The Endogenous Growth Theory:
A Lakatosian Case Study in Program Adjustment

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Introduction: the issue

Any lively research program in economics undergoes evolution due to internal and external factors. This is what occurred to neo-classical growth theory, as worked out and expressed since the fifties. For almost two decades, from the middle 1950s through the late 60s, growth theory, or rather, the effort to work out formal models to explain the vigorous economic development of industrialized economies, was the dominant theme in (macro) economic research. In the 70s, the situation suddenly began to change. The interest in growth theory waned in a few years and this topic, with few exceptions, disappeared from the macroeconomist's research agenda for more than a decade. Two reasons can be put forward to explain such a change. First, from the early 70s onwards, the business cycle attracted great attention in the economic profession. The instability of the industrialized economies shifted the focus from long-run to short-run macroeconomic phenomena. Secondly, and more importantly, the attempts to expand the Solow-Swan model in richer directions, as in the multisectorial or vintage models, for example, failed to improve its heuristic power, but, on the contrary, highlighted the gap between the ascending order of mathematical sophistication and real economic phenomena (Britto 1974, 1360).

In the mid 80s, growth theory experienced a remarkable revival and became once more a very active area of macroeconomic research. Starting from the seminal articles by P. Romer (1986) and R. Lucas (1988), the research took a precise direction in the sense that, in contrast to the earlier neo-classical view, it called for an endogenous determination of technological change, which means an endogenous determination of the sources of growth. Two closely-linked points characterize the new approach in "endogenous growth" literature. The first is the departure from the usual assumption of diminishing returns of capital, or, more generally, of the accumulated factor. In the more recent approach, long-run growth is made possible by the effect of increasing returns to scale due to some form of externality, which guarantees that marginal productivity in the factor accumulation does not go to zero when these factors are accumulated.

The second novel aspect that is worth considering is the will to give a coherent microeconomic foundation for economic growth, so that all behavioral relations must be derived explicitly from the axioms of rational action and the maximization process. By way of example, Romer observes that "technological change arises in large part because of intentional actions taken by people who respond to market incentives" (1990, 72). In this approach, the term "endogenous" means based on optimising the behaviour of the firm, in contrast with the previous Solowian view in which economic growth was driven by exogenous technological progress.

This article will concentrate on the treatment of endogenous growth by neo-classical growth theorists. It uses the Methodology of Scientific Research Programs (MRSP) proposed by Lakatos (1970) in order to explain why the endogenous growth approach was not incorporated into the neo-classical growth program until the late 1980s, although the essential features were well known during the 1960s. The thesis which results is that the new growth theory may be seen in terms of an extension of the neo-classical research programme to incorporate theoretical elements which previously fell beyond its scope.

MRSP was introduced into economics methodology by S. Latsis (1972) and in the following decades was used intensively as a way to study the nature of progress in many branches of economics: R. Weintraub (1979, 1984, 1984) in a series of papers analysed the development of general equilibrium analysis, M. Blaug (1975, 1980) focused on the Keynesian revolution, R. Maddok (1971) considered the rational expectations approach as it emerged from its monetarist root, and R. Backhouse (1988) adopted a Lakatosian perspective to appraise contemporary macroeconomics, to cite but a few examples. Even if the MSRP is not without its critics among economic methodologists (for example Hands 1990), it remains a useful framework within which to analyse the evolution of economic ideas.

The development of the neo-classical growth research program

In this section and in the following, we will try to characterize neo-classical growth theory in Lakatosian terms. The scheme requires a brief exposition of the main elements of Lakatos' methodology and their interpretation, based on *Falsification and the Methodology of Scientific Research Programs* (1970).

Lakatos started from the idea that in order to reconstruct the dynamics of scientific theories it is not enough to consider a single theory but rather a sequence of theories which, if taken together, make up what Lakatos calls a "research programme". For Lakatos, whose methodological standpoint is well rooted in a conventionalist view of science in the school of Popper, a research programme is made up essentially of two elements: a hard core with its protective belt and its positive heuristic. A research programme, in his view, starts with some methodological decisions taken by researchers who promote the programme: these decisions aim to identify those hypotheses which are to be considered essential, which cannot be changed, according to a methodological choice and which make up the core of the programme. Alongside this there are a number of peripheral hypotheses which may be modified and which make up the protective belt. The core hypotheses are viewed as unchangeable by those who take part in the research programme and anomalies are incorporated into the programme not by changing the unrenouncable hypotheses but rather by modification of the auxiliary hypotheses, the initial conditions and the observation set.

In the second place, each research programme is characterised by a set of methodological rules: some of these (the positive heuristic) indicate what the researcher should do, whereas others (the negative heuristic) are injunctions concerning what not to do. The negative heuristic has a purely protective role and aims to prevent the hard core's propositions being changed and tested. The positive heuristic outlines development directions of the research programme and consists of a set of suggestions concerning how to change or modify some aspects of the research programme which may be refuted. In Lakatos' view, the positive heuristic plays a determinant role in the development of the research programme. The theories, as Lakatos observes, are submerged in an ocean of anomalies and counter-examples and it is up to the positive heuristic to define a strategy to deal with them through ongoing adaptation and modification.

A research programme is not a static entity but evolves over time: new facts are discovered and new problems arise which require changes in the protective belt and the positive heuristic. For Lakatos, research programmes may be *progressive* or *degenerating*. If a research programme is progressing well, if it leads to the discovery of new facts which are successfully explained on the basis of the programme elements, then there is a *progressive problem shift*. The progressive shift of the programme involves the introduction of hypotheses which modify the positive heuristic so that a programme which is in a degenerating phase is now able to deal successfully with anomalies and explain new facts. If, on the other hand, the programme is running out of steam and the new hypotheses added are ad hoc hypotheses, and thus partial adjustments which do not increase the empirical content of the programme, then the programme undergoes what Lakatos calls a *degenerating problem shift*. The programme may then be ousted by a rival programme which is vital and progressive.

Finally, a research programme may not be considered an isolated entity but, as a rule, there are many research programmes competing with one another and the researcher is required to choose, as the need arises. Lakatos' method requires, as a norm, that researchers abandon degenerating programmes in favour of progressive ones. But this criterion is not easily applied for each research programme goes through alternating phases and a research programme which might at the moment appear seriously compromised may in the future prove to be more progressive than rival programmes. The elimination or setting aside of regressive programmes requires not only that the old programme be no longer able to offer adequate replies to emerging anomalies, but above all that a new programme emerge able to compete with the existing one and offer new and broader content than its predecessor.

To illustrate the essential features of the neo-classical research program it will be easier to divide the exposition into two parts. In this section, we will consider the short-run dynamic model. The main result is that the basic model shows only transitional dynamics, i.e. dynamic behaviour that emerges from the steady state. In the next part, we shall see under which hypotheses it will be possible to extend the model to encompass long-run phenomena and obtain a theory of economic growth.

The best illustration of the guidelines and the most important results of the neoclassical growth programme remains Solow's essay, *Growth Theory: An Exposition*, 1970. From this can be gleaned how the neo-classical hard core[1] organised around the following propositions:

N1) Growth theory concerns itself with the conditions under which an economy grows in steady-state conditions.

N2) The dynamics of an economic system is determined by the accumulation of the factors of production.

N3) The supply side of the economy is described by an aggregate production function which allows complete and immediate substitutability of factors of production, which typically are labour and capital.

N4) The aggregate production function is characterised by constant returns to scale on the factors employed (the production function is linear and homogenous).

These propositions are not the same in nature. The first two are wholly general conditions which can be found also in research programmes other than the neo-classical. N1) was introduced by Harrod (1939) who was the first to pose the problem of formalising the way in which an economic system can reach a position of long-run steady growth. For Harrod, the idea of steady-state growth is nothing other than the adaptation to the dynamic case of the notion of equilibrium which

[1] Following Backhouse we consider only the proposition which are relevant for growth theory. For a complete presentation see Remenyi (1979) and Waintraub (1985)

we find in statics, even if this move represented "a real revolution in mentality". Proposition N2) goes even further back in the history of economic thought and translates the idea of the classical authors according to which economic growth appears essentially as a circular process: in order for the economic system to expand, it is necessary for a part of output to be saved and used to increase the stock of factors of production, primarily, capital. Economic growth and factor accumulation are two processes which, from Adam Smith on, largely coincide.

Propositions N3) and N4) are the aspects typical of the neo-classical approach. N3) makes it possible to endogenise the capital - labour ratio, which in Harrod was constant. Solow's criticism of Harrod is that the latter chose to study long-run phenomena using short-run technical tools, such as that which requires technical coefficients of production to be constant. N4) comes from the theory of distribution and requires that output be shared among the factors according to their marginal productivity. These two propositions, on the basis of which the capital-labour ratio may vary and its variation is regulated by the quantity of available capital for the economy, enabled the young Solow to provide a brilliant solution to the problem left unsolved by Harrod of instability on the economic growth path, an instability brought about by the divergence between warranted rate of growth and natural rate of growth.

The positive heuristic of the neo-classical research programme can be illustrated by the following propositions:

EP1) Build models where the agents optimise.

EP2) Build models which allow predictions on the equilibrium states.

EP3) Show up the logical supremacy of allocation of resources over distribution.

EP4) The dynamics of the economic system is determined by the accumulation of physical capital.

EP5) Every model is a metaphor, and therefore an imperfect and approximate description, of real phenomena.

The first two propositions are typical of the neo-classical view, in the broadest sense, and do not require any particular attention. The idea that also macroeconomic phenomena should be based on the optimising behaviour of the single economic agent is one of the essential points of the neo-classical view, even if in the case of growth theory it is a research strategy rather than a preliminary assumption. EP3) expresses the fact that dynamic allocation of resources is determined purely by technology and by the initial stock of resources. Solow here shifts radically from previous tradition which considered growth and supply as two fundamentally inter-dependent processes and profit was the driving force in economic growth. EP4) is representative of the deeply-held conviction, shared by those studying economic growth in the '50s and '60s, that economic development was driven by the accumulation of capital and so by industrialisation. In this perspective, capital accumulation became the key variable to watch to explain economic growth. This does not mean that the importance of other factors was not recognised, but simply that they did not have any great weight in theoretical elaboration (Arnt 1990).

It is worth taking a closer look at EP5). From the methodological point of view, this hypothesis is a typical defensive move often found in the neo-classical literature, above all during the '70s when the research programme was in a degenerating phase. It served to protect the models from criticism of poor realism and irrelevancy on the empirical level which were often levelled at the neo-classical approach. Granted every economic model is an abstract description which represents only a few aspects of reality, this was even more the case in dynamic analysis in which the contrast is even greater between the complexity of real phenomena, determined by a variety of factors, and the need to have them fit into simple and effective logical schemes. For supporters of the neo-classical programme, steady-state analysis is but the first step towards a more realistic and complete theory of economic development, a resolution, however, which remains to be put into practice. The consequence of this methodological assumption is that one must not be too severe in judging a theoretic model and that the model is to be judged mainly on its internal coherency and on the plausibility of its underlying ideas rather than on its empirical relevance (Mirrlees 1974).

We can formalise Solow's dynamic model as follows. Assuming that the production function is linear and homogenous, with a totally general expression $Y = f(K, L)$, and differentiating with respect to time, we get the following expression, $\dot{Y} = f_k(K, L)\dot{K}$. If savings are given by a constant portion of income, so that the ratio $\dot{K} = sY$, holds, we have the following differential equation which describes the growth rate of output

$$\frac{\dot{Y}}{Y} = sf_k(K, L) \qquad 1)$$

Equation 1) clearly shows how the growth rate of income, and of other economic elements in a balanced growth regime, depends on the marginal productivity of capital, assuming that the average propensity to save is constant. As marginal productivity of capital is an inverse function of accumulated capital stock, in the long run the growth rate of the economy runs to zero and the economy reaches a steady state. In the neo-classical model, the guiding idea is pro capita capital accumulation and thus the capital deepening of productive processes. The increase of capital deepening translates into increased output per worker but with decreasing returns to scale. As capital becomes more abundant with regard to labour, the real interest rate will tend to zero and consequently also the growth rate will tend to zero. If some regularity conditions are attained to on the function of aggregate production, the so-called Inada conditions, the economy will reach a steady state which will prove to be globally stable; that is, the economy will tend to have static values whatever the point of departure. In its basic version, the neo-classical model has a form of dynamic behaviour only outside the steady state. This is a transition dynamic completely missing in Harrod's model.

From the dynamic model to the theory of growth

It is Solow himself who observed that the solution to the problem of Harrodian instability, albeit an undoubted step ahead on the theoretic plane, does not provide a solution to Smith's problem: to identify which factors determine growth in the long run. Solow writes :

> "There is of course one glaring deficiency in this account of steady-state behaviour. It accounts for a steady state in which the ratio of employment to capital is constant. As the ratio of capital to product is also constant, so the aggregate product grows at the same rate as supply of labour and the pro capita output is constant. But the facts, whether stylised or plain, require that both output and the capital stock grow faster than employment. Modern industrial economies grow steadily more capital-intensive and the productivity continues to rise. Something must have been left out of the model." (Solow 1970, 33).

To move from the dynamic model to growth theory, as required by empirical evidence, we must add a further element to the model, so far missing, which can support the dynamics over the long term. With his usual clarity, Solow states that "there are two obvious candidates: technological progress and increasing returns." (1970, 34). Both exogenous technological progress and increasing returns to scale are tools which can offset the consequences resulting from diminishing returns in the accumulated factor. Exogenous technological progress obtains this effect via continuous innovation which postpones the production function and returns to scale via those processes of cumulative causation which are linked to the increase in the size of the economy. In both cases, the result is an increase in pro capita output and capital, with a single restriction that, to be compatible with the steady-state condition, both returns to scale and technological progress must be introduced into the model in a very particular way.

As is well-known, Solow chose exogenous technological progress and consequently the idea of increasing returns to scale disappeared from the scene for more than twenty years. So to the list of hypotheses included in the hard core must be added:

N5) Technological progress tends to be a temporal exogenous trend which increases output at a constant rate.

In view of N5), in the long run, the growth rate of the economy coincides with the growth rate of labour efficiency, to which must be added, if necessary, the growth rate of the working population. The continuing increase of labour efficiency creates new opportunities for profit, which, in equilibrium, exactly compensate its downward tendency following the process of accumulation.

From a methodological point of view it is not difficult to see how N5) is a rather typical situation in which a theoretic model is adjusted to empiric reality simply by the introduction of an ad hoc hypothesis. In the methodological literature, the notion of ad hoc hypothesis refers to the various stratagems used by researchers to introduce new assumptions solely to save the model in the face of contrary empirical evidence. An hypothesis is ad hoc when it cannot independently produce new predictions and hence does not improve the empirical content of a theory. With Popper we can say that the adjustment of a theory for the sole purpose of protecting it in the light of contrary evidence is not good scientific practice. The modification introduced into the dynamic model with the addition of exogenous technological progress was ad hoc because it did not lead to any further predictions, backed up in turn by further checks and observations. The empirical content of the theory was reduced rather than increased.

But there is also a further aspect beyond the typically Popperian, which characterises an hypothesis as ad hoc and this aspect has been highlighted by economists. Lakatos claims that it may happen that an hypothesis be ad hoc not just because it prevents the genuine falsification of a theory, but because it conflicts with the programme's heuristic and so weakens its internal coherence and unity. This is the case for theorists of rational expectations who hold that other types of expectations have been damaged by ad hoc assumptions, not so much because they are contrary to available evidence but rather that they are inconsistent with the principle of maximisation which represents the key assumption of neo-classical economics (Hands 1988). The same criticism can be levelled at the hypothesis of exogenous technological progress: it is an ad hoc hypothesis not because lacking in the capacity to produce new empirical evidence but because it is not derived from the optimising behaviour of the individual agent and therefore it is inconsistent from the point of view of microeconomics basis.

It is a remarkable instance in the history of economic thought that a research programme with such a flimsy empirical basis and supported by an ad hoc assumption should have gained such an important position as to hold the scene for two decades before being challenged by recent models. Once again it is Solow who offers us the key to understanding the success of his approach to economic growth:

> "I shall concentrate on technological progress without taking returns to scale into account, for two reasons. In the first place, I reckon that technological progress must be the more important of the two [elements under consideration] in real economy. It is difficult to believe that the US is enabled to increase output per man at something over 2% a year by virtue of unexploited economies of scale. I should like simply to suggest that their effect has probably been obscured by the effects of technological progress. Second, it is possible to give theoretical reasons why technological progress might be forced to assume a particular form required for the existence of a steady state. They are excessively fancy reasons, not altogether believable. But that is more of a lead than we have on the side of increasing returns." (1970, p. 43)

Here Solow clearly puts forward two different arguments, equally decisive for our ends. The first is a meta-analytical argument which can be defined as of a rhetorical type. The second is the formal argument that makes it possible to show how a mathematical structure may be found which is coherent with the basic viewpoint.

The argument whereby the technological progress hypothesis seems to Solow to have greater persuasive force must be qualified in that Solow is here referring not so much to growth theory as to the whole structure of neo-classical economics. What appeared convincing was the fact that the Solow parabola may be considered the extension to the dynamic case of the theory of general economic equilibrium with all the supports of associated hypotheses, among which the essential one regarding constant returns to scale. If the essential aim of growth theory was to offer a dynamic vision of the Arrow-Debreu model, it follows naturally that the principle of increasing returns was almost completely abandoned because incompatible with the theory of competitive equilibrium and the invisible hand. It fell to Solow's followers to point out this ideological interpretation of the neo-classical growth model. Burmeister and Dobell note that: "Pontryagin and colleagues have discovered a new and more powerful principle of the invisible hand. Pontryagin's principle can be considered the final point in a logical sequence which originated in Adam Smith's maximisation principle. "(1975, 356). Even more explicitly: "So our analysis, although not defending a particular type of social organisation, leaves us, insofar as we are members of a particular society, with an important lesson. We have seen that the effectiveness of the market mechanism in solving complex economic problems applies also to the problems of dynamics and accumulation." (1975, 360)

So it was not empirical evidence or analysis of facts which indicated the research path to be followed but rather a theoretical vision in which the economy tends naturally towards co-ordination of economic decisions through the price mechanism and is highly suspicious of intervention in the economy. All that could challenge such a prospective was set aside by methodological decision. This rhetorical vision which tended to justify a particular vision of the economic system hinging on free-play in the market was not without consequence for the development of the research programme. Neo-classical theory was gradually consigned to irrelevance on the empirical plane and its position became even more feeble when it was strongly criticised and its theoretic foundation and internal coherence challenged (Harris 1980). On the other hand, the theory of economic development as a separate discipline from growth theory was given a boost and great importance was held in it by all those elements which were ignored by the rival model, starting with the active role of the state. (Arnt 1984)

The second argument advanced by Solow was the necessary conclusion of the preceding one. The fact that technological progress is exogenous and in particular takes the form of increased labour efficiency, makes it possible to maintain all the model's implications, from monotonous convergence to stability. As in the case of static equilibrium, also in dynamics the desired results in terms of existence, uniqueness and stability of the equilibrium solution are obtained.

Increasing returns to scale

It may be surprising that in his 1970 essay Solow should mention increasing returns to scale as a possible engine for long-term growth. But looking more closely we find that the question of increasing returns is very much present in the neo-classical literature and amply dealt with in text-books as well as in review articles (Hahn and Mattheus 1964, Wan 1970, Hamberg 1974, to cite a few authors). As Solow recently (Solow 1999) again expressed his belief that increasing returns may be incorporated, albeit under particular conditions, in the neo-classical approach and so do not constitute a real theoretical challenge, it is worth examining the issue briefly as it developed around the late sixties.

A very clear exposition of the role of increasing returns can be found in Arrow and Kurz's *Public Investment, The Rate of Return And Optimal Fiscal Policy,* 1970. This text is important for two reasons: for the standing of its authors who have made fundamental contributions in this field and also because it is the first and complete exposition of the technique of optimal control applied to the problems of dynamic optimisation. So this text is a remarkable preview of the macro-economics approach which became prevalent in the following decade.

At the end of the first chapter, after the paragraph dedicated to exogenous technological progress, Kurz and Arrow conclude their exposition of the standard model with a paragraph on returns to scale. The two authors note that:

"We can, with little change in the analysis introduce certain forms of Increasing Returns into our model. Just as labour-augmenting technological progress creates few major analytic problems but requires reinterpretation, so appropriate modifications of the way labour enters the production function introduce interpretative but not analytic difficulties." (Arrow and Kurz 1970, 22)

What are the general conditions which make it possible to integrate increasing returns into the neo-classical programme. The first is that they cannot concern capital, the accumulated factor. If capital accumulation were subjected to dynamic economies of scale, balanced growth would be impossible. The second is a direct consequence of the first: returns to scale are assigned to labour which grows at an exogenous rate; all improvements to productive efficiency which derive from production and accumulation activities must lead to an improvement in labour efficiency.

Arrow and Kurz present two basic models which were to be developed, as will be seen, during the 1960s in the literature on endogenous growth. In the first case, labour enters the production function (Cobb-Douglas) with an elasticity value which is greater than the unit,

$$Y = F(K,L) = G(K,L^b) \qquad 2)$$

with G homogeneous degree one. As $b > 1$, the function presents increasing returns to scale. In a Cobb-Douglas, the production function becomes:

$$Y = K^a L^{b(1-a)} \qquad 3)$$

It is to be noticed that in 3) returns to scale are increasing with regard to the set of production factors, but are decreasing with regard to the factor accumulated, the capital. We look for the steady-state solution. Differentiating 3) with regard to time, after logarithmic transformation, we have:

$$\frac{\dot{Y}}{Y} = b\frac{\dot{L}}{L} \qquad 4)$$

taking account of the fact that the working population grows at a constant and exogenous rate. 4) lends itself to immediate interpretation: economic growth remains completely exogenous as linked to population growth, whereas the growth rate is modified to take into account the action of the increased output parameter, b.

The second model is more interesting and is obtained when the production function presents the following form, which is better articulated than the previous one:

$$Y = F(K, L) = G(K, K^b L) \qquad 5)$$

with G homogeneous degree one. Equation 5) has this economic significance: each act of investment produces as a collateral effect an increase in labour productivity. This increase in labour productivity, as Arrow and Kurz fleetingly point out, being interested only in the analytical structure and not the economic view, may be considered as a public good. In the case of a Cobb-Douglas function, 5) becomes:

$$Y = K^{a+b(1-a)} L^{(1-a)} \qquad 6)$$

To determine the steady-state solution, we transform 6) into logarithms and then differentiate with regard to time and obtain the following:

$$\frac{\dot{Y}}{Y} = (\frac{1}{1-b})\frac{\dot{L}}{L} \qquad 7)$$

7) substantially reproduces the results of 4) with a further restrictive condition which requires that $b < 1$. Also in this second case, the growth rate of macro-economic variables is a multiple of the growth rate of the population.

It is clear at this point why the introduction of increasing returns cannot change the basic analytical framework and so Solow’s idea is confirmed that even the standard model can incorporate increasing returns without consequence. Given the characteristics of the production function and since the effect of the returns is ascribed to labour, the growth rate of the economy comes to depend on the growth rate of the working population and thus remains completely exogenous as in the model with constant returns. To obtain different results from the application of increasing returns a different path would have to be followed, as was to happen with the new growth theory.

Development of the neo-classical research programme.

We saw that for Lakatos a research programme is not a static entity. New facts are discovered, new problems emerge and consequently the protective belt undergoes some adjustment. Lakatos holds the idea that a research programme should be evaluated on the basis of its ability to evolve with time. If modifications made are not able to explain new facts, then the programme is *degenerating* . If, on the other hand, the changes made not only explain the anomalies, but can also predict or interpret new facts, then the programme is *progressive*.

In the 1960s the neo-classical research programme was enjoying most favour; new hypotheses were added to the base model which seemed to be able to increase its ability to interpret and its analytical richness via subsequent progressive shifts. In economics, a useful criterion among the many available to establish if a theory or a research programme are progressive consists in evaluating the relationship which exists at any moment between exogenous variables, that is, the inevitably arbitrary starting point of any research, and the endogenous variables, that is, the elements which the model sets out to explain. Generally-speaking, we have a moment of progress when the programme increases its scope and variables which were originally considered exogenous are in a subsequent phase endogenised.

Seen from this standpoint, we can say that most of the theoretical research in the golden age of the neo-classical programme concentrated on the attempt to make savings and technological progress endogenous. Endogenisation of savings was the work of a group of young economists of an analytical orientation, among whom are Cass (1965), Uzawa (1965), Shell (1969), Arrow (1968), Ryder (1967) and Kurz (1970), who, in a relatively short time, successfully managed to apply the techniques of dynamic optimisation, at that time only recently elaborated in theoretical physics and economic theory. The belief rapidly took hold that there was a complete analogy between the problems of dynamic optimisation and the analysis of consumption in an inter-temporal context. Progress was made at the level of mathematical formalisation but there was no equivalent advance at the level of analysis of the factors which determine economic growth and so at an interpretative level. Retrospectively, Shell noted that “the success of the Hamiltonian view in the analysis of economic growth has been rather limited” (Shell 1987) since, even in the refined maximising version, economic growth was completely independent of savings, or rather, of typical consumers’ preference.

To come now to technological progress. As in the neo-classical view, but not only, technological progress is the fundamental factor that determines economic growth, it does not surprise us that the analysis of technological progress was the main area of research in growth modelling. Essentially, two problems were posed: a) establishing the effects of technological progress on distribution quota and b) establishing if this factor was endogenous or exogenous to the economic system. Let us pass point a) by and concentrate solely on point b).

In the literature of the 1960s, there is a clear awareness that technological progress was to a great extent an endogenous element (Jossa 1974) but the question set was how to translate this common conviction onto the analytical level. The endogenisation of technological progress followed basically two paths. The first came directly from Kaldor's observation (1957) that the means via which technological progress is realised is capital accumulation. Kaldor's idea that technological progress is incorporated in new capital goods was at the base of the *vintage approach* in which capital was disaggregated by year of output. Within the neo-classical system this attempt to link investment and technological progress took hold with an essay by Solow in 1960 in which he developed the assumption that "technical innovation influences technological progress only if incorporated into new capital goods or via substitution of outdated equipment with the latest models" (p. 200). Models with capital divided by year sparked off a lively body of research (Wan 1970) and constituted the dominant approach to the analysis of the relationship between technological progress and economic growth.

However, notwithstanding the various and fanciful ways of treating goods by year (complete substitutability, ex-ante, but not ex-post, substitutability, no substitutability) and the efforts made in this direction, in the long run the growth rate ended up being constant over time and equal to the rate of productivity increase of the new investment. As Phelps observed (1962), even according to the new view the "rate of development over the long-term depends on the rate of technological progress, not on the type of progress" (p. 256). In the models with capital incorporated, technological progress still ends up exogenous and in a steady-state. There is no difference if the technological progress concerns all capital goods or only new ones. If, on the one hand, the year-by-year approach had the merit of making the theory more realistic, on the other, it did not change the underlying view of economic growth.

The second road followed to endogenise technological progress fixed on a closer consideration of knowledge as a factor of production. This was a minor research direction but which fed an original research tradition. If acquired knowledge becomes an essential factor of production, then its growth, and so technological progress, becomes dependent on the amount of economic resources assigned to it and also on the way in which innovation spreads within the economic system. Economic growth backed up by research and innovation becomes an endogenous process. Within this approach we can distinguish three separate research paths, each of which has focused in different ways on knowledge as a factor which can be produced, owned and accumulated.

The *old* theory of endogenous growth: Arrow, Uzawa and Phelps

The first direction of research started with Arrow's famous article in 1962 which was the fundamental contribution of the neo-classical approach to endogenous growth up to present-day models. Arrow's model was extended by Levhari (1966[a], 1966[b]) to the case in which capital is a homogeneous good and successively it was reformulated using optimum control theory by Sheshinksy in 1968.

The innovation Arrow introduced was to hypothesise that labour efficiency was an increasing function of work experience. As each work activity implies learning, workers over time become more productive. In Arrow's model, work experience is represented by the cumulative flow of new investment as it is in the production of new capital goods that learning is shown. Arrow's original idea was that learning-by-doing was a non-linear function of total investment.

From the analytical point of view the main innovation introduced by Arrow's model is to hypothesise that the parameter which measures workers' productive efficiency, *A*, is a function of accumulated capital:

$$A = \left(\int I dt\right)^b = K^b \qquad 8)$$

Let us now consider a conventional production function in which technological progress is represented in the usual increasing labour efficiency form $Y = K^a (AL)^{1-a}$, where the variables have the usual meaning. Inserting 8) into the aggregate production function we get:

$$Y = K^{a+b(1-a)} L^{1-a} \qquad 9)$$

Equation 9) brings up some important considerations. The first is that the function so-defined presents increasing returns to scale with regard to the two factors considered together. What has happened is that, by introducing experience, an indirect effect of a variable, the level of technical knowledge, has been introduced on the other, the stock of capital, which assumes the form of a positive externality. As capital stock increases, learning increases and so too does output.

We find here Kaldor's idea that an increase in capital generates a greater than proportional increase of output.

The second consideration is that there is the problem of reconciling the presence of returns to scale with the hypothesis of perfect competition. Arrow indicates Marshall's solution: the increase in productivity is wholly involuntary and derives from an externality effect of capital accumulation. The hypothesis of perfect competition is maintained because the factors are still paid according to their productive contribution but the allocation result is no longer efficient from the social point of view.

The dynamic of Arrow's model is obtained easily by differentiating 9) with regard to time, after logarithmic transformation, to obtain:

$$\frac{\dot{Y}}{Y} = [a + b(1-a)]\frac{\dot{K}}{K} + (1-a)n \qquad 10)$$

Imposing the steady-state condition, that is, that $\dot{Y}/Y = \dot{K}/K$, we have:

$$\frac{\dot{Y}}{Y} = \frac{n}{1-b} \qquad 11)$$

The interpretation of 11) is already known. Notwithstanding the assumption of incresing returns to scale, the growth rate is still determined by an exogenous parameter, the growth rate of the population. The presence of externalities connected to learning increases the long-run growth rate due to the fact that parameter b is less than the unit. If, for argument's sake, the effect of externalities were fairly great, with $b > 1$, we would have the paradoxical situation of a continued fall in capital brought about by a too rapid growth in population to the detriment of capital accumulation. This result is determined essentially by the peculiar way in which increasing returns come into the production function.

To sum up, Arrow's model has represented the most important attempt to propose an endogenous mechanism for growth in the neo-classical school. Even though it undoubtedly represented a step forward by introducing greater realism, on the other hand it has two basic limitations which have reduced its theoretical use. In the first place, long-run growth is only partially endogenous due to the learning parameter b and in the long run depends solely on working population dynamics as in Solow's version. In the second place, its interpretative capacity is rather weak. The effect of learning is not determined by an economic choice but is the involuntary by-product of the process of accumulation. With these two elements in mind, it is hardly surprising if Arrow's approach has been considered an ingenious sophistication of the neo-classical model but has not brought any substantial changes to the prevailing paradigm.

A second approach to endogenous growth was formulated by Uzawa and is contained in a 1965 essay: *Optimal Technical Change in an Aggregative Model of Economic Growth*. This contribution was long ignored, probably as it is highly technical. Uzawa proposed his model using an advanced formulation of the theory of optimum control which was not yet familiar to scholars working in dynamic macro-economics.

The novelty of Uzawa's model lies in the fact that he explicitly inserts, alongside the sector which produces the final good, a second sector which is to produce new knowledge. Uzawa hypothesises that the efficiency of this sector which produces new ideas is a concave increasing function of the quota of labour employed in this sector. In this way, the parameter which measures work efficiency in the final goods sector, parameter *A*, does not develop exogenously but follows a dynamic trajectory:

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

$$f'(\bullet) > 0 \quad f''(\bullet) < 0 \qquad 9)$$

In this last equation, the growth of technical and scientific knowledge depends on the quota of workers employed in the research sector, $(1-u)$, while the δ parameter captures the idea that some inventions are not useful and productive. Total output is given with the usual Cobb-Douglas production function, where work is weighted in terms of efficiency $Y = F(K,AuL)$ where u indicates the quota of workers employed in the sector which produces the final goods.

Uzawa's model may be interpreted as follows. The research sector employs labour to produce new ideas which shift upwards the production function of the final sector. How strong this form of technological progress will be depends on the proportion of the labour force employed in the research and education sector. As the research sector requires only employment of labour, an economy will grow more if a higher proportion of the labour force is employed in this sector.

Assuming with Uzawa that 9) is homogeneous degree-one, then:

$$\dot{A} = A(1-u) - A\delta \qquad 10)$$

As usually happens with this class of model, the dynamics of the system is determined by the accumulation equation, in our case by 10). This equation tells us that the economic growth rate is determined by the parameter $(1-u)$, the proportion of the work-force employed in the research sector. The more resources are devoted to research, the higher the rate of economic growth. Uzawa's is the first model we have of endogenous growth in the modern sense, in which the driving sector is research and accumulation of knowledge plays an essential role in long-run dynamics.

Notwithstanding the interesting results it might well have led to, the line of research opened up by Uzawa has long been ignored. There are probably two reasons for this. Firstly, from the empirical viewpoint, Uzawa's model behaves exactly like Solow's, that is, the two models are not distinguishable on the level of observation data. Equation 10) could be rewritten in terms of exogenous progress, seeing that in a steady-state condition u is constant. In the second place, the attempt to make the model more complete led to not very realistic results. If with Phelps (1966) we hypothesise that the research sector uses labour as well as stock of technology, we get the odd result that the technological parameter A grows at the rate of population growth and output grows at a rate which is $2n$, that is, twice the growth rate of technological progress (Phelps 1966).

The *old* theory of endogenous growth: Shell's contribution

In this section we take a look at Shell's contribution to the first wave of studies on endogenous growth. Shell's contribution is particularly relevant and we find the exposition in a series of works which indicate a precise line of research (Shell 1966, 1967, 1976).

The analytical viewpoint Shell adopts to endogenise economic growth is very close to Uzawa's in the sense that accumulation of knowledge, and so technological progress, is made to depend on the resources allocated to the research sector. The more resources employed in the search for new ideas, the greater will economic growth be. What, on the other hand, distinguishes the two models, and this is where Shell's originality lies, is the assumption that the new ideas captured by parameter A may be considered a factor of production in their own right. Shell develops an original form of the function of production in which stock of knowledge is considered as a third factor of production alongside labour and capital:

$$Y = F(K,L,A) \qquad 11)$$

The extension in the number of inputs in 14) has two important implications for the model. The first is that it is no longer possible to hypothesise that technological progress increases productive efficiency of labour, as in Arrow or

Uzawa. The second is that it is now necessary to specify how growth of knowledge occurs and thus the solution of the model requires that a second accumulation equation be introduced.

The second required element is the assumption that technology can be considered a public good, and this assumption will play a central role also in the endogenous growth theory of the 1980s. Public finance tells us that a commodity is public when it yields non-rivalrous consumption and is non-excludable. Non-rivalrous means that the use of a public good by one economic agent does not deprive other agents from using it. Non-excludable concerns ownership rights in the sense that use of the good may be restricted to authorised agents only. Shell observes how, in the case of technology, the most interesting element is non-rivality.

"Technical knowledge can by employed by any economic agent without altering either its quantity or its quality. Thus, we must think of technical knowledge as a public good – primarily a public good in production." (1974, 79).

If new ideas and patents are a non-rivalrous input, this requires that the hypothesis of returns to scale be abandoned and the aggregate production function show increasing returns to scale. Formally we have:

$$F(A, tK, tL) = tF(A, K, L) < F(tA, tK, tA) \qquad 12)$$

This expression tells us that a proportional increase of all the inputs leads to a more than proportional increase of output. The usual argument of replicability, which is advanced to justify constant returns to scale, is not applicable here because the firm can use available knowledge without any added cost. Because of the presence of externalities it is no longer possible to hypothesise that firms operate in perfect competition, for in this case the firms would take a loss. To obviate this problem, Shell adopts the Marshallian hypothesis that returns to scale are external to the firm and thus can receive no remuneration. In this case, the competitive hypothesis is valid even if the market result is not generally optimal, for social benefit is greater than marginal benefit. In practice, the firm which innovates produces a benefit also for other firms from which, however, it cannot reap any advantage.

In this situation the aggregate function of the representative firm becomes:

$$Y=AF(K,L) \qquad 13)$$

where the firm may decide optimally the stock of capital and labour employed, while parameter A lies beyond its possible choice and captures the externality effect. We may take it that term A represents the technical knowledge which the economy has at its disposal at any given moment.

The third assumption of the model is that the production of new ideas is a function of the resources devoted to research and development. For Shell, knowledge is not just a factor of production, but one which can be reproduced and accumulated. He explicitly introduces a second sector and hypothesises that the accumulation of new ideas shows the following equation:

$$\dot{A} = \sigma a Y - rA \qquad 14)$$

where σ represents productivity in the research sector, a denotes that part of output channelled into research and, finally, δ is the rate of failure in innovation. As can be seen, in this formulation, technological progress is endogenous as the production of new ideas depends on the proportion of output invested in research.

The accumulation of capital is the same as in Solow's model. The stock of capital varies according to savings which is constant, so that:

$$\dot{K} = s(1-a)AF(K,L) - \delta K \qquad 15)$$

where $(1-a)$ measures the proportion of income which is used to produce new capital goods. Bearing in mind 16) the accumulation equation for knowledge is:

$$\dot{A} = \sigma a AF(K,L) - \delta A \qquad 16)$$

Long-run dynamics of the economy can be had by zeroing 14) and 15). Notice, firstly, how thanks to 14) , the system reaches a steady state in capital. Having observed this value, the equilibrium level can be obtained for the stock of knowledge. So, even in Shell, the system reaches equilibrium in the level of variables and not in growth rates.

It is not difficult to understand why Shell also cannot obtain a genuine endogenous growth result. The two accumulation equations are not independent but linked sequentially to one another and the only factor which actually accumulates is capital, which is then allocated to the two sectors. Once the equation for *A* reaches the steady-state, technology grows at a constant rate. If we substitute this growth rate in the production function, we have the same effect as the growth model of the neo-classicists in which technological progress is exogenous.

Finally, we notice that also in Shell's model increasing returns are not enough to guarantee a positive growth rate in the long term. This happens because, as in the Arrow model, returns to scale are increasing on the production function but decreasing on the real factor which is accumulated, capital. This was a well-known result in the literature of the 1960s. With increasing returns to scale, the economy tends to experience explosive growth and thus it is impossible to find a stable equilibrium, but if, at the same time, marginal productivity of the accumulable factor is decreasing, then the system reaches equilibrium. But precisely this condition which guarantees the steady state properties of the model is the one which prevents the system from showing endogenous growth.

Elements of the new theory of endogenous growth

Notwithstanding the remarkable analytical intuitions, endogenous growth theory remained a relatively minor research area during the 1960s, with the occasional contribution offered within the wider neo-classical research programme. The reasons for this have been outlined in the previous section and consisted in the difficulty of marrying the idea of increasing returns to scale with the theory of competitive equilibrium.

The 1970s was a very difficult period for the neo-classical research programme. The attempt to make the theoretical apparatus more realistic led to an increase in its technicism, as for example in the multi-sectorial models (Burmeister 1980), which produced the opposite result. The core of the programme was no longer able to respond satisfactorily to theoretical and logical criticisms, starting with the adequacy of the notion of production function and capital as a factor of production (Harris 1980). In addition, there was an external element: in the '70s it is macroeconomic theory which abandons the study of long-run phenomena to concentrate on short-run ones such as the theory of the economic cycle, stagflation, the impact of rational expectations and, more generally, the crisis of Keynesian orthodoxy (1999 Snowdon and Wane).

The downturn in the neo-classical programme's fortunes came with the International Economic Association Congress in Jerusalem in 1973 which was entirely given over to growth theory. As documented in Mirrlees' introduction to a selection of the papers published the following year, this was a momentous occasion. Everyone who was actively involved in growth theory took part, with Solow in the chair, and the range of discussion can be understood from the numerous sections into which the work was divided. One section was dedicated to *Growth and Technology* and hinged on two papers, one by Shell and another by Weizsacker, both dealing with the endogenous aspects of technological progress. In the following years, the interest for the neo-classical theory waned, at least in neo-classical circles and this led S. Fisher to observe in a long and detailed review on developments in macro-economics in the 1970s and '80s for the *Economic Journal* that " after a rapid development in the '50s and '60s, the theories of economic growth and capital have received little attention for almost two decades" (Fisher 1988, 37).

There has been a soaring revival of interest only recently. Endogenous growth theory is spreading and many mechanisms have been adopted by neo-classical authors to make growth an endogenous process, showing that there is no limit to the analytical flexibility of the basic framework and that the possibilities for the introduction of new elements are immensely vast. As it is not our aim to supply a review nor a classification but rather to analyse the evolution of the idea of endogenous growth within the neo-classical research programme, we shall limit ourselves to a consideration of the essential elements in Lucas' and Romer's approach, as their contributions remain landmark (Jones and Manuelli 1997).

Stiglitz (1988) observed that all progress in growth theory must overcome two types of obstacle. The first has to do with the mathematical constraints which characterise every dynamic model, constraints which generally are not to be found in static analysis. The second is of a different kind and calls into question the view of economic processes underlying the analytical superstructure. Each advance in economic theory requires that new intuitions be elaborated which give an economic significance to advances on the analytical level. We shall apply this interpretative key to the new growth theory as elaborated by Romer and Lucas.

As regards the analytical aspect, it is Lucas (1987) who clearly defines the essential ingredient in the new approach to economic growth models. To obtain an endogenous growth model, in the present sense of the expression, the marginal product of the accumulated factor must be strictly greater than zero (but higher than the interest rate). If this is not the case, the sector which produces the accumulable factor is not sufficiently productive to guarantee long-run product growth. As Lucas observes:

> "What lesson can we draw from the failure of the neo-classical model? I think there are two. First, the villain is the Law of Diminishing Returns. It is this feature that makes it hard to get sustained growth in a model of a single economy ……We have to find a way to repeal this law, theoretically. (Lucas 1987, 68)

In other words, for there to be economic growth also in the long term, returns on investment, represented by the marginal product which in a single commodity model is the same as the interest rate, should not decline with accumulation but be independent of it and also sufficiently remunerative. The crux of the problem, in an intertemporal context in which the usual representative agent maximises his utility, is that conditions on technology, and so on the supply side, must be defined appropriately so that the remunerativeness of the accumulated factor is not zero with the growth process. What Lucas calls for, and what the new models will supply in many ways, is some modification of the traditional aggregate function of production which moves in the direction required which is that of annulling the effect of decreasing returns. We must turn, then, to the hypothesis of increasing, or at least, non-decreasing, returns to scale, re-elaborated as necessary to satisfy the criterion of balanced growth.

If this is the common analytical skeleton of the new class of growth models (Jones and Manuelli 1997, 80), there are a number of ways of reaching the required result according to the specifications of the way in which knowledge is used, produced and distributed in the economy. Romer and Lucas, and later many others, could not but return to reflect on the issue, but barely-sketched during the 1960s, concerning the concept of knowledge as an autonomous factor of production which has particular characteristics which are totally different from other traditional factors of production. To quote Lucas again and his criticism of the Solow model:

> "Second, the neo-classical model focuses on the capital accumulation decision, but it is growth in ideas – non merely capital – that drives the system. This observation suggests a shift of focus from decisions on capital accumulation to decisions that determine rate of production of ideas." (Lucas 1998, 68)

With economic growth now depending on the accumulation of ideas and no longer on the accumulation of physical capital, the points in common between the old and new theories of endogenous growth are plain. The two approaches share the same plan even though the end results were to be very different. What is clear in particular is that, albeit in a different form, both Romer and Lucas pick up again the concept of increasing returns to scale, or rather, they give a different reply from Solow's to the problem of inserting increasing returns into a general equilibrium model.

Without going into the analytical details of the models, the basic idea behind Romer's approach is outlined clearly and concisely in a short essay with the pertinent title: *Are Non-Convexities Important to Understanding Growth?* (1990). His thesis can be summarised in the following terms: if technological progress consists in the accumulation of new ideas and immaterial goods, then it is inevitable that we should turn to the principle of increasing returns to scale. Knowledge in fact is a non-rivalrous factor which has a high production cost but it can be replicated without excessive cost. Here we find Shell's, and before him, Kaldor's, idea that technology is a public commodity and that consequently the function of production is characterised by increasing returns to scale. In Romer's words:

> "The oldest question in Economics is what causes growth. One of the oldest conjectures, built into Adam Smith's story of the pin factory, is that nonconvexities are important for growth […]. We now know how to fit this kind of effect into an aggregate growth model, and we can already see that these models generate many theoretical possibilities" (Romer 1990, 98)

But as we have already seen in Shell, technology as a public good cannot grant endogenous growth. Romer's step forward consists in assuming that increasing returns are due to an externality effect linked to the accumulation of capital on the part of the single firm, that is, that it has the characteristics of a public commodity but is produced privately. As new discoveries are non-excludable, the single firm produces knowledge from which all the other firms can also benefit thanks to the circulation of information. This externality effect, practically irrelevant at a micro-economic level, becomes the decisive factor on the macro-economic level and thus also for growth theory. To ensure that the long-run growth rate is constant it is necessary to introduce an extremely particular condition. The aggregate effect due to capital accumulation must exactly balance the tendency to decreasing returns which are found at micro level. Otherwise, it is impossible to achieve a balanced growth situation and the economic system tends to explode or reach a steady state. Here we find once again, albeit in a different form, the problem of instability which seems to characterise dynamic linear models from Harrod on.

Lucas' model is less innovative than Romer's on the interpretative level but nonetheless has its roots in earlier endogenous growth literature. Lucas recognises his debt to Uzawa and presents his 1988 model as a variant of Uzawa's of 1965. In his words: "In 1965, Uzawa showed that a growth model based on human capital accumulation, without diminishing returns, can produce sustained growth without the deus ex machina of exogenous technical change" (1987, 68). Lucas gives Uzawa's model a microeconomic syntax which was totally missing from the original model. The research sector is replaced by the notion of human capital, but, above all, the accumulation of human capital depends linearly on the time which each worker dedicates to study and training. With these modifications of interpretation but with the same analytical structure, long-run growth rate per man becomes endogenous in the sense that it depends on the fundamental parameters of the economic system, such as preferences and production function parameters.

Lucas is aware that his model comes up against the same limitations as Uzawa's: that it is not distinguishable on the empirical plane from Solow's, and, as its scope is precisely that of demonstrating the superior interpretative ability of his approach, he, too, feels the need to introduce increasing returns into the model. Lucas' additional hypothesis is that the single worker's productivity depends also on the aggregate human capital which produces an externality effect: this is not necessary to obtain endogenous growth, but it is for diversity in long-run growth rates.

To sum up, both Romer and Lucas completely re-orientate in neo-classical growth theory, shifting the mainstay of the analysis from material resources to immaterial, picking up again the thread of the endogenous growth theory of the 1960s. Once on this road, the new growth theory also found itself with the problem of how to incorporate increasing returns into the theory of general economic equilibrium. Their reply was to completely set aside the problem of distribution, that is, the basic idea of the neo-classical school that there is a correspondence between the quantity of a factor and its price, seeing as this was the obstacle which had to be overcome.

Changes to the research programme

The new growth theory had remarkable success in giving new energy to the neo-classical research programme, going back to the fundamental question of the factors which determine economic growth and abandoning the static vision of competitive economic equilibrium. This, moreover, made it possible for the theory to recover its empirical orientation.

The blossoming of the new models was made possible by a change which concerned the research programme's hard core. The principle of decreasing returns proved to be a barrier to the understanding of growth. It was substituted by a new proposition which made it possible to view long-run growth as an endogenous fact, that is, tied to the behaviour of economic agents. The core of the neo-classical research programme on growth now included the following propositions:

N1) Growth theory concerns itself with the conditions under which an economy grows in steady state conditions.

N2) The dynamics of an economic systems is determined by the accumulation of the factors of production.

N3) The supply side of the economy is described by an aggregate production function which allows a complete and immediate substitutability of the factors of production which typically are labour and capital.

N4) The aggregate production function is characterised by constant returns to scale on the accumulated factor.

N5) Growth is determined by the accumulation of immaterial capital.

That there should have been changes to the hard core of the research programme begs the question whether there has been a progressive change in the research programme and therefore an internal adjustment, or whether we are faced with a new programme which relegates the Solowian model to the attic.

When Lakatos describes the creative shifts of a research programme it is clear he refers to changes in the positive heuristic while the hard core remains intact. This could suggest that with the new endogenous growth theory we do not have a shift forward of the programme as in the case, for example, of the endogenisation of savings in the 1960s or of the vintage models, but a whole new growth research program. It could be argued that the new growth theories have in fact created and alternative program to the dominant Solowian program. The new growth theory can explain the predictions of the dominant programme but can also interpret existing anomalies via the generation of predictions which have empirical support.

But this rigid application of Lakatos' approach would, however, would lead us in the wrong direction. We could hardly say that economists involved in the endogenous growth research project are outside the neo-classical research programme, in the usual meaning of the term. The endogenous growth approach shows a large grade of continuity in the neo-classical research programme and the greatest effort on the part of Lucas and his school is to prove the superiority of the neo-classical research programme over rival programmes (Lucas 1988).

This seeming paradox springs from the difficulty of precisely identifying the elements of a research programme and can easily be overcome if we use Remeny's suggestion, discussing the application of Lakatos' methodology to economics (Remeny 1979), that the categories of a research programme be made more flexible by introducing the idea of demi-cores. For Remeny, each research programme generates in its development a series of specialties and sub-disciplines that have common features, each of which is characterised by its own core, named demi-core. The protective belts of sub-programs can overlap and, although their demi-cores may be distinct, they share common elements mediated through the hard core. For Remenyi, " the demi-core is to the sub-discipline what the hard core is to the SRP" (p.33). The important point is that the dynamics of a research programme is determined by the evolution of the sub-programmes it can generate which map out the heuristic path of the programme. He states: " It is a fundamental result of the theory of core demi-core interaction that the number of demi-core is not constant over time" (p. 34), but the heuristic of the core continually generates specialties and demi-core which testify to the vitality of a research programme.

This elaboration of Remeny's allows us to get out of the impasse into which a rigid application of Lakatos' methodology led us. The new growth theory may be considered not so much a new research programme but rather a new articulation of the neo-classical programme on economic growth which has led to the formation of a new demi-core capable of filling the gaps in the previous one even though belonging to the same research programme.

Which is the element which distinguishes the new demi-core from the previous one? For the new growth theorists the answer is plain: the fundamental limit of the Solowian approach is to be found in the fact that it was lacking a micro-economic theory of technological progress. The new theory of endogenous growth may therefore be considered part of a more complex and ambitious project carried on by the new neo-classical macro-economics to rethink macro-economic analysis on the basis of the fundamental assumption that individual agents make optimal choices in markets which are linked to each other and that these markets reach some sort of equilibrium. Equipped with tools from general equilibrium economics theory, growth economists tried to solve the old problem of giving a serious micro-economic foundation to macro-economics. In the 1970s, the economists of the new classical macro-economics school developed a theory of the economic cycle as optimal deviation of output around a trend; in the following decade they attempted to explain the trend itself. As growth theory economists have often pointed out, their contribution was to have successfully inserted the old idea of increasing returns into a general economic equilibrium context.

In the new growth theory we do not find any concern for the theory of distribution built into the models and, so, for efficiency outcomes to which the mechanisms of allocation lead. Rather, precisely because of the presence of externalities, accumulated factors cannot be paid on the basis of their productive contribution and, in general, allocation is not socially efficient. The reason for this lies in the fact that general equilibrium theory applied to macro-economic phenomena does not coincide with the competitive markets theory of Arrow-Debreu, which is a particular but not so interesting case for growth theorists. The general equilibrium approach is less demanding and requires solely that there be optimising agents which co-ordinate via market mechanisms. The social result of that co-ordination will depend on the institutional constraints and particular mechanisms which characterise economic processes.

Concluding remarks

In this work we have tried to analyse the evolution of the neo-classical research programme on economic growth from the Lakatos prospective. The main conclusion which emerges is that a rational reconstruction of the dominant growth theory from Solow on is possible. The Solowian project set out to construct a dynamic theory of competitive markets which would be analogous to the static theory of general economic equilibrium. To achieve this end, Solow detached himself from the prevailing research tradition using a tool, the concept of decreasing marginal productivity, derived from distribution theory. Solow criticised Harrod for having used short-run conceptual tools to analyse long-run phenomena. A similar criticism may be levelled at Solow who used a static concept, used for the determination of the distribution of resources, to deal with dynamic problems. Subordinated to a particular distribution theory, by virtue of which the distribution of the product depends solely on technology and on the initial stock of factors, growth theory developed in a single direction, that which was compatible with the general equilibrium of competitive markets.

Based on the key hypothesis of exogenous technical development, the neo-classical model first flourished and later, in the 1970s, stagnated, perhaps even experiencing a full-blown crisis. Present rebirth was determined by the return to earlier frame-sets, primarily that based on increasing returns to scale and cumulative processes. Thus the conclusion is that the neo-classical research programme is progressive on the theoretical plane. Increasing returns have been fully incorporated in a theoretic scheme of general economic equilibrium which has proved to be remarkably flexible and able to adapt.

From this viewpoint, the new growth theory may be seen in terms of an extension of the general economic equilibrium programme in order to understand principles which had remained outside its sphere of application. The result of this change in perspective is that we now find in the new frame-set some elements which belonged to classical tradition. In particular, we mean the analytical category of profit which had been totally obscured by Solowian tradition and which now plays a decisive role in the new models. As for the classics, also for the new growth theorists there is an indissoluble tie between economic growth and profit opportunity even though the latter, following the positive heuristic of the programme, is totally determined by the technical conditions of production (Kurz and Salvadori 1997).

It cannot be doubted that the new growth theory has represented a remarkable success on the analytical plane, formalising, within a vision of general equilibrium, principles which were previously excluded even though absolutely relevant on the level of interpretation of facts. However, we know, with Lakatos, that every research programme is bound to a particular metaphysic and on this it depends totally. That economic growth can be described applying Hamiltonian formalism with appropriate specifications regarding technology, as the new growth theory requires, or whether this formalisation adds little to a real understanding of the factors which determine economic growth, as the critics of the neo-classical approach claim , leads us back to a dialectical confrontation between rival research programmes, a confrontation which for Lakatos is the driving-force of scientific progress.

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