N \ (24)$$

As in equation (22), equation (24) represents the growth of total factor productivity for country *i*. Both $f(H_i)$ and $c(H_i)$ are non-decreasing functions of H_i. Thus, the growth rate of technology for a follower is given by two elements: the endogenous growth rate $f(H_i)$ plus a catch-up factor. The leader will grow at the rate $f(H_L)$, that is $A(t)=A_L(0)e^{f(H_L)t}$. This hypothesis represents the crucial difference with the previous model. In NP $f(H_i)=0$, where this assumption implies that H_i affects the growth rate of A_i only in transition. In this case, the more human capital is allocated to the R&D sector the better it will be for long-run growth. As a consequence, the dynamics among countries are here more complex, and the convergence to a common growth rate may be an extremely long process[33]. Despite the differences, both the NP model and the Benhabib and Spiegel (hereafter BS) model share the same conclusions. First, if a group of economies shares the same level of human capital we should in the long-run observe complete convergence in both per capita income and growth rates. Secondly, if we assume that H_i remain constant in each country (or that the ranking of H_i does not change across countries over time) the mechanism of technology diffusion and catch-up will at least guarantee convergence in growth rates: all countries eventually grow at the same rate as the leader, the latter acting as the locomotive. Their contribution is also of an empirical kind. In particular, their study was

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[33] This is true if, for example, we assume that f(Hi)>c(Hi).

one of the first attempts to estimate the NP approach and to distinguish between what they call the neoclassical convergence effect and catch-up due to technological transfers.

In a more recent paper, Benhabib and Spiegel (2002) examine an alternative formulation that introduces a mechanism whereby the rate of technological diffusion decreases as the distance to the leader increases. A logistic model of technology diffusion is given by:

$$\frac{\dot{A}(t)}{A(t)} = f(H_i(t)) + c(H_i(t))\left(1 - \frac{\max_j A_j(t)}{A_i(t)}\right) \qquad \text{or}$$

$$\frac{\dot{A}(t)}{A(t)} = f(H_i(t)) + c(H_i(t))\left(\frac{A_i(t)}{\max_j A_j(t)}\right)\left(\frac{\max_j A_j(t)}{A_i(t)} - 1\right) \qquad (25)$$

The difference between eq. (24) (defined as the exponential model of technology diffusion) and this logistic model is the term $\left(\frac{A_i(t)}{\max_j A_j(t)}\right)$. In this formulation, the second term of the RHS includes two contrasting mechanisms. The first is the standard catch-up mechanism, but the extra term acts in an opposite direction since the positive contribution of human capital to TFP growth tends to be smaller, the greater the distance between the leader and the follower. This implies that the usual catching-up mechanism is therefore more effective at intermediate distances from the leader, while is less effective for both very laggard and advanced countries. Therefore, the logistic model further stresses the importance of investments in human capital: countries with a very low level of human capital may become unable even to exploit their advantage of backwardness and risk being "trapped in the wrong club". That is, this model identifies an explicit 'club convergence' mechanism. Assuming that the ranking of H_i does not change across countries and over time it is possible to show that if a country *i* has $c(H_i) + f(H_i) - f(H_{leader}) > 0$ then this country will *converge in growth rates* with the leader, while if $c(H_i) + f(H_i) - f(H_{leader}) < 0$ growth rates diverge, and the laggard country will continue to further distance itself from the leader.

Again, in their study BS make an interesting empirical contribution. In general, the empirical literature on convergence clubs has probably not evolved *pari passu* with its theoretical developments. Evidence of divergence and, in particular, "twin peaks" evidence in cross country analysis that use the income distribution dynamics methodology developed by Quah[34], is certainly consistent with the club hypothesis. Nevertheless, there are very few attempts to estimate what is one of the main implications of these models, which is the presence of thresholds that cause a country to settle in either the poor or rich countries club. As observed by Azariadis and Drazen (1990) for their "…model to have sharp predictions, one would need to know the location of such human capital thresholds…and if they differ across economies".[35]. Unlike Azariadis and Drazen, they use empirical analysis to derive a point estimate for the minimum initial human capital level necessary for a country to exhibit catch-up in TFP relative to the leader economy.

Finally, we conclude this introduction to the NP approach with the Jones (1995) critique. Jones observes that the NP approach, and Romer's (1990) may be included in this framework, implies counterfactual predictions. With the exception of BS(2002), in this approach the growth rate of A, an index of technology, is an increasing function of H, the level of educational attainment. Thus, we should observe in actual data that increased research effort causes an increase in the growth rate. But this is not the case. In most developed countries human capital and research effort have increased continuously in the last decades but these countries did not experience accelerating growth rates. Thus, to reconcile theory with data it is necessary to assume some form of decreasing returns in the R&D sector, with new discoveries becoming increasingly hard as the stock of existing knowledge (or human capital) increases. Otherwise, as noted by Cannon (2000), to be consistent with the stylised facts concerning human capital, the relationship linking technology to human capital should be modified. The growth rate of A should be an increasing function of the human

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[34] See Quah (1996), (1997) and (1999).

[35] And they conclude that "In the absence of such information, the working hypothesis that emerges is that economic growth should be correlated with human investments relative to per capita income".

capital to output ratio[36] with an "augmented Nelson-Phelps approach" characterised by $\frac{\dot{A}(t)}{A(t)} = \gamma\left(\frac{H}{Y}\right)$, where γ is some function with a positive first derivative. However, in this case it becomes impossible to distinguish this augmented NP approach from Lucas, as Cannon shows that the Lucas approach implies an identical relationship between A and H/Y unless we assume that there is no variation in the ratio of human capital to output. But this, again, seems a counterfactual assumption.

8 Human capital, catch up and openness to trade

The models reviewed above describe a catch up mechanism resulting from technology transfers with human capital levels acting as the main determinant. However, these models do not describe any mechanisms that may affect the existence of transfers of technology among countries. In the models analysed so far, with the possible exception of BS (2002), where human capital needs to exceed a certain threshold for catch up to take place, transfers of technology and catch up are considered as inevitable or automatic. In contrast to this approach, other studies focus specifically on the possible existence of barriers to the adoption of technology from abroad. Quoting Parente and Prescott (2000): "The relevant question is: Why don't poor countries use the existing stock of usable technology more efficiently?" [37] Many factors have been identified as important for a country to be able to imitate and implement new technologies from abroad. We saw in section 6 how Abramovitz (1986) distinguishes between potential and realised catching up and how the latter depends on the *social capability* of a country identified with its technical competence, human capital as well as the structure of its political, financial and industrial institutions. Parente and Prescott [(1994) and (2000)] have further developed this idea. They focus in particular on the existence of barriers to the adoption and efficient use of more productive technologies, where such barriers are the primary result of country-specific policies. Aghion,

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[36] See Segestrom (1998) and Howitt (1999).

[37] "…This is why the focus of the book is on barriers to the adoption and efficient use of more productive technologies, and not on the creation of more productive technologies." Parente and Prescott (2000) page 5.

Howitt and Mayer-Foulkes (2003) focus on the effect of financial development on convergence and examine how financial constraints may prevent countries from taking full advantage of technology transfer.

However, among the factors influencing technology diffusion, trade policies have been identified as one of the main determinants, since they are a sort of necessary vehicle for technological spillovers to take place[38]. For Abramovitz (1986), trade helps to explain why we observe catching up among western economies. He identifies the years following World War II as an exceptional period, where many of the elements required for rapid growth and catching up came together. There was a group of countries with similar economies, large technological gaps but with a relatively (highly) educated labour force that opened them to trade. In general, theoretical models have identified different positive channels through which trade affects an economy's productivity[39]. Firstly, the larger variety of products and intermediate capital goods available to an open economy may enhance its productivity. Secondly, trade is usually associated with cross-border learning of a) new product designs, b) new production and organisational methods and c) market conditions. In other words, we can think of technology transfers as taking place directly through flows of ideas or indirectly through flows of goods, where both are enhanced by trade-friendly policies. All these factors increase the efficiency with which domestic resources are allocated, and enable a laggard economy to learn and imitate foreign technologies. Thus, trade-induced technology transfers may lead to cross-country convergence. However, the standard international trade literature stresses also another effect of trade. In fact, in a multi-sector framework, trade may induce a country to specialise and, thus, allocate its factors of production to specific sectors, determined by its comparative advantages. As we shall see later, if different sectors have different growth potential, this allocation effect may induce divergence instead of convergence.

The idea that trade is both 1) a necessary vehicle for

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[38] Empirical evidence of the presence of R&D spillovers through trade among different countries may be found in Coe and Helpman (1995) and Coe, Helpman and Hoffmaister (1997). More recently, the positive role played by trade in the adoption of new technologies is also stressed in Cameron, Proudman and Redding (1999) and Comin and Hobijn (2003) among others.

39 See also the discussion in Coe, Helpman and Hoffmaister (1997).

technological spillovers that bring about convergence and 2) a possible cause of divergence due to the specialisation induced by the working of the law of comparative advantage, was the subject of a study by Rivera Batiz and Romer (1991). They looked in particular at how two economies interact through trade and investigate the possible effects of competition, market size and trade policy on both long-run growth rates and steady state levels of per capita income. Human capital factors are of fundamental importance in explaining both the long-run growth rate as well as convergence. Countries will only converge towards the same level of per capita income if they have the same stock of human capital allocated to the R&D sector. Within this framework, we explicitly consider two different countries (1), home country, and (2), foreign country and their interactions through trade. If we extend the nonrival nature of technology to this two country-two sector case[40] we should observe the presence of increasing returns due to international knowledge spillovers. We focus here on the so-called *knowledge driven*[41] specification of the R&D process that represents a simple extension of Romer (1990) to open economies[42]. Moreover, we assume that countries are identical, that is, they have similar endowments and technologies. This assumption is essential since we need not be concerned with the "comparative advantage" effect that would arise in a multi-sector trade model and can thus focus on the pure scale effect of trade. Countries produce only one final good by means of raw labour, human capital and the stock of capital. To examine the main features of this model we focus on the R&D sector. In autarchy technology for both countries evolves according to the rule, $\dot{A}^{i} = \lambda H_{A}^{i} A^{i}$, with $i=1,2$, and λ, the research success parameter, is assumed constant between

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40 As shown in section 1.3, Romer's model (1990) can be reduced to a two-sector model, where the manufacturing sector includes both the final good sector and an intermediate good sector.

41 We find similar conclusions with the so called lab-equipment specification of the R&D process. In this specification of the model it is not necessary to observe a free flow of ideas for catching up to take place. It is sufficient that there be of free trade of goods. See Rivera Batiz and Romer (1991).

42 The description of the structure of production technology in the manufacturing sector is based on equations (15), (16), (17), while (19) describes the structure of production technology in the manufacturing sector in both countries.

countries. After trade this process is characterised differently. Rivera Batiz and Romer (1991) distinguish two possibilities: 1) free trade of goods with no flows of ideas and 2) free trade of goods and ideas. The first case implies there will be a level effect of trade. In fact, given this view of technology, growth rates are not affected by trade. However, free trade of goods implies that the number of machines used in each country approaches twice the number that have been produced domestically since in their pursuit of monopoly rents, researchers in both countries will avoid redundancies. Therefore, trade affects the level of output produced in both countries but does not have any effect on growth rates.

In contrast to the previous case, the second case involves a growth effect. In particular, if we define $A^{world}=A^1+A^2$, free flows of ideas imply:

$$\dot{A}^1 = \lambda H_A^1 A^{world} \qquad \text{and} \qquad \dot{A}^2 = \lambda H_A^2 A^{world} \qquad (26)$$

In this case the rate of growth of new ideas in each country depends not only on the human capital allocated to the R&D sector, $H^1{}_A$ and $H^2{}_A$, as before, but also on A^{world}, which represents the sum of the stock of knowledge of both countries. In other words, the entire stock of knowledge can be used in both countries[43] at the same time. But, if economies are identical then $A^{world} = 2A$. Therefore, eq. (26) implies the presence of knowledge spillovers and, as described, the R&D sector is characterised by the presence of a scale effect. Integration immediately raises the long-run growth rates of these countries, purely because it increases the extent of the market. In fact, economic integration with knowledge spillovers improves the efficiency of the research sector. In autarchy, we would observe redundant efforts, with one economy devoting resources to discovering a design that already exists in the other country. Finally, note that, in the long run growth rates will be equal in both countries as the technology growth rate may be rewritten as:

$$g_A^1 = \frac{\lambda H_A^1 \left(A_1 + A_2\right)}{A_1} = \lambda H_A^1 \left(1 + \frac{A_2}{A_1}\right) \qquad (27)$$

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43 And also in both sectors.

As in the Lucas (1993) model (equation (19)) the presence of the ratio of A_2 to A_1 on the RHS in (27) implies that the free flow of ideas/technology would finally equate the long run growth rates in both countries.

However, Rivera Batiz and Romer (1991) develop other interesting cases that imply different results. In particular, when countries are not similar, there is another possible effect of trade liberalisation to consider, i.e. the so-called allocation effect. This effect may explain how specialisation creates persistent growth differentials and, thus, shows when interaction among countries is not beneficial. As stated above, trade can also influence the allocation of human capital among sectors, thus affecting a country's pattern of growth. The idea is a simple one. Trade may strongly affects the reallocation of inputs of production between sectors on the grounds of comparative advantage. In these models, comparative advantage can be determined by different initial conditions. Therefore, the flow of goods that follows from the opening to trade could induce an increase in specialisation and the presence of increasing returns with specialised inputs in the manufacturing sector. In this case, we can hypothesise two different scenarios. Firstly, if trade causes H_A to expand as a result of increased specialisation, assuming the absence of knowledge spillovers among sectors, the allocation effect increases the long-run rate of growth of one country. Conversely, the allocation effect has a negative influence on growth in the other trade partner, because trade causes H_A to fall. In other words, the different allocation of basic inputs between the two sectors affects sectoral output which in turn affects long-run growth. In conclusion, it is only in the absence of the allocation effect, that the scale may turn out to be the source of large dynamic gains, uniformly distributed among countries with similar economic structures. Therefore policy implications in this case are not so simple. A country should open to trade only if the resulting allocation effects are small, and this will be true only if trade occurs among similar countries. Note that this model assumes absence of spillovers across different sectors. In this case, we may even observe two countries converging to different steady state levels of per capita income but towards the same long-run growth rate.

When trading partners have different initial conditions, Lucas (1988)[44], Grossman and Helpman (1991) and Young (1991) show the conditions under which comparative advantage produces large allocation effects and growth can be larger under autarchy.

9 Different notions of convergence and predictions of exogenous and endogenous models

The previous analysis stresses as within the growth literature there is no single concept of convergence and each possible concept of convergence is associated to dissimilar patterns. To clarify this question, we will try to summarise some of the differences below[45]. Among exogenous models, we have seen that in his influential studies Solow was probably more interested in the analysis of *within country convergence* than in its *across countries* dimension. The concept of w*ithin country convergence* should actually relate to the transitional dynamics of the solovian model, where each economy converges towards its dynamically stable equilibrium whatever its initial condition. In other words, each economy inevitably converges towards its long-run equilibrium. At first, the notion of within country convergence was associated with the concept of *across country convergence*. Indeed, if a group of economies share the same long-run equilibrium we should observe poor countries catching up with the richer ones. We have called this hypothesis *unconditional or absolute convergence* hypothesis. However, later developments showed that the presence of within country convergence will not necessarily mean that across country convergence will take place.

The *conditional convergence* literature demonstrates that there is not necessarily a unique equilibrium among countries, since each country tends to converge to its own equilibrium level of income. In particular, this hypothesis assumes that, across countries, convergence is valid only if factors affecting the long-run equilibrium are the same. Note then that, despite the possibility of different steady states, the conditional convergence hypothesis assumes that each country converges towards its own unique equilibrium. This specification is important if we want to

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[44] We are not referring to the model described in section 2.1 but to a second model always described in Lucas (1988).

[45] See Islam (2003) for a survey of the different concepts of convergence that may be found in empirical studies.

distinguish the concept of conditional convergence from the notion of *convergence clubs*. In fact, the two concepts are often assumed to carry the same meaning. Nevertheless, there is another possible interpretation, where, unlike conditional convergence, the convergence clubs hypothesis implies the possibility of the existence of multiple equilibria for each country.

Further, it is important to distinguish between *convergence in growth rates* versus *convergence in levels*. In general, we have seen that both the concepts of conditional and unconditional convergence imply that, in the long-run, each country converges towards the same, exogenously given *growth rate*. Therefore, it is sometimes said that conditional convergence models entail *convergence in steady state growth rates* of per capita income, while they do not assume *convergence in steady state levels* of income.

Finally, the sections above show endogenous growth models characterised by both *divergence* and *catch up*. Divergence implies that each country converges towards its own long-run level of income and its own long-run growth rate. Conversely, the catch up hypothesis implies convergence in levels and growth rates but must be distinguished from standard solovian convergence, since the first is due to technology transfers while the latter to capital accumulation.

In other words, a process of *convergence in steady state levels across countries* may be due to these different mechanism:

1. Convergence due to capital accumulation;
2. Convergence due to technology transfers (catch up);
3. Convergence due to both (1) and (2).

Conversely, evidence of the absence of *convergence in steady state levels across countries* may be theoretically explained by models implying:

- Divergence (or absence of convergence in both steady state levels and growth rates across countries);
- Conditional convergence (with the presence of convergence in steady state growth rates across countries);
- Convergence clubs (with the presence of convergence towards different steady state growth rates depending on the club).

Moreover, this survey shows as the prediction of convergence/divergence in both exogenous and endogenous growth models depends on initial assumptions since the same model may describe both mechanisms. In particular, it shows that many growth models could actually produce convergence or divergence with human capital playing an important role in generating these mechanisms.

For example, in exogenous models, assuming countries share the same technology, preferences and human capital steady state levels (and possibly, other determinants of the steady state) the transitional dynamics of the solovian model imply convergence will occur. Conversely, when countries are dissimilar, the Solow model predicts conditional convergence, since in this case transitional dynamics cause different countries to converge towards different steady state levels. A similar mechanism may be found in Nelson and Phelps (1966): assuming countries have the same stock of human capital, these models predict convergence due to technology catch up. Conversely, when countries have different human capital endowments, this model implies what we have called conditional catching up: laggard countries still enjoy the advantage of backwardness and still converge towards the same (exogenously given) long-run growth rate, but they never reach the steady state level of per capita income of the most technologically advanced economies.

Within endogenous literature, models are more complex and the classification becomes more puzzling. In general, endogenous growth studies suggesting the possibility of convergence in per capita levels of GDP among different countries usually assume the existence of knowledge spillovers from rich to poor countries that eventually generate a catching up process. Moreover, to be able to explain convergence, these models need to assume that different countries are somehow "similar". In particular, many models assume that we would only observe convergence (and also convergence in growth rates) when different countries share the same stock of human capital. In other words, when countries are not *similar*, these models predict divergence.

10 Summary

Among the determinants of the growth and convergence processes identified by the theoretical literature, human capital is certainly one of the most important. This paper offers a selective survey of the more recent contributions of the theory of human capital and growth. In particular, our aim is to provide the necessary link between the theory on growth, convergence and human capital and the empirics of convergence. Summarising with a play on words, we might conclude that during the last fifteen years there has been a convergence of ideas between endogenous and exogenous models with respect to the convergence hypothesis where human capital plays an important role. Despite the still theoretically important difference between models that assume exogenous versus models that assume endogenous long-run growth rates, both theories predict that a mechanism of convergence is possible, but it will only be so among similar economies. In particular, most theoretical literature assumes that similar levels of human capital are fundamental for catch up to take place. Therefore, both theories are currently able to explain a stylised fact of the empirical literature on growth, namely the observed convergence among groups of homogeneous countries and the absence of convergence when large and heterogeneous data sets are introduced. This observation explains why, with current econometric techniques, it is not possible to discriminate endogenous versus exogenous models by simply using a convergence regression.

In other words, given these theoretical developments, simple convergence tests cannot be considered fully supportive of one theory against the other. However, this conclusion does not imply that empirical investigations on convergence across economies have become an uninteresting issue in growth literature. It implies rather that this literature is now called to new challenges as the three fundamental questions of any convergence analysis "Are poor countries catching up with the richer ones? How quickly? And, ultimately, what are the determinants of this process?" are of primary importance for human welfare and, thus, undoubtedly represent crucial issues for growth economists. In spite of their importance, clear-cut answers are not available yet in the literature.

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