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Endogenous growth theory twenty years on: a critical assessment

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Abstract - Endogenous growth literature emerged from dissatisfaction with one result of the neoclassical growth model: the independence of the growth rate from the saving ratio, which is seen as a variable subject to policy influence. There are at least three generations of EGT models: the old one of the sixties; the new one of the late eighties; and the most recent one, from the second half of the nineties. EGT models of any vintage fall into one of two fields: neo-Solovian (or semi-endogenous models) or fully endogenous models. Models from the sixties would generally fall into the first class and for good reasons. Indeed, most of the early generation of fully endogenous models from the late eighties fell under the 'Jones critique' (Jones 1995b), which pointed out some of the difficulties of these models. The most recent models have found various ways to avoid those problems. It is shown that these *stratagems* were anticipated by Marvin Frankel in the sixties and by Lucas in the eighties. One suspects that these devices arose in order to fix the theory rather than from, say, some ex-ante empirical observation (which is often provided ex post). More importantly, this paper indicates some problems common to all vintages of EGT models, beginning with the Cambridge capital theory critique, and suggests some alternative routes for growth analysis outside neoclassical theory.

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Introduction[*]

From the point of view of economic theory, one main 'key' to the origins of endogenous growth theory (EGT) can be found in the dissatisfaction that emerged in the late fifties with one aspect of the neoclassical growth model of Robert Solow (1956), that is the independence of the economy's (steady state) growth rate from the saving ratio, i.e. the ratio between the (full employment) saving supply and output, a variable that is subject to policy influence, e.g. by tax treatment favourable to saving and investment. Earlier work pointed out the difficulties met by both earlier and new generations of endogenous models in trying to relate growth to saving rates (Cesaratto 1999a, 1999b, Serrano and Cesaratto, 2002). In the meantime the literature on EGT has been enriched by further models and empirical verifications that have endeavoured to overcome those difficulties. From a vertical, temporal perspective, three generations of EGT models can be distinguished: the seminal one of the sixties; the newer one of the late eighties; and the most recent generation, of the second half of the nineties. From a horizontal, analytical viewpoint, EGT models can be divided in two fields: those that defend the Solovian approach (semi-endogenous models) and those that attempt to depart from it (fully endogenous models).

A 1962 paper by Marvin Frankel, published six months after Arrow's better known learning-by-doing model, may help corroborate this interpretation of EGT.[1] Frankel observed that in the Harrod-Domar model, which uses a production function $Y = aK$ (where a is the output-capital ratio), the rate of economic growth depends on the saving ratio s, according to the well known Harrodian formula $g = s/v$, where $v = 1/a$. Economists, he argued, "have found such models attractive because of their relatively simple structure, because of the emphasis they give to capital accumulation as an 'engine of growth' – an emphasis with deep roots in economic thought – and because of their pragmatically satisfying results" (1962, p.996). However, he continued, "the production function $Y = aK$ has nothing interesting to say about resource allocation or income distribution. Worse than this, as a general statement of the resources required in production, it is positively wrong, as any one-factor production function must be" (ibid). In contrast, the Cobb-Douglas production function, although more satisfactory from the point of view of "resource allocation or income distribution", leads, in a growth context, to a growth rate that depends on the rate of growth of the labour force and where the investment rate (that in this marginalist framework

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depends on the saving rate) does not affect either the aggregate growth rate or, through productivity growth, that of output per worker (ibid, pp.996-997). Labour productivity growth could be introduced into the model, but its sources remain "exogenous" in the specific sense that it does not depend upon the endogenous saving choices of the community or of a representative agent (it is widely recognised that to get the sense of the debate on neoclassical growth theory it is irrelevant whether the saving rate is taken as given, or whether choices are analysed through a Ramsey model. The latter would just add maths but no substance, see e.g. Mankiw, 1995, pp.279-280). The same dissatisfaction with regard to this specific result of Solow's neoclassical growth model was expressed by other authors in those pioneering years (cf. Cesaratto, 1999a, 1999b for the references). We shall see that Frankel's solution to the dilemma he posed anticipated in its essence that provided by the very last vintage of EGT authors.

Since the beginning of the most recent endogenous growth literature, dissatisfaction with Solow's model has taken another, more empirical turn. According to Solow's model, as long as countries have access to the same pool of technical knowledge, they would converge to the same rate of per capita income growth (absolute convergence, in the EGT jargon), although countries with a higher savings rate would enjoy a higher per capita income (conditional convergence). The empirical evidence is that of persisting differences in the international growth rates, or a lack of absolute convergence. Were the access, or the rate of growth, of technical knowledge unevenly distributed among nations, then the theory would predict different rates of growth. However, this would just add to the early frustration: not only does the saving rate not have an effect on the growth rate, but it is also irrelevant in explaining the different regional technological endowments and dynamics.

We shall start by asking whether the relationship between the investment (saving) ratio and the growth rate is just a theoretical supposition – albeit one 'with deep roots in [traditional] economic thought' - or whether it is also a proven empirical fact. In this respect we shall first consider the recent controversy regarding the empirical evidence of this relationship in section 1. It seems that most of the results confirm the relationship - an outcome unfavourable to Solow's prediction of its absence in the secular equilibrium. Solow's model did leave a space for this relationship, however, in the transition from one secular equilibrium to another. In section 2 we will therefore look briefly at some recent defences of Solow's model, based on the length of the transition towards the steady state. Given the frailty of this defence, we shall then look in section 3 at proper EGT models recalling Frankel's and Arrow's seminal and archetypal models, not for the sake of history of thought, but since new and recent EGT has not moved far beyond the stage set by those earlier models, apart from by adding further theoretical and empirical considerations to lean in favour of one or the other of the representative approaches displayed on that podium. More specifically, the archetypal models posed some problems that have been inherited by the new EGT models. These troubles have not gone unnoticed, due in particular to the influential contributions of Charles Jones – the 'Jones critique' (after Michl, 2000, p.185), which is illustrated in section 4. Not surprisingly, in the light of the difficulties, Jones argues in favour of sticking to the Solow's traditional growth framework. The most recent generation of EGT models have countered Jones' criticism by introducing another battery of *ad hoc* assumptions which, however, are also reminiscent of the archetypes, as we shall point out in section 5. After having discussed Jones' neo-Solovian perspective in section 6 and 7, in the last section we will deal with a methodological defence of neoclassical growth modelling, according to which one should not be too critical of the analytical or empirical limitations of single models, but rather acknowledge the insight provided by each of them. In view of this indulgent remark, we will advance three basic objections to all neoclassical growth theory - exogenous and endogenous - based, *inter alia*, on the non-conventional Sraffian and Keynesian criticisms of mainstream economics.

1. Econometric growth theory

Earlier and more recent presentations of growth theory, including those of Solow (1970) and Jones (2002), have focused on explaining Kaldor's six famous 'stylized facts' of economic growth, which are so well known, it is pointless to recall them here. Two additional stylised facts that growth models may aim to explain can be added to this list, although they are more controversial: a positive correlation between the investment (saving) rate, that is the ratio between investment (saving) and output, and the rate of economic growth, either in aggregate (g_Y) or per-capita terms (g_y). Not surprisingly, those who disregard these two additional stylised facts include supporters of the Solovian view. The debate has thus focused on the empirical relationship between the investment rate (I/Y), taken in a closed economy as a proxy of the saving rate (s),[2] and per capita growth rate.[3] We shall see that most contributions find an empirical correlation between I/Y and g_y. Defendants of Solow's model, however, have found various ways to shield his results.

In an earlier study, Hill (1964) examined the abovementioned relationship in a group of industrialised countries over the period 1954-62 and found a significant correlation (particularly strong for the larger economies) between I/Y and g_Y, as well as with g_y especially when investment in machinery and equipment was considered. More recently, this kind of investment has been the subject of some much quoted papers by De Long and Summers (1991, 1992), who also found that productivity growth was positively associated with high investment in equipment during the Second World War II period, in a large sample of rich and developing countries.[4] Abel (1992, p.200) assigns to De Long-Summers' finding the status of a 'new stylised fact'.

In their influential paper, Mankiw, Romer and Weil (MRW, 1992; see also Mankiw, 1995) show that Solow's model, once 'augmented' to include 'human capital', is able to explain a good deal of the variations among countries in per capita income *levels* (not growth rates). They propose a production function such as:

$$Y_t = K_t^{\alpha} H_t^{\beta} (A_t L_t)^{1-\alpha-\beta}$$

where H represents 'human capital' and A the traditional exogenous technical progress (hereafter we shall omit the time subscript from the equations), and $\alpha + \beta < 1$. According to MRW this function would lead to good predictions of the variations on Solovian lines, that is those based on differences in the saving rates and in population growth, without recurring to exogenous (or endogenous) technical change.[5]

These results concern the differences in the levels of per capita income, but not the growth rates. In this respect MRW acknowledge the *leitmotiv* of EGT, that 'countries with a higher saving rate grow persistently faster and that they will not converge to a same steady state growth path even if they have the same technological endowment' (ibid., p.421-422). Recall that, according to Solow's model, countries with similar saving rates and technology would still show different growth rates when starting from different initial per capita capital (or income) levels, although they will in the long run converge towards their common growth rate. Taking advantage of this result, Mankiw (1995, p.278) maintains that: "The inability of saving to affect steady state growth (…) might appear inconsistent with the strong correlation between growth and saving across countries. But this correlation could reflect the transitional dynamics that arise as economies approach their steady states'. In addition, MRW (1992) approvingly quote Barro (1989) who argues that there is little evidence of a convergence across countries in the sense that poorer countries (those starting with a lower per capita capital endowment) do not generally tend to grow faster and catch up richer countries. They introduce, in this regard, the concept of *conditional convergence*, thereafter included in textbook expositions, whereby countries do not converge towards a common growth rate, but each converges towards its own: '[T]he neoclassical model predicts that each economy converges to its own steady state, which in turn is determined by its saving and population growth rates' (Mankiw, 1995, p.284). Thus, they conclude, growth rates can differ both (i) as countries are in 'transitional dynamics', and this may explain the relationship between *s* and g_y; and (ii) because they converge towards different secular paths, and this is might be explained by the differences in *s* and population growth (*n)* (MRW, 1992, p.423).[6]

Jones is critical of De Long-Summers' results, arguing that whereas the total and equipment investment share of GDP has increased in the main economies, (per capita) output growth rates 'have fallen, if anything, over the post-war era' (Jones, 1995b, p.508). Jones' idea seems to be that although De Long-Summers may be right to envisage a cross-country correlation between I/Y and g_y, it is not, however, true that an increasing I/Y leads to a higher g_y for each country over a period of time.[7] Jones, in turn, is criticized by Li (2002), who conducts time-series regressions for 24 OECD countries over the period 1950-1992 and for five industrialised economies over the period 1870-1987, finding that total investment is positively related to growth in more than half of the cases. Jones' outcome would be different since he relies on durable investment alone and because the focus on the U.S. would be misleading (ibid, p.97). Temple (1998, p.59) also concludes that 'equipment investment is often weakly correlated with growth in the OECD, but strongly so in a large group of developing countries'.

Comparing their results to those of De Long-Summers, Blomstrom, Lipsey, Zejan (1996) find that the 'long term relationship' between I/Y and g_y was 'due more to the effect of growth on capital formation than to the effect of capital formation on growth', as argued by De Long-Summers (ibid, p.269). This does not seem to conform to the conventional saving-led explanation of investment. Vanhoudt (1998) is not surprised by the results of Bolmstrom et al., since in Solow's model a rise in the saving ratio *s* results in a sudden rise in the growth rate, followed by a decline towards its steady state level. It is therefore not surprising that statistical tests suggest a negative effect of saving on growth: 'Since the mentioned Granger causality test control for lagged growth, it is not surprising that positive Granger causality from saving to growth does not show up' (ibid, p.78). Blomstrom receives some support from Attanasio, Picci and Scorcu (2000, e.g. pp.198-199),[8] while a more ecumenical outcome is attained by Podrecca and Carmeci (2001), according to whom the causality can go in both directions. A halfway position is also held by Madsen (2002), whose results for 18 countries over the period 1950-1999 tend to show that investment in equipment does cause growth, whereas non-residential investment in buildings and structures is caused by economic growth (this appears perplexing to those who see investment in equipment as demand-induced and construction works as an autonomous component of aggregate demand). In their survey of the literature on growth econometrics Kenny and Williams (2001, pp.8) tend to trust studies that see investment as the most robust variable related to economic growth, with causality running from growth to investment.

Bernanke and Gurkaynak (2001) present empirical results that are strongly in favour of a positive influence of I/Y on g_y.[9] The two authors also show that the saving rate (I/Y), as well as population growth, is positively correlated with total factor productivity (*tfp*), contrarily to the prediction of the Solow model, that *tfp* should be exogenous to factor accumulation. This would show that endogenous mechanism, saving or fertility decisions, have external or scale effects such to determine endogenous rather than exogenous growth. In their comments David Romer and Mankiw reiterate their thesis that economies are not necessarily in their steady state.

While it seems that most of the empirical outcomes are in favour of a positive association between the investment (saving) rate and g_y (e.g. Mankiw, 1995, p.302), much effort has been made on both fronts to check this correlation by seeing whether other variables could play a more significant explanatory role. However, opinions tend to converge on the idea that these exercises are of limited value since they are highly sensitive to the variables included or excluded, the time span, the country considered and other factors. Thus we hear Solow say that: 'the main fact about these empirical studies' is that '*they are not robust*' (1992, p.78, italics in the original). Similarly, Mankiw (1995, pp.307-308) states that: 'Using these regressions to decide how to foster growth is …most likely a hopeless task. Simultaneity, multicollinearity, and limited degree of freedom are important practical problems for anyone trying to draw inferences from international data. Policy makers who want to promote growth would not go far wrong ignoring most of the vast literature reporting growth regressions'. Other sceptical views include Kenny and Williams (2001), Rodrik (2005), who also quotes some other critical surveys, and Rodriguez (2008). Finally, Felipe and McCombie (2005) point out the weak *theoretical* foundations of the econometric work by MRW and others, recalling the Cambridge criticism of the aggregate production function (see below). We may therefore stand with Mankiw (1995, p.308) when he argues that: 'Basic theory, shrewd observation, and common sense are surely more reliable guides for policy'. Let us therefore go back to 'basic theory'.

2. Transitional dynamics

As seen above, MRW and other economists adjust Solow's model to the empirical results, which are generally favourable to a positive association between I/Y and g_y, by relying on sluggish 'transitional dynamics'. In the earlier days of neoclassical growth theory a fast time-convergence towards the steady state was regarded as validating the description of secular growth provided by Solow, while presently (making a virtue of necessity) a slow convergence rate is seen as supporting his model, insofar as during the transition the saving (investment) rate, and the policies that affect it, do influence g_y. It is well known that the seminal contribution on the speed of convergence was made by Ryuzo Sato (1963), who showed that convergence was a slow process. A relevant assumption that affects the speed of adjustment concerns the capital share (α). As is known, given the neoclassical growth equation $\dot{k} = sf(k) - (n+\delta)k$ (standard notation), the secular equilibrium is where $\dot{k} = 0$, that is when $sy = (n+\delta)k$. Bearing in mind the standard graphical representation of Solow's model and using a Cobb-Douglas production function, the curvature of the $sy = sk^{\alpha}$ function hinges on the value of the capital share α: given, for example, an upsurge in s that shifts the sy curve upwards, the higher α is, the further away the new stationary level of k will be from the initial k_0.[10] As seen above, MRW rely on 'human capital' to raise the capital share to two-thirds of output in order to obtain a slower convergence rate. An analogous suggestion was put forward by Conlisk (1966, p.553 and passim) who noted: 'Human capital is accumulated by diverting resources from other uses; and the amount of human capital accumulated depends on the amount of resources diverted. Hence, logically, human capital should be included in the factor *K*, and not in the factor *L* …If human capital is included in *K*, then a substantially larger value of α is called for than if human capital is not included in *K* ' (see also Ramanathan 1982, pp.245-248, to which we refer for a broader discussion). More recently, King and Rebelo (1993) have argued that convergence is a fast process, in thus ruling out a role for policies in Solow's model. The idea is that if an economy is hit by a shock that reduces its capital stock, the marginal product of capital will be very high. Rational savers will react by increasing their saving supply, thus accelerating accumulation and convergence towards the steady state. According to King and Rebelo this result is not favourable to the Solow model, in so far as 'transitional dynamics …cannot account for an important part of sustained cross-country differences in rates of economic development' (ibid., p.929). Slower convergence speeds could be obtained, but 'even if one makes agents very unwilling to substitute over time', at the price of a very high initial marginal product of capital, of the order of 500% or more (ibidem).[11]

Therefore, in summary, different authors' conclusions are often strongly dependent upon the analytical functions they select and upon the value attributed to the parameters used, while empirical tests do not provide unequivocal results (this is not surprising, since we cannot empirically distinguish between transitional and secular growth rates). While this might be defined as a cheap criticism, it is worth noticing the switch of position in the Solovian camp: from seeing fast convergence as a confirmation of the practical relevance of the secular neoclassical path, to defending a lethargic gravitation as showing the relevance of policy in a Solovian context. Given the host of special assumptions that EGT models have to make in order to bring endogenous growth home, neo-Solovian economists have a point in sticking to their well established framework that emphasises the duration of the transitional dynamics. However, two issues remain. A long transition process presupposes a high capital share obtained by merging the accumulation of 'human capital' with that of physical capital, which would only inflate the insurmountable troubles that neoclassical theory has to overcome in measuring the value of the aggregate physical capital stock. Secondly, as we shall see in sections 6 and 7, neo-Solovian authors present explanations of the growth sources that may also be considered unpromising. Let us therefore turn to the EGT proper debate.

3. Arrow, Frankel and the AK model

Which strategies are open to neoclassical growth theory to endogenise growth? It is well known that according to Solow's model the secular growth rate is given by: $g_Y = n + h$, where n is the growth rate of the labour force and h represents (labour augmenting) technical progress. One possibility is to endogenise n, and a number of authors have explored the relationship between fertility choices and growth. The exploration of a possible relationship between saving choices and technical progress is another opportunity pursued by most of the EGT literature. Clearly, for neoclassical economists the saving rate is a main determinant of capital accumulation, but because of the decreasing marginal productivity of capital (for a given a labour supply), a higher saving rate could not persistently raise the accumulation rate which, in the end, has to adjust to the exogenous rate of growth of the workforce (in physical or efficiency units). On the other hand, it was this adjustment that permitted Solow to conclude that full employment was the long run rule, overturning the contrasting conclusions of the Harrod-Domar (HD) model – which, however, as cleverly pointed out by Frankel, offered a saving-led growth formula. Notably, substitutability amongst 'production factors' was ruled out by the HD model.

Frankel (1962) proposed a new growth model capable of preserving the distributive role of the Cobb-Douglas production function, but in which the growth rate depends on the investment rate, as in the HD model. The trick, which has became a sort of *cliquet* for all endogenous growth theory to date, was to craft a relationship between the saving rate and technical progress. This has been done in recent literature, following Arrow, Phelps, Uzawa and other authors from the sixties (Cesaratto, 1999a, 1999b), by linking labour productivity growth to externalities from (the endogenous) capital accumulation, or by relating it to surrogate saving decisions such as those associated with the resources devoted to R&D or education, which also imply the diversion of resources from present to future consumption. A short cut has instead been taken by the economists who have just come back to HD via the so-called *AK* model - not surprisingly, in view of Frankel's abovementioned account of the neoclassical growth theory dilemma. Frankel's model is particularly intriguing in this regard.

As we have recalled, given a production function $Y = AK^{\alpha}(HL)^{1-\alpha}$, where H represents labour-augmenting technical progress, the growth rate of the economy is given by the summation of the growth rates of the labour force n plus that of the labour-augmenting technical progress h. (It is known that the stability of the neoclassical growth model implies that technical change assumes this form. This is, of course, a further limitation of this model, cf. e.g. Serrano and Cesaratto, 2002, p.9). Let us then assume, with Frankel, that H depends on per-worker capital endowment, that is:

$$H = (K/L)^{\gamma} \qquad [1]$$

what Frankel calls the 'modifier', where he assumes $\gamma = 1$. In order to preserve competition, technical change takes the form of an externality due to (per capita) capital accumulation. As Frankel (1962, 1004) put it: 'If one enterprise alone were to add to its capital, it would encounter diminishing returns to that factor. But when all do so, all are beneficiaries of compensatory shifts in the modifier'. Suppose then that the saving rate s rises. According to Solow's model K/L would consequently rise and so would H. Technical progress is thus clearly 'endogenous'. Substituting $H = K/L$ in the production function yields $Y = AK$ (Frankel used 'a' instead of 'A'). Logarithmic differentiation gives $\hat{Y} = \hat{A} + \hat{K}$ (where the 'hat' stands for growth rate). Assuming there is no exogenous technical progress, that is $\hat{A} = 0$, and since $\dot{K} = sY = sAK$, or $\hat{K} = sA$, then $\hat{Y} = sA$. Interpreting A as the inverse of the capital-output ratio v, we get $\hat{Y} = s/v$, that is Harrod's well-known warranted (endogenous) growth equation. Per capita growth is: $g_y = s/v - n$.[12]

Frankel therefore succeeds in retaining both the neoclassical production function, with its 'nice' distribution properties, and Harrod's growth equation, with its 'deep roots in economic thought'. Of course Harrod's and Frankel's models are only superficially similar. [13]

Six months before Frankel's paper came out, Arrow (1962) had published another, more famous, article on endogenous growth that, however, failed to deliver endogeneity (we refer here to a simplified version attributed to Sheshinsky, 1967). The technical progress function (hereafter TPF) selected by Arrow was:

$$H = K^{\gamma} \qquad [2]$$

where Arrow sets $\gamma < 1$. The idea, not dissimilar to Frankel's own, was that the experience from capital accumulation brought about an externality in the design of new machinery and, as a result, in the efficiency of the labour force. Substituting in the production function $Y = K^{\alpha}(HL)^{1-\alpha}$, taking the log derivatives and imposing the balanced growth condition whereby $\hat{Y} = \hat{K}$, we obtain an aggregate growth rate equal to:

$$g = \frac{n}{1-\gamma} \qquad [3]$$

This is clearly an exogenous rate that depends on the growth rate of the labour force. It is not an encouraging result, although Arrow defended it by arguing that it “seems to be that under full employment, the increasing labor force permits a more rapid introduction of the newer machinery” (1962, p.166). Note that in this model the production function shows increasing returns to scale but, nonetheless, growth remains exogenous. This is not surprising given that $\hat{H} = \gamma\hat{K}$: that is capital accumulation is not sufficient to generate a parallel increase in the labour efficiency, so growth will run out of steam without an exogenous growth force.[14]

Why did Arrow not assume $\gamma \geq 1$? Suppose that $\gamma = 1$. The production function would then look like $Y = AKL^{1-\alpha}$. Supposing there was no exogenous technical change ($\hat{A} = 0$), the growth equation would look like: $\hat{Y} = \hat{K} + (1-\alpha)n$. A positive labour growth rate ($n > 0$) would clearly lead the economy outside a uniform secular growth rate (e.g. Ramanathan, 1982, pp. 95-96, Serrano and Cesaratto, 2002, p.17).[15] As rather harshly commented by Cesaratto and Serrano (2002, p.18): ‘Therefore if the labour force grows we see here that, rather than accumulate capital more quickly to seize the externality, what rational agents should do is to save very little and generate a demographic explosion, which in any case need not be too big because any positive rate of growth of the population quickly leads the economy to growth rates that tend to infinity! The result is even more disputable than that of the learning by doing model in which, due to the increasing returns of the economy, a constant rate of growth of the labour force generates a positive per capita growth rate. The reason for this even less reasonable result is that the learning by doing model still retains the decreasing returns to capital, which guaranteed that a constant positive growth rate of the population failed to accelerate the growth rate continually, since there was a counteracting tendency for the capital-output ratio to increase.’

One can now appreciate why the particular shape of Frankel’s modifier made it possible to preserve the gravitation towards uniform secular growth even with $\gamma = 1$ and $n > 0$: while with $\gamma = 1$ the externality from capital accumulation is sufficient to determine a parallel increase of labour in efficiency units, a positive growth in physical labour has no net effect on growth for the reasons explained above.[16]

As we know, the famous *AK* model of new EGT can be regarded as an Arrow model with the strong assumption $\gamma = 1$ and $n = 0$ (Romer, 1987, and Rebelo, 1991, are usually quoted in this regard, cf. e.g. Jones, 2002, 162-163). In this case we return to the HD model again, since $\hat{Y} = \hat{K}$ and $\hat{K} = sA$, where $A = Y/K$, that is $\hat{Y} = sA = s/v$. Solow’s trenchant comments were: ‘The essence here is that there is no primary factor, labor has disappeared’, and ‘It is rather amazing. …modern literature is in part just a very complicated way of disguising the fact that it is going back to Domar, and, as with Domar, the rate of growth becomes endogenous' (1992, p.18 and 32 respectively).

4. The new EGT and the 'Jones Critique'

From a slightly simplified viewpoint, new EGT has taken two roads: one has been to follow Arrow's contribution to link increasing returns to capital accumulation in a way summarised by the just mentioned *AK* model. The other has been to see the source of EG in R&D (or education) efforts and it is currently seen as prevailing, '[p]hisical capital has been pushed to the periphery', as Jone and Romer put it (2009, p.4). The second route was anticipated in the sixties by Phelps, Shell, Uzawa and others (cf. Cesaratto, 1999a, 1999b; Cesaratto and Serrano, 2002). The problems with both these directions are similar, so it is not really necessary to deal with them separately. In order to grasp this similarity let us look at Charles Jones' exposition and criticism. Jones' theoretical work along neo-Solovian lines has perhaps been the most influential in the last decade or so, paralleling the earlier empirical contribution by MRW (indeed, Jones' first influential contribution was also empirical).

In a number of papers Jones (1995a; 1995b; 1999 2003) summarized a number of 'R&D based models' (defined as 'R/GH/AH models' after the contributions by Romer, 1990; Grossman and Helpman, 1991; Aghion and Howitt, 1992) through the following equations:

$$Y = H^{\sigma} L_Y \qquad [4]$$

$$\dot{H} = \delta H^{\phi} L_H^{\lambda} \qquad [5]$$

$$L = L_Y + L_H \qquad [6]$$

$$L_H = s_H L \qquad [7]$$

The production function [4] implies that there are constant returns to scale to labour, the only physical and 'rivalrous' input, and increasing returns to labour combined with the 'nonrivalrous' input called 'ideas' represented by the term *H*. Increasing returns are measured by the exponent σ. These would be due to the fact that knowledge can be repeatedly used in production, 'the use of an idea by one person does not preclude… the simultaneous use of the idea by another person' (Jones, 1999, p. 139). Our attention will mainly focus on equation [5], the TPF to which we shall return frequently. Equation [6] suggests that labour can be allocated either to direct production (L_Y) or to indirect "knowledge" production (L_H). In equation [7] the term s_H indicates the share of total labour that is "saved" and allocated to the knowledge sector. R/GH/AH models typically assume $\phi = 1$ and $\lambda = 1$. Applying these assumptions to the TPF [5],

$$\hat{H} = \delta s_H L \qquad [8]$$

The resulting growth rate is endogenous as it hinges upon the term s_H that indicates the community's choice between using labour for direct production or for the production of 'ideas'. The trouble with equation [8] is that a positive growth in the scale of the R&D labour force, due *cet.par.* to a positive growth rate of the labour force, will correspondingly raise the productivity growth rate, which good sense would lead us to reject. Jones has called this the 'strong scale effect' (or 'growth scale effect').[17] In a particularly influential paper, Jones (1995b) showed that while the U.S. per capital growth rate had been approximately constant over the period 1880-1987 (1.81 % annually), the number of R&D scientists had increased five-fold. Similar results apply to other OECD countries. Therefore, Jones concluded: '[t]hese models predict that growth rates should be proportional to the level of R&D, which is clearly falsified by the tremendous rise in R&D over the last 40 years' (1995b, p.513). The parallel with Arrow's (1962) model is clear (Jones 1995a, fn.10; Cesaratto 1995): as much as the assumption of $\gamma = 1$ in Arrow's TPF led that model into trouble in that it could not accommodate a positive growth rate of the labour force, in the present 'class' of R&D models the assumptions $\phi = 1$ and $\lambda = 1$ lead to similar difficulties.

5. Modified modifiers

In an exemplarily clear paper Jones (1999) summarised his criticism to the R/GH/AH models and extended it to another 'class of models' - the Y/P/AH/DT models (after Young, 1998; Peretto, 1998; Aghion and Howitt, 1998; Dinopolous and Thompson, 1998) that have tried to save endogenous growth without running into the 'scale growth effects'. These models can be summarised as follows. Suppose that output *Q* is composed of a variety *B* of consumption goods *Y*, all produced in the same amount, so that $Q = BY$. (Following Peretto and Laincz (2006) each product is manufactured by a monopolistic firm but this aspect is not relevant for the line of criticism we are pursuing here). Recalling equation [4], each product is supposed to be produced using labour L_Y and a stock of 'ideas' *H*: $Y = H^{\sigma} L_Y$. In turn, the variety B depends on the population level, according to a function like $B = L^{\beta}$. Finally, and this is the key assumption, the stock of ideas evolves according to the TPF:

$$\hat{H} = \delta \frac{L_H}{B} \qquad [9]$$

The rationale of having the term *B* in the TPF is that population growth has two effects. On the one hand it has a positive effect on the production of ideas through a larger amount of L_H labour, while on the other hand it also leads to a greater variety of products, so that the amount of L_H per product line does not increase. As Peretto and Laincz (2006, p.264) summarise: 'The early models posit R&D technologies that feature proportionality of productivity growth to *aggregate* R&D inputs. In contrast the Y/P/AH/DT models shift the focus from the whole economy to the individual product line as the main locus of innovation. In such a disaggregated framework it is straightforward to dispose of the scale effect. A process of development of new product lines fragments the economy into submarkets whose size does not increase with population'. As above, the amount of labour devoted to the generation of ideas depends on the endogenous preferences of the community regarding the shares of L_Y and L_H respectively: $L_H = s_H L$ and $L_Y = (1 - s_H)L$. The TPF [9] can be therefore written as:

$$g_H = \delta s_H L^{1-\beta}.$$

The *aggregate* output growth rate is given by: $g_Q = g_B + g_Y$. The first term on the right hand side is $g_B = \beta n$, and the second term $g_Y = \sigma g_H + n$ (from equation [4bis]). *Per capita* growth will then be: $g_q = \beta n + \sigma g_H + n - n$, or:

$$g_q = \beta n + \sigma \delta s_H L^{1-\beta}.$$

Assuming with the Y/P/AH/DT models that $\beta = 1$, we obtain:

$$g_q = n + \sigma \delta s_H \qquad [10]$$

we see that growth does depend on the endogenous preferences of the community, expressed by the term s_H, and is positive even with zero population growth. There are no growth scale effects since the term L has disappeared from the growth equation.

At this point attentive readers, having registered that what distinguishes the Y/P/AH/DT's TPF from R/GH/AH's one is the term *B* as the denominator, which with $\beta = 1$ is equal to *L*, will have noticed that this is the same distinction that differentiates Arrow's and Frankel's TPFs (figure 1 below presents a summary of the models).

Jones' (1999, pp. 142-143) criticism points to the *ad hoc* nature of the assumption $\beta = 1$. Indeed, with $\beta < 1$ the number of sectors would grow proportionally less than the population, so that the model would still exhibit growth scale effects. With $\beta > 1$ the number of sectors would grow proportionally more than the population, which has a negative effect on productivity growth as a rising L_H workforce would be spread over an even more rapidly rising number of sectors. Asymptotically, growth would then still depend upon (exogenous) population growth. This kind of criticism, focusing upon the value of the "exponents" of the TPFs, is the standard critique raised against new EGT since its inception (Cesaratto, 1999b, p.788 for the references). Peretto and Laincz (2006, pp.271-272) concede that the 'proportionality between the number of firms and employment [...] might induce one to conclude that this class of models requires another "knife-edge" condition in that one needs to assume that the number of firms is exactly proportional to population'. The justification would be that 'if the economy is subject to an increase in population, the growth rate jumps up because the larger labor force is initially absorbed by the existing firms that thus become larger and do more R&D. Over time, new firms enter and draw workers away from existing firms. As a result of this fragmentation process the growth rate gradually slows down and eventually reverts to the original steady-state value independent of population. In other words, in the long run the increase in population is fully absorbed by the number of firms, leaving firms' size and thus growth unaffected' (ibid., p.273).

Whatever the empirical justifications, we want to emphasize the striking but so far overlooked analogy between Frankel's and Y/P/AH/DT's modifiers (Jones only quotes Frankel in passing, 2002, p.162, fn. 5). It has also not yet been noticed that they are, in turn, both similar to the modifier proposed by Lucas (1988) in another seminal paper of the new EGT (Serrano and Cesaratto 2002, pp. 22-24). In Lucas we find a TPF like:

$$\hat{\mathrm{H}} = \vartheta z$$

where $z = L_H / L$ is the share of labour devoted to education, R&D or the like. Notably, the difference from equation [8] is that L appears as the denominator, as much as in Frankel's equation [1] and Y/P/AH/DT's equation [9]. Like the latter TPFs, Lucas' TPF does indeed fit well into Solow's model without perturbing its main features (Lucas 1988, p.19-20).[18] Paraphrasing Serrano and Cesaratto (2002, p.23): in these models the increase of efficiency does not depend on knowledge accumulation itself, but on knowledge accumulation per worker (in strict analogy with the Frankel modifier that enabled efficiency to grow with the quantity of physical capital per worker), or per product, or per firm, provided that the number of products and/or firms rises with the population.[19]

6. Neo-Solovian models

Having thus pointed out both the problems with the R/GH/AH models (growth scale effects) and with Y/P/AH/DT models (*ad hoc* assumptions in order to avoid the growth scale effects), Jones proposes a model that avoids the growth scale effects, although at the price of sacrificing endogenous growth. Let us reconsider equation [5]: $\dot{H} = \delta H^{\phi} L_H^{\lambda}$. Jones assumes $\phi < 1$ and $\lambda < 1$. His explanation of these assumptions is as follows (e.g. Jones 1995a, pp.764-766; 2002, pp. 99-100). The simplest TPF inspired by P. Romer would be: $\dot{H} = \bar{\delta} L_H$, that is the number of new 'ideas' is proportional to the number of individuals engaged in R&D activities. The term $\bar{\delta}$ measures the rate at which new ideas are caught. $\bar{\delta}$ can in turn be seen as a function of the ideas already discovered: $\bar{\delta} = \delta H^{\phi}$. Now, if $\phi > 0$ this means that the generation of new ideas is a positive function of the stock of earlier ideas – that is, past discoveries open the way to new ones, the 'standing on shoulder effect' - whereas $\phi < 0$ would correspond to the 'fishing out' case, in which new discoveries are arduous and achieved over time, and the most obvious but groundbreaking discoveries are made earlier. If $\phi = 0$, the two facts compensate each other precisely. Jones (1995a, p.766) argues that $\phi > 0$ is a plausible assumption, whereas the value $\phi = 1$ assumed by R/GH/AH would be an arbitrary condition. Finally, the exponent $\lambda < 1$ in equation [5] suggest that there might be duplications in R&D.

Given equation [5] and the assumptions $\phi < 1$ and $\lambda < 1$, the growth rate of the stock of ideas is given by:

$$\hat{H} = \frac{\delta L^{\lambda}}{H^{1-\phi}} \qquad [11]$$

Along a balanced growth path the growth rate of ideas, g_H, should be constant. This implies that, taking the logarithmic derivatives of both sides of equation [11], the growth rate of ideas must be: $0 = \lambda \hat{L}_H - (1-\phi)\hat{H}$. It is reasonable to assume that the number of idea hunters does grow at the same rate of population, that is $\hat{L}_H = n$, so that we have:

$$g_H = \frac{\lambda n}{1-\phi} \qquad [12]$$

In Jones' parlance (2002, p.106), this model would show 'weak scale effects' or 'level effects': similarly to Solow's model the saving rate (here represented by s_H) influences *y* but not *g*. The model would thus show 'the somewhat surprising implication that this eliminates the long-run growth effects of policy'. With $\phi = 1$, as noted above, policy would become effective, but 'this assumption generates the counterfactual prediction that growth rates should accelerate over time with a growing population'. The similarity of equation [12] to Arrow's growth equation [3], and to the conclusions drawn on that basis (see above section 3), is striking, as fully acknowledged by Jones (e.g. 1995a, fn.10, p.768), so that the origin of his 'surprise' is mysterious.

7. Millenary explanations and the Mozart effect

According to equation [12], as well as in equation [3], productivity growth depends on population growth. Jones fervently defends this sort of causality (e.g. 2002, pp.103-104). After all, he argues, humans are the ultimate fuel of the process of research, and it should not be surprising that faster population growth has a positive effect on the generation of new ideas. Jones' favourite quotation is from Phelps (1968, pp.511-512), according to whom: 'One can hardly imagine …how poor we would be today were it not for the rapid population growth of the past to which we owe the enormous number of technological advances enjoyed today. …If I could re-do the history of the world, halving population size each year from the beginning of time on some random basis, I would not do it for fear of losing Mozart in the process'. One might certainly argue that halving the German speaking population of the eighteenth and nineteenth centuries would entail the risk of losing many of the greatest musicians ever, but this could be done to other populations of comparable size, in that or other periods, without much fear of losing outstanding talents. Ruling out genetic factors, something therefore seems to be missing from this population-driven mechanics of growth.

Jones (2004, pp. 48-56) discusses these possible objections at some length. Looking at different regions of the world in the very long term (12,000 years or so), some relationship seems to emerge between population size at the beginning of the period and their technological rank measured at the year 1000/1500 or so (before European explorations ended the isolation of various areas). The rationale of this correlation (ibid, p. 56) would lie in the following virtuous circle: at the beginning a small population could only generate ideas over long periods of time. Low productivity levels and subsistence kept the population constant. However, once one idea was produced subsistence levels and fertility rose, leading to a larger population. This in turn facilitated the production of new ideas over shorter lapses of time, and so on and so forth (see also Jones and Romer, 2009, pp. 10, 14, 24-25).

A scholar quoted in this regard is Jared Diamond (1997) who is, however, totally misinterpreted by these authors. In his famous book, Diamond argues that some environmental advantages, in particular the availability of suitable vegetable and animal species, made possible to some luckier populations some 10 thousand years ago to realise a food surplus and to become "large, dense, sedentary, stratified populations" (1997, p.87 and passim). More precisely, *the realisation of food surpluses* permitted these populations to grow more rapidly and to support a political class that, at the price of the exclusive control of the surplus, provided organisational, institutional, and military leadership. Moreover, the surplus allowed for the sustenance of those who Adam Smith would have called 'philosophers or men of speculation, whose trade it is, not to do anything, but to observe everything' (1776 [1979], p.21). It is clear from Diamond that population growth is not and cannot be the original source of "ideas" since both division of labour and population growth both logically and historically originate from the emergence of food surpluses. This is enough to show the closeness of Diamond to the Classical economists' surplus approach, as well as his distance from the poor growth mechanics of EGT.

8. Accomplishments and limitations of EGT

Various classifications of the neoclassical growth literature are possible. In view of the interpretative approach taken in this paper, it is perhaps suggestive to organise them as in figures 1 and 2 according to the two archetypal models by Arrow and Frankel, respectively. We have located the neo-Solovian economists (semi-endogenous models) in figure 1. These economists limit the policy impact over the transition periods and attribute a questionable role to population growth in explaining not only aggregate growth (which sounds quite odd to a truly Keynesian economist), but even productivity growth. The other groups of models obtain fully endogenous growth and policy effectiveness over long-run growth, although at the price of special assumptions such as the knife-edge value in the exponents of the TPFs, zero population growth or the use of the various *ad hoc* modifiers *a là* Frankel. These modifiers look a sort of *post hoc ergo propter hoc* devices: since the model would work with a specific modification, then reality is also thought to work that way.

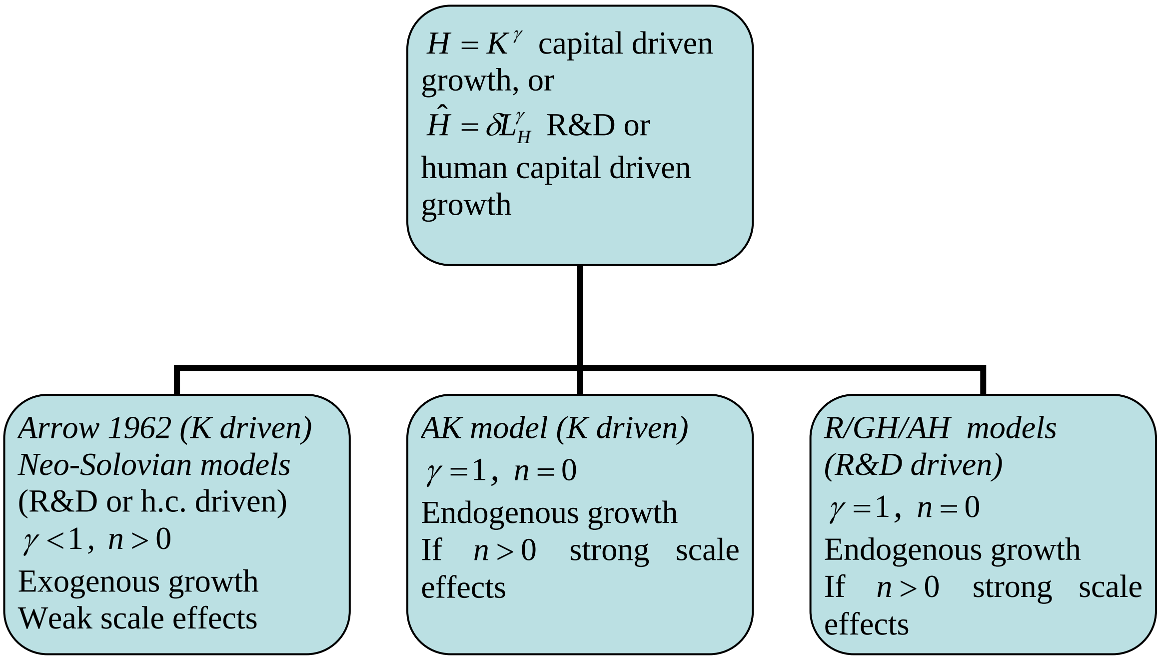

Figure 1 - Arrow's tradition

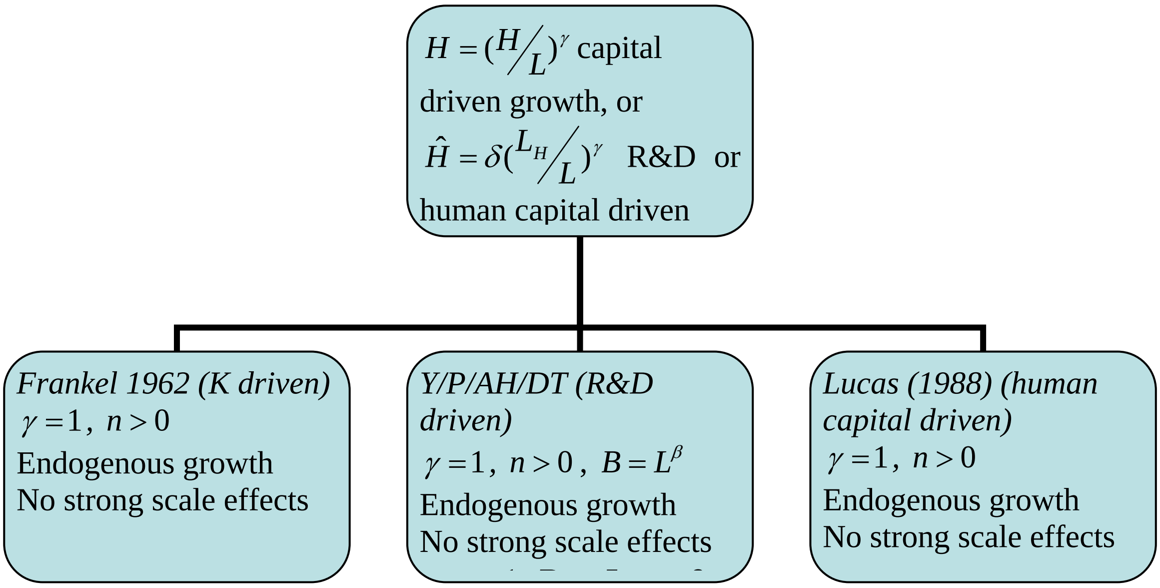

Figure 2 - Frankel's tradition

This leads us to the stance of senior economists such as Frank Hahn (1994, p.1), who has been quite critical of the 'backward reasoning' employed by proponents of the new EGT in selecting their TPFs: the description of reality is bent to fit a steady state growth model, and not the other way round as it would seem natural to do. In this respect, in their survey of applied growth theory Kelly and Williams (2001, p.10) quote Mark Blaug to argue that 'nearly all econometric work on growth has been "playing tennis with the net down": attempting simply verification rather than falsification – proving that the evidence does not contradict the theory, rather than that the evidence proves the theory'. Laincz and Peretto (2006, pp.265 and 285), for instance, contend that data and econometric tests are *consistent* with the theory, that is to say that the theory is not explaining some apparent stylised fact, but is not contradicted ex post by the evidence.

In contrast to these critical views, a sensible defence of EGT has been advanced by Temple (2003, p.501 and passim) in an stimulating article. He maintains that too much attention is paid to long run 'balanced' growth, whereas we do not really know empirically whether the economy is moving along in a steady state or, perhaps, converging to it. Balanced growth requires the very peculiar knife-edge assumptions recalled above, even in the exogenous Solovian framework (ibid, pp.499-500). In this context Temple quotes a point made by Jones (2004, pp.60-64) - that what is required for steady state growth is *linearity* in the TPFs, be it of the exogenous Solovian variety or of the endogenous species.[21] Once we are not obsessed with balanced growth, Temple concludes, these knife-edge assumptions my be taken at their face value - as simplifying hypothesis to make theoretical explorations that provide different views of reality: 'growth models are often best seen as laboratories for thought experiments, and apparently competing frameworks can form a useful complement to one another' (Temple, 2003, p. 508). This is a sensible position and one that may also explain the sense of accomplishment that, after all, mainstream growth economists display with regard to the past twenty years of the revival of growth theory. Of course, if we pass from academic results to the capacity to provide practical policy suggestions, the glass would appear half empty (to be generous), as Temple (ibid, p.501) or Mankiw (1995, p.309) are next to admit (see also Kenny and Williams, 2001, pp.15-16). Indeed, the glass may appear to be completely empty if we take into account at least three shortcomings common to all neoclassical growth literature.

First, neoclassical growth theory, in any of its ramifications, is the natural victim of the capital theory critique (e.g. Garegnani 1970). This critique shows that there is no reason why an increase, say, in the saving rate should lead to the adoption of more capital intensive techniques, thus casting doubt on the mere theoretical existence of a stable neoclassical growth path. With the demise of the belief in a demand function for capital that is negatively elastic to the interest rate, confidence in the long run working of Say's Law is also undermined. This trust exposed neoclassical growth theory to its *second* shortcoming, that is its neglect of the role of aggregate demand in long run growth. The decisive role of aggregate demand as the key to economic growth in both short and long run periods is of course one *differentia specifica* of non-orthodox schools (Garegnani, 1992; Cesaratto et al., 2003). At least, they should. Non-conventional authors such as Kurz and Salvadori (cf. e.g. 1998) have emphasised the continuity of EGT with the 'classical tradition' presenting 'classical' *saving-led* endogenous growth models. This is not the place for a full assessment of this approach, so I refer the reader to Cesaratto (2006) where I criticised this class of models albeit in another context.

Indeed, the role of aggregate demand should not be restricted to the explanation of investment decisions according to the old acceleration hypothesis, but should also be used to explain technical change, according to the Smithian insight that the division of labour depends on the size of the market. Elsewhere I contrasted this view to Schumpeter's emphasis on the 'innovative entrepreneur', which I found a poor and overly 'subjective' explanation of technical change (Cesaratto 1996).

This remark leads us to the *third* shortcoming of neoclassical growth theory, which is more marked in its 'Schumpeterian' versions, that is the idea that technical change is almost exclusively led by market competition. The 'almost' is justified by the role assigned by EGT to tax incentives to private R&D and education that, in turn, rather mechanically originate technical progress. In both the recent and less recent history of capitalism, however, market competition has never played an autonomous role in fostering economic and technical progress, but has always been assisted by State intervention. This is considered by neoclassical neo-institutionalism in the limited sense of the State as protector of property rights and competition. In the history of the discipline there was probably full awareness of the complex intertwining of Power and Plenty that is behind any episode of economic development only at the Mercantilist age (Viner 1948; Medeiros 2001). Unfortunately this tradition only survives at the margin of conventional economics (Cohen, 2008) and will deserve future exploration.

Notes

[1] I first mentioned Frankel's contribution in Cesaratto (1995). Frankel's forerunning paper was also 'rediscovered' by Cannon (2000) who, however, does not place Frankel's original contribution in the context of the troubles met by the old and new EGT.

[2] After the empirical results of Feldstein and Horioka (1980), some scepticism has emerged amongst neoclassical economists regarding the influence of foreign capital on domestic investment.

[3] The fact that neoclassical economists focus upon only one of the two additional stylised facts should not come as a surprise. As known, the aggregate growth rate is given by the summation of the growth rate of the workforce plus labour productivity growth. In a neoclassical full-employment model, the workforce grows at a natural demographic rate *n*. That the aggregate growth rate should adjust to the (exogenous) growth rate of the workforce irrespective of the investment (saving) rate is

something that the neoclassical *Weltanschauung* cannot cast doubt upon, so the discussion centres on the rate of per capita (or per worker) income. By contrast, for non-conventional economists it is the aggregate growth rate that is more important, since they believe that market economies do not, on average, have full employment. Productivity growth is also important, of course, to measure the competitiveness of a country and as a source of technological unemployment (see Cesaratto et al., 2003).

[4] These authors attribute great importance to differences in the price of equipment goods between countries. A high saving ratio associated with a low price of equipment would generate high productivity growth (e.g. De Long and Summers, 1991, pp.484-485). Yet the causes of the low price of capital equipment are not clearly explained by these authors. They reject an accelerator explanation of growth, whereby it is growth that leads to high investment shares, because in their view this would be associated with a higher equipment price, rather than with the lower price shown by their data (e.g. De Long and Summers, 1991, pp.473-474; 1992, p.176).

[5] Without 'human capital' the traditional model would only partially explain those inter-country variations (Mankiw 1995, pp.282-284). The reason for including 'human capital' is that without it Solow's model would still explain the variations mentioned well, but with an income share α accruing to capital over two-third (against a usual value of one third). A high value of α would be justified once the returns to educated labour are assimilated to capital returns. The economics of the model is that a higher 'human capital' component would lead to a higher per capita income and saving supply; the latter does in turn lead to a higher per capita income (MRW, 1992, p.417; Mankiw, 1995, p.290). Although in their model there is a touch of endogenous growth, in the sense that the accumulation of 'human capital' is an endogenous decision, the model is not able to generate endogenous growth (that is the endogenous decisions to accumulate physical or 'human' capital do not affect the rate of growth; the model would become a fully endogenous model with $\alpha + \beta = 1$ (in this case the production function becomes $Y_t = K_t^{\alpha} H_t^{\beta}$ similar to the one adopted by the endogenous models reviewed in sections 3 and 4). We put 'human capital' in inverted commas given the difficult to define nature of this magnitude (cf. Steedman 2001 who sheds doubts about the way broad notions such as 'knowledge' or 'ideas' are given a scalar measurement by this literature).

[6] These authors do not attribute much importance to international differences in technological endowments to explain the divergences in per capita income level growth across countries, although this sounds strange if we compare the actual techniques in use in poor and rich countries, respectively. They seem to explain this by arguing that although the production function is roughly the same in all countries, since 'knowledge …travels, around the world fairly quickly' (Mankiw, 1995, pp.300-301), the specific technique - say using either spades or tractors - in each country depends on its own stage of growth: 'To use the neoclassical model to explain international variations in growth requires the assumption that different countries use roughly the same production function at a given point in time. …change [of techniques] should be viewed as a movement along the same production function, rather than as a shift to a completely new production function' (ibid., p.281). The neoclassical growth literature never ever mentions that the acquisition of superior foreign technology and education is a costly process. Once this is considered, the 'foreign liquidity constraint' - the necessity to collect enough international currencies to finance the acquisition of embodied and disembodied foreign technology - would appear as one main obstacle to economic growth.

[7] Charles Jones was still a student at MIT when (in his Siena doctoral lectures on growth) Solow (1992, p.85) approvingly mentioned Jones' forthcoming results that, he reported, were obtained 'before [Jones] had read De Long-Summers' paper'.

[8] It is impressive how much Keynesian thought has been forgotten by these economists, who explain the 'dynamic link running from growth to investment' by arguing that '[h]igher growth

might drive saving up, leading in turn to higher investment' (ibid, p.183). Elsewhere they admit, and their results do not exclude, a 'Granger causation running from investment to saving'. However, they continue: 'the exact mechanisms at work are hard to spell out in detail, if an increased demand for capital goods stimulates saving – maybe through interest rate effects or the endogenous development of the financial instruments that permit the mobilisation of saving – saving might adjust to investment' (ibidem). No mention is made by these authors of concepts such as the investment accelerator or the Keynesian multiplier (for a Keynesian mechanism of adjustment of saving to investment in a long run framework cf. Garegnani 1992).

[9] As MRW (1992), Bernanke and Gurkaynak use the Penn World Tables, a multicountry data set is used by Heston and Summers (MRW over the years 1960-1985, BG 1960-1995).

[10] The intuition provided by Ramanathan (1982, p.246) is that when α is high and capital relatively more important in production, if capital (saving) becomes more abundant, the scarce factor (labour) takes more time to limit growth (the marginal product of capital falls more slowly): 'the exogenous labor input …bottlenecks the growth rate. …if the share of capital is larger, then firms can substitute capital for labor and thus evade the bottleneck for a longer period of time'. As noted by Jones (2002, p.159), in the limiting case of $\alpha = 1$ and constant labour (the case of the AK model, cf. below section 3), the production function is a straight line and the marginal product of capital never falls, so that we have an endless transition - a 'perfect' endogenous growth situation.

[11] Solow (2000, pp.164-165) seems to applaud to King-Rebelo's point about a *fast* convergence rate, probably because he regards it as a confirmation of the practical relevance of the secular growth rate predicted by his model. Rather inconsistently, in his Siena doctoral lectures (1992, p.82) Solow argued that De Long-Summers' results regarding the influence of the investment rate on growth might have been due to a *slow* convergence path, so as not to disconfirm his own model.

[12] Frankel (1962, p.1003 and 1005, footnote) maintains that it is reasonable to assume that $s/v > n$.

[13] In particular, the source of endogenous growth in Harrod derives from the fact that growth is constrained from the capital side only – at least assuming that labour is abundant and that there is no possibility of factor substitution in production. That is $\hat{Y} = \hat{K}$, where $\hat{K} = sY/K$. The source of endogenous growth in Frankel lies in the technical change function. Look at the production function $Y = AK^{\alpha}(HL)^{1-\alpha}$. Suppose for a start that L is constant (n = 0) and normalised to 1. A raise in s is such that K and H increase by the same proportion and so Y. There are no decreasing returns to the variation of K (for a given L) because the variation of K implies a corresponding variation of H, that is of the amount of labour in efficiency units, so that K and HL can proceed, so to speak, in parallel. Therefore there are no decreasing marginal returns to capital accumulation, because labour efficiency units accumulate *pari passu* with the capital stock, so that no change arises in the scarcity of the relative factors (the source of marginal decreasing returns). Suppose then that $n > 0$. On the one hand this positively affects output Y, but on the other hand it also correspondingly negatively affects H; the net effect is nil, and capital accumulation and the amount of labour in efficiency units HL can still proceed in parallel. Not surprisingly, labour growth does not affect the aggregate growth rate as much as in Harrod.

[14] In other words, there are still marginal decreasing returns to capital. What it is necessary to generate endogenous growth is that decreasing, (marginal) returns to capital or to any other factor that can be accumulated are kept at bay. This can done by assuming very strong increasing returns to scale, or by specific functions that govern the accumulation of the 'accumulable factor': capital, 'knowledge', or 'human capital'.

[15] Intuitively: if $H = K$, then $\hat{H} = \hat{K}$ and since in balanced growth $\hat{K} = n + h$, then $\hat{H} = n + h$. But then, since in balanced growth output grows at the summation of population growth n and labour

productivity growth $\hat{H}$, we have $\hat{Y} = n + (n + h)$. As a result, given the propensity to save, we get $\hat{K} = n + (n + h)$ and $\hat{H} = n + (n + h)$, so that we obtain $\hat{Y} = n + [n + (n + h)]$ and so on. The growth rate increases to infinity.

[16] By comparison with the preceding fn, if $H = K / L$, $\hat{K} = n + h$ but $\hat{H} = (n + h) - n$, so that $\hat{Y} = n + h$. A similar 'modifier' was advanced by Conlisk (1967): see Cesaratto (1995), fn. 24 and (1999b), pp.251-252.

[17] Strong scale effects are defined as follows: 'In models that exhibit "strong" scale effects, the growth rate of the economy is an increasing function of scale (which typically means overall population or the population of educated workers)' (Jones 2004, p.38). We have 'weak scale effects' when 'the level of per capita income in the long run is increasing in function of the size of the economy' (ibid). The problems with the R/GH/AH models and with some of the earlier generation of EGT models were also pointed out at various points in my 1995 paper. Of course these problems were well known before Jones (and, *si parva licet*, me).

[18] Jones (1995a, p.762-63; 2004, pp. 42-43) does not regard Lucas' TPF as an appropriate solution, since the idea that the absolute number of R&D employees matters for technical progress would be lost in Lucas' TPF, in which only the share of the total workforce really matters (we shall come back to the relevance of the absolute number of scientists, which Jones calls the 'Mozart effect'). In addition, the empirical evidence would be that in the U.S. a threefold increase in the R&D effort (*z*) would have not been followed by a parallel increase in the secular growth rate (the same would apply to other countries).

[19] Alternatively the similarity between Lucas and Frankel can be seen by writing $\dot{H} = jzLe$, where $e = H/L$ measures the 'per capita' amount of knowledge. The endogenous rate of technical change would be $\hat{H} = jz$.

[20] This is also the opinion of Peretto and Laincz (2006, p.269) who respond to Jones' criticism of their model by arguing that that there is little empirical evidence in favour of a positive correlation between population growth and income per capita growth. In this regard they quote a survey on demographic and economic change which concludes that '[n]o empirical finding has been more important to conditioning the "population debate" than the widely-obtained statistical result showing a general *lack* of correlation between the growth rates of population and per capita output'.

[21] Exogenous technical progress also requires a linear TPF, e.g. $m = \dot{H}/H$. Suppose the TPF were $\dot{H} = mH^{\gamma}$; with, say, $\gamma > 1$ the growth rate would be progressively increasing, since the term H on the right hand side of the equation $\dot{H}/H = mH^{\gamma - 1}$ would be persistently rising.

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