The Evolutionary Perspective on Growth

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Abstract - Although the Solow's model with technical change explained the stylised facts, the main problem appeared to be the impossibility to distinguish between a move along the production function and a shift in the production function. Further theoretical developments on growth have attempted to solve this problem. Endogenisation of technological change has been the main aim of new growth theory (NGT), which, in line with the neoclassical tradition, still treats technology as a freely available and easily transferable public good. Besides the mainstream approach to economic growth, heterodox alternatives have also tackled this issue. In fact, the renewed interest in economic growth can be framed in an epoch of major theoretical developments in the economic realm. The 1970s malaise on the status of economic theory exploded in theoretical critical alternatives to orthodoxy in the 1980s. Among others, evolutionary theory proposes a dynamic view of the economic reality, which, rooted on learning by doing, uncertainty and path-dependency, is based upon a selection process.

The development of an evolutionary growth theory can be read as an attempt to overcome the limits of the neoclassical tradition in order to provide a more in-depth understanding of the growth phenomenon. By adopting a dynamic setting fed by a selection mechanism, evolutionary growth models are microfounded and grounded on a concept of technology broader than the neoclassical tradition. The aim of this paper is to provide a critical review of some selected evolutionary models proposing an alternative perspective to mainstream economics on growth.

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1. Introduction

The interest in economic growth, central in the classical writers, declined in the first half of the 20th century and re-emerged during the post-World War II period under the need of

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explaining the rapid growth of the American economy. The revised version of the Solow's model (1957) has been for long time the most successful attempt in explaining total output growth. However, the widely recognised weakness of the model was the identification of technological change with the 'residual', which did not allow to specify how important technological change should be. Consequently, although the Solow's model accounting for technical change explained the stylised facts, the main problem appeared to be the impossibility to distinguish between a move along the production function (due to the increase of one kind of capital) and a shift in the production function (due to the increase of another kind of capital).

Further theoretical developments on growth have attempted to solve this problem. Endogenisation of technological change has been the main aim of new growth theory (NGT). However, the main problem of NGT models lies in their unrealistic assumptions of perfect-information and the consequent maximisation rule, in the equilibrium analysis and in the understanding of technology as a freely available and easy transferable public good. On the lines of the positivist tradition of neoclassical economics, theorising on growth has proceeded by testing particular theories against data rather than describing and explaining phenomena as they have been observed (Nelson and Winter, 1982). For these reasons, endogenous growth theory seems to fail to encompass the historical account of technical change and related activities and institutions since it has not yet achieved consistency with empirical record (Nelson, 1996). Therefore, although representing an advance on the 'old' neoclassical growth models, endogenous growth theory still proposes an understanding of economic growth as a smooth process based upon the concept of continuing equilibrium, thus disregarding an evolutionary perspective built upon trial and error.

Conversely, evolutionary theory attempts to overcome these limits by adopting a behavioural approach to individual firms, thus rejecting the maximisation rule. Firms' differences are framed in a continuous evolving uncertain environment where corporate actors are selected on the grounds of the results of their searching process aiming to enhance their fitness. This logical structure allows evolutionary theory to explain the macroeconomic phenomena explained by neoclassical theory on the grounds of more realistic assumptions.

The aim of this paper is to provide a critical review of some selected evolutionary models proposing an alternative perspective to mainstream economics on growth. It should be, however, underlined that, due to the microeconomic perspective of economic change, no single evolutionary model can account for all aggregate regularities at the same time, although a certain degree of consistency emerges between the different models (Dosi and Nelson, 1994).[i] The models discussed here have been selected on the grounds of a classification made by Dosi and Nelson (1994). Therefore, this review does not intend to be exhaustive of evolutionary growth modelling, by all means. Nonetheless, we believe that the models discussed provide a quite complete overview of the main features of the evolutionary perspective on growth.

The paper is organised in five main sections. Next section provides an overview on evolutionary theory as a critic alternative to orthodoxy in economics. Section 3 reviews the basic evolutionary growth model. Further developments of evolutionary growth theory are exposed in section 4. Section 5 discussed the contributions of the evolutionary perspective to growth theory. A few conclusions are drawn in section 6.

2. An overview on evolutionary (versus orthodox) theory

The emergence of evolutionary theory in the economic realm may be framed in the widespread dissatisfaction on the state of economic theory openly lamented. This sense of malaise has been mainly directed towards the inability of orthodox theory[ii] to come to grips with empirical reality. In this context, the evolutionary critique to the mainstream economic approach has been addressed to three main fundamentals of the orthodox structural logic (Nelson and Winter, 1982). First, the continued reliance on equilibrium analysis (even in its more flexible forms) neglects phenomena associated with historical change, as disequilibrium situations are outside the focus of investigation. Second, the perfect-information assumption (even in its more relaxed forms) limits the explanatory power of the theory when facing complex realities by implying that economic agents can foresee all possible contingencies and weigh their consequences.[iii] Third, the economic rationality of the agent - in the sense that he/she optimises - assumes clear anticipation, calculation and clarity of risks taken by this actor in dealing with realistic complexity without accounting for confusion about the situation, distraction and mistake concerning the actor.

Evolutionary theory criticises neoclassical theory, as the latter does not offer an explanation of why decision rules are what they are on the basis of its two structural pillars: maximising behaviour and the concept of equilibrium. The rejection of the notion of maximising behaviour lies in the consequent rejection of the distinction made by orthodox theory between the choice set and choosing. In fact, according to the evolutionary viewpoint, the economic agent engaging in the decision process is not aware of all possible alternatives he/she can face, but (some of) those alternatives will be discovered during this process by trial and error. In this sense, the determination of decisions and the decision outcome involve a stochastic element and may be non-optimal. Therefore, agents' behaviour cannot be assumed to be prompt and rational.[iv] As far as the concept of equilibrium is concerned, although the analysis of a stable equilibrium configuration in which particular forces no longer produce change is recognised to be important, the drastic narrowing of orthodox investigation to the equilibrium situation is strongly rejected as it allows to explain the relations among the efficient survivors, but not the competitive struggle consumed in disequilibria. Conversely, the later aspect is captured in the evolutionary perspective by the concept of selection.

Going into the details of evolutionary economics, this is built upon population thinking rather than typological thinking as the orthodox approach. In fact, the concern is with frequencies of behaviours that differ, not with uniform behaviour. While in the population perspective variety is a natural state, variations around the ideal type are regarded as accidental. In Hayek's (1948, 98) words "when we deal, …, with a situation in which a number of persons are attempting to work out their separate plans, we can no longer assume that the data are the same for all planning minds". Each firm has its interpretation of economic opportunities and constraints and, consequently, different firms perform better in different things. This is due to the fact that the firm's capabilities are embedded in its organisational structure, which allows it to pursue certain strategies more easily than others are. Unlike the orthodox theory, in a highly uncertain environment there is not a global optimisation over a given set of choices comprising all objectively available alternatives. Drawing on the managerial school, evolutionary theory goes further by claiming that firms as such may not have any objective in the sense that what is required to operate in the business world is just a procedure for determining the action to be taken, rather than a defined object function. In evolutionary thinking, this procedure depends upon the concept of 'routines' which can be understood as genes in evolutionary biological theory. Routines, defined as "a repetitive pattern of activity in an entire organisation" (Nelson and Winter, 1982, 97), are persistent features of the firm as well as determinants (together with the external environment) of the firm's behaviour. This implies that the making-choice is a firm-specific process. Like genes, routines are heritable as tomorrow's plants generated by today's firms have the same characteristics (path-dependency). They are selectable as shown by the fact that firms owning certain routines perform better and increase their importance over time through a continuous selection. This selection mechanism is well described by the Darwinian biological concept of natural selection and evolution, thus the label of 'evolutionary' to this new economic approach.[v] In this sense, evolutionary theory is concerned with a dynamic rather than static analysis. In this process, firms with different routines compete in a rival selective process by attempting to differentiate one to another (*variety*).[vi] Firms operations are framed within an uncertain environment by which they are affected (*mutation*) and to which they adapt by trial and error (*adaptation*). In this sense, the environment pushes firms to continuous learning and adaptation (both of which are firm-specific processes). Competition is then understood in terms of dynamic selection over time promoting economic change because "new discovery of better ways of satisfying wants progressively displace outmode models" (Metcalfe, 1998). This change proceeds gradually and in a *localised* manner as exploration and development of new techniques is likely to occur in the neighbourhood of the techniques already in use as already highlighted by Atkinson and Stiglitz (1969) in their critique to the neoclassical concept of technical progress.

Drawing on the Schumpeterian tradition, in evolutionary theory change arises partly from within the firm and part as the selective effect of the environment. Due to the struggle for survival engaged by firms, technology is a crucial factor in the selection process.

Successful firms are major technological innovators and/or imitators[vii] as in the capitalist reality technology-based competitiveness is a source of major advantages (Schumpeter, 1942). This may be better understood when recalling the definition of technology provided by evolutionary theory. Unlike the orthodox tradition, evolutionary authors (Nelson and Winter, 1977, 1982; Kline and Rosenberg, 1986; Nelson, 1992; Cantwell, 1989, 1991, 1994; Dosi and Malerba, 1996) distinguish between a public and a tacit element of knowledge. The former, better defined as potentially public knowledge, can be codified in patents, blueprint, textbooks, etc., implying that ‘public’ technology can be easily transferred and, therefore, traded between firms - this corresponds to the neoclassical understanding of technology. The latter is a private element embodied in the firm’s organisational routines, expertise and skills acquired through a process of learning and takes the shape of a firm-specific set of practises. If the public aspect of technology can be easily transferred, the tacit element is non-tradable and difficult to transfer as the result of a process of learning-by-using (Rosenberg, 1982). Therefore, since tacit knowledge is developed through an internal learning process, technology is also partially *context-specific* in the sense that it develops linkages with the local environment. Technological advantage proceeds autonomously in terms of knowledge and inventions, but “innovation - i.e. application and diffusion of specific techniques in the productive sphere - is very much determined by social conditions and economic profit decisions” (Perez, 1985). This aspect is strictly linked to the concept of technological paradigm[viii] as well as to the concept of institutions (understood in a both narrow - e.g. governments, regulatory bodies, etc. - and broad way - e.g. universities, business culture, tacit patterns of behaviour, etc.).[ix]

3. Evolutionary growth theory

Drawing on the features of an evolutionary theory briefly sketched in section 2, an evolutionary model is characterised by a dynamic analysis accounting for random elements that generate some variation in the variable in question (e.g. the firm or the technology) through a mechanism selecting on extant variation (Dosi and Nelson, 1994).[x] In this process, learning and discovery by trial and error play a great in role in defining adaptation and mutation in the variable in question. Based on the Schumpeter (1942) tradition on the centrality of the firm in the capitalist economic development, evolutionary growth model are microfounded in the sense that firms are the key actors in making investments to develop and adopt new technologies, and in the use of these technologies to produce goods and services.

3.1 The basic model

Following Dosi and Nelson's (1994) classification of evolutionary growth models, this section focus on the basic evolutionary growth model of Nelson and Winter (1982). The model, developed in different stages (Nelson and Winter, 1974, Nelson, Winter and Schuette, 1976), is based upon the logical apparatus set forth in Winter (1971) where decisions rules, search and selection mechanisms are provided analytically.

It is assumed that each firm has the same convex constant returns to scale technology represented by a production set Y in 3-dimensional Euclidean space where it is assumed that there are two inputs and one homogeneous product. The generic element of Y is indicated by y. In this context, natural selection is formalised by a finite Markov chain. That is, each firm has the same technology defined by a 3 x M matrix A. Each column is a list of input and output flows that is feasible in a single plant in a single period, and at least one row is strictly negative. In each period, a firms is characterised by a stock of capital K_j, which is assumed to be entirely employed

This structure provides grounds for the mechanism of the decision rule (for production decisions). This rule is represented simply by one column of A and can be formalised for each firm j in time t by the vector $(r_{jt} = 1, a_{Lt}, a_{Kt}.)^T$, where a_{Lt} (a_{Kt}) indicates the amount of labour (capital) needed to produce one unit of output. Thus, at any point in time, a state of a firm is defined as a pair of inputs a_{Lt}, a_{Kt} and its capital stock K_j. An industry state is simply a list of firms' states $[(r_1.,K_1.), \ldots, (r_P., K_P.)]$ (where P is the number of firms potentially in existence). An industry state in a given time period implies a certain aggregate capital stock in use $\sum \frac{K_j}{a_{Kj}}$ and a certain aggregate labour employment $\sum \frac{a_{Lj}}{a_{Kj}}$.

The prices of the output and inputs are determined by the industry state according to a continuous demand price function, which maps the aggregate capital, labour and output quantities into a list of nonnegative prices of output, capital and labour which ensure market equilibrium. It is also assumed that this function ensures positive profits for all firms for some industry state. More specifically, it is assumed that the industry wage rate is determined according to the following rule

$$w = a + b \left(\frac{L_t}{(1+g)^t} \right)^c \tag{1}$$

where t is the time period, L_t is the aggregate labour used in the period and a, b, c and g are constants. If $g = 0$, labour supply conditions are constants over time and the model as a whole is a Markov process with constant transition probabilities. If $g \neq 0$, then labour supply conditions undergo through changes and the model is still a Markov process but with time-dependent transition probabilities. In turn, the wage rate allows to determine the gross profitability of the firm. Gross investment is determined by gross profit.

From one period to the next, the state of an individual firm changes according to probabilistic rules that depend on the initial state of the firms and its profitability (determined by the initial state, the wage rate and constant parameters). Since the industry state is the list of firms' states, the transition probability rule for individual firms define the transition probability in the set of industry states.

It is assumed that there are extant firms and potential entrants. Transition probability rules for productive techniques are specified on the grounds of firms' gross return on capital according to the whether firms belong to group 1 or group 2 defined as follows:

GROUP 1: Firms with positive capital in the current state satisfice with respect to decision rules if they are sufficiently profitable - that is if they make a gross return on capital exceeding a target level. Therefore, they retain the production technique of the state with probability 1 (*satisficing*).

GROUP 2: Firms that make a gross return on their capital less than the target level undergo a probabilistic technique-change process. This process may develop either as seeking incremental improvements of the firm's present methods (*local search*) or looking at what other firms are doing (*imitation*), but not both at the same time.

In the *local search* case, search is local in the sense that the probability distribution of what is found is concentrated on techniques close to the current one. Distance between technique *h* and *h'* is give by

$$D(h, h') = \mathrm{WTL}\,|\log a_L^h - \log a_L^{h'}| + \mathrm{WTK}\,|\log a_K^h - \log a_K^{h'}| \qquad (2)$$

where WTL+WTK = 1. That is, the distance between the two techniques is a weighted average of the absolute differences in the logs of inputs coefficients. The closer the techniques between each other the higher the probabilities for transition from one to another.

In the case of *imitation*, the probability that firms looking at what other firms are doing will find a particular technique is proportional to the fraction of total industry output produced by that technique in the period in question. Alternative techniques turned up in the search process are adopted by the firm only if they yield a higher return per unit of capital than the firm's current rule.

As far as entrance is concerned, potential entrants are classified into two groups:

1. firms with zero capital in the current state contemplating the use of a production decision rule that implies a return to capital exceeding the target level. These firms became actual entrants with a given size probability less than one;
2. firms contemplating rules that yield capital return less than the target level and they do not enter with probability 1.

3.2 The simulation

The final aim of the authors is to show that an evolutionary model of the sort described above is able to explain the macroeconomic patterns explained by neoclassical theory, as represented by 1957 Solow's article. In that article, data on gross national product, capital input, labour input and factor prices over forty years are considered. Nelson and Winter (1982) through computer simulation generates the same macro aggregates by building them up from microeconomic data. That is, the model described above generates time paths of firms and industry inputs and outputs, time path of the industry wage rate and firms and industry rate of return on capital, the labour share and the capital share. Setting the original conditions of the model in order to make them corresponding to the conditions revealed in Solow's data, the two authors obtain a smoother aggregated "technical progress" than that found by Solow in the real data for the US, this confirming the gradual and incremental character of technical change hypothesised by evolutionary theory. Moreover, the simulation model does generate "technical progress" with rising output per worker, a rising wage rate and a rising capital-labour ratio, and a roughly constant rate of return on capital. Therefore, although Nelson and Winter's evolutionary model does not adopt a neoclassical production function, this does not affect the explanatory power of their model as the simulated economy is capable to reach the same conclusions without losing the microeconomic details (e.g. inter-firm dispersion of techniques and differential growth rates).

However, it is worth emphasising that, although firms simulation model respond to profitability signals in making techniques changes and investment decisions, they are not maximising profit. Conversely, emphasis is placed on corporate behaviour: firms, that are doing well, relax making only small changes when they do change their decision rules; firms subject to payout constrains grow by maximising investments. Similarly, the model does not rely on the concept of equilibrium. At any point in time, there are different techniques used and rates of return obtained as a result of the fact that there are always better techniques not being used because not yet found and lagging-behind firms using technologies less economical than current best practises. Therefore, the evolutionary interpretation of long-run productivity change differs from the neoclassical one, based on the distinction between "moving along" an existing production function and shifting to a new one. In the evolutionary setting, firms are engaged in searching and, according to the results obtained, they may improve their procedure and go through a selection mechanism. Thus, search and selection substitute maximisation and equilibrium, leaving no space to the notion of the neoclassical production function. In fact, it assumed the existence of a set of physically possible techniques, a subset of which is not assumed to be known at each particular time. Rather this subset is explored historically through an incremental process where non-market information flows among firms played a major role and firms know only one technique at the time. This leads to the evolutionary critique to growth accounting attempting to single out the relative contribution of different factors on growth given the impossibility of exactly specifying the production set.[xi]

4. Further developments: the role of diffusion

The evolutionary basic growth model discussed in the previous section has been further developed giving rise to two streams of evolutionary modelling attempting to tie together analysis of diffusion patterns and productivity change explaining technological asymmetries (i.e. gaps between firms in terms of costs of production and product characteristics), technological variety (i.e. diversity related to differences between firms in their search procedures, input combinations and products, despite similarity in their production costs) and behavioural diversity (i.e. within the same industry firms show different strategies). The issue addressed in these models concerns the processes involved in economic development of low-income countries, which appears to have been unsatisfactory tackled by neoclassical growth theory. Although development issues are outside the focus of this survey, there is scope for including these models. In fact, the results they obtained (e.g. the significance of the learning process internal and external to the firm, of the proprietary aspect of technology, and of embodied technological change) can provide significant insights in explaining growth.

Under the assumption of a Cobb-Douglas production function, neoclassical growth theory explained cross-country differences in productivity levels in terms of differences in the quantity of capital per worker. However, although high-income countries possess more capital and other inputs per worker than low-income countries, they operate on a higher production function. Even considering the conditional β-convergence argument, the neoclassical explanation of the development process is rather weak when confronted against empirical evidence. According to evolutionary theory, the process in question involves less developed countries learning about and adopting the (capital-intensive) technologies of more developed ones. Therefore, from an evolutionary perspective economic growth in a more or less developed economy can be viewed as a disequilibrium process involving different firms employing different vintages of technologies. In this context, there is no room for a neoclassical production function and for productivity differences across countries in terms of different points along such a production function. First of all, new technologies need to be embodied in new equipment, while the capital stock of less developed countries is older than the capital stock of advanced countries. Second, there are time lags to be considered in the acquisitions of the skills to operate modern technologies by labour in less developed countries.

In discussing these models a distinction will be made between models adopting only two technologies (an old and a new one) and models allowing a multitude of technologies. In both cases, the stochastic element of the new-technique generation or finding process is eliminated focusing on a selection of techniques that are initially in use. Therefore, in what follows emphasis will be placed on the results obtained, while providing a brief intuitive overview of the model.

4.1 Diffusion in a two-technology model

Following the classification of Dosi and Nelson (1994), the discussion will focus on Silverberg, Dosi and Orsenigo’s model (1988). In this model, industry level demand is taken as given and growing at some exponential rate. Firms own some market share of this demand at any given time, although market shares may change over time with a characteristic time constant as dynamic response to disparities in relative competitiveness. For each firm, competitiveness is defined as a linear combination of market price and current delivery delay. Firms' market share changes according to the deviation of the firms' competitiveness to the industrial average competitiveness. It is assumed that entrepreneurs are aware of the process of economic growth and technological change, whose developments are taken into account when deciding on their fixed investments. Thus, the decision-making process is based on certain rules of thumb and animal spirits in the form of decision rules governing replacement policy and expansion capacity. Technical change is embodied in vintages. The capital stock of each firm is represented as an aggregate of gross investment carried out between the current period and the scrapping date. This capital stock may be composite of different technologies as well as different vintages of a single technology trajectory. The change of capital stock over time is defined as a linear combination of net expansion, gross investments and removals due to scraping. The desired level of capacity expansion may be set initially at any level, but revised over time in order to account for the deviation of the rate of capacity utilisation from its desired level. Labour is the only current production cost firms face. The total quantity of labour per unit of capital is given by the average of the technical labour-output coefficient at different times comprised between the current period and the scrapping date weighted by the vintage. Changes in the total quantity of labour over time are due to more productive equipment through investments and removal of equipment due to scrapping. Changes in the levels of production reflect deviation of the current delivery date from an industry-wide standard level. Prices are determined as a dynamic compromise between the desired mark-up on unit costs and relative competitiveness.

The core of the model concerns the comparison of two technological trajectories representing at any time the maximum productivities achievable in best practice vintages of respective technologies. It is assumed that these technologies are changing at some rate and that the second is always superior in productivity. Initially, all firms are using technology 1, which is already mature in the sense that skills levels are saturated at 100%. As far as technology 2 is concerned, firms possess lower efficiency and are unaware of the margin for further development. Therefore, they can only guess about the rate of further improvements in efficiency and technological progress. This reflects the fact that the productivity of a technology concerns specific expertise and experience internal and external to the firm rather than the employed machines. Therefore, investment decisions rely on the ability of evaluating the prospects for further development either by acquiring experience with the best practise technology or by waiting for the right moment in order to avoid possible development costs. The rate of change of the internal skills level of firm i using the new technology, s_i, follows the rule

$$s_i = A\left[P_i / \left(CP_i + C\right)\right] s_i \left(1 - s_i\right) \qquad \text{if } s_i > s_p \tag{3}$$

where A is a parameter, P_i is the firm's current production, CP_i is its cumulated production with the new technology, C is a constant proportional to corporate capital stock and sp is the level of skill generally available in the industry also to those firms which are not yet producing on the new technological trajectory. This "public skill" can be thought as skilled labour and management moving between firms, operating instructions of some industrial equipment diffused by manufacturers to users, industrial and trade publications, etc… Thus, the rate of change of the level of generally available skill can be formalised as

$$\dot{s}_p = A\left(\left\langle s \right\rangle - s_p\right) \tag{4}$$

where $\left\langle s \right\rangle = \sum_i^N f_i s_i$ with f_i constant parameter and N the number of firm is the industry. Firms enjoy this learning externality even if they are not yet employing the new technology: $\dot{s}_i = \dot{s}_p$ if $s_i = s_p$. In deciding whether to switch to the new technology firms may abandon their investment criteria indicated above in order to take into consideration the gains in productivity due to the installation of the new equipment as well as to the early proficiency in use. These considerations depend on how optimistic firms are about the future development potential of the new technological trajectory. Thus, firms select an "anticipation bonus" (X_i) they award to the new technology in making their choice of technique. The new technology will be preferred to the old one according to the following rule

$$(P_2 - P_1) / (c_1 - c_2 / s_i X_i) \leq b_i \tag{5}$$

where P_1 and P_2 are the price of the old and the new technique; c_1 and c_2 are the unit costs of the old and new technique and b_i is the target payback period of the firm i. Therefore, the new technique will be preferred to the old one if its adjusted productivity is higher than that of the old one and it is cheaper ($P_2 < P_1$) or it is more expensive ($P_2 > P_1$) but the difference in price is counterbalanced by lower unit costs ($c_2 < c_1$) within the desired payback period.

Due to the complex mathematical properties of the model, the authors run computer simulations in order to uncover some of the economic properties of the model. In doing so, they focus on the anticipation bonus reflecting expectations about the future course of the new trajectory in order to explore further the strategic aspects of the diffusion process and the problem of the interdependence of behaviour. Computer simulations reveal interesting results concerning firms' strategy, which are likely to affect the growth rate of the whole economy. If all firms anticipate to incur the development costs associated with brining the new technology to commercial maturity, none of them will adopt the new technology. Conversely, if the rate of internal learning is accelerated, this will raise dynamic appropriability of the innovation of the early adopters, who became the beneficiaries showing high efficient levels. Equally the evolution of firm-specific and external skill levels allows middle and later adopters to start from higher initial levels of efficiency due to external learning, and to overtake the early adopters. Therefore, technological innovation and diffusion are characterised by collective effects and social tensions between private and social gain, which impact on the aggregate economic growth. The rate of internal and external learning affects firms' investments decisions concerning production techniques. In turn, this affects corporate productivity and growth, which impact on aggregate economic growth.

4.2 Diffusion in multiple-technology model

The model taken into account in this subsection refers to Soete and Turner (1984). As before, the discussion is focus on the core of the model dealing with technological diffusion, although supplying an intuitive description of the overall structure of the model.

It is assumed that there are a large number of firms producing a homogeneous good by using different N techniques. The number of the different techniques may change over time as a result of new technological innovations. Each technique uses two factors of production (capital and labour). For each technique, the capital-output ratio and labour-capital ratio may change over time due to increase in efficiency. The capital stock of the economy is given by the sum of the capital stocks used by each technique. No depreciation or scrapping is assumed. Assuming a common wage rate, the rate of return on capital obtained by all firms using the a technique is denoted by r_a and the return on capital for the whole economy is denoted by r. A particular technique is the best practise technique if it yields the highest rate of return given the common wage rate. The entrepreneurs will search for the most profitable technique to invest in, but not all of them will be successful in that search. The underlying behavioural assumptions is that entrepreneurs make different decisions as a results of "retardation" factors such as uncertainty about the profitability of the new technique, costs and time involved in learning it and use it, possible protection, etc. Therefore, the adoption of the new technique may be delayed until information about other firms' experience is available. This behavioural pattern, which is reflected in the entrepreneurs looking for greater profitability, who will not adopt the most profitable technique immediately because of some retardation factors, can be formalised in the following investment function for the
technique

$$I_a = sr_a K_a + h(r_a - r) K_a \tag{6}$$

where $s < 1$ is the saving ratio out of profits assumed to be the same for all techniques, K_a is the total capital stock embodied in technique type a and h is a constant. If ($h = 0$, investments in the technique a will come only from surplus generated by the a technique $(sr_a K_a)$; if $h \neq 0$, then investment in the technique α will be greater or less than the surplus generated by the α technique depending whether $r_a > r$. That is, more profitable technique will attract investment, which, conversely, will decline if the technique is not very profitable. Given $g = sr$ and $g_a = (s + h)\, r_a - hr$, the differential growth rate of each technique $(g_a - g)$ is given by

$$g_a - g = (s + h)\,(r_a - r) \tag{7}$$

This implies that the difference in the growth rate of a particular technique α is proportional to the difference between the profitability of this technique and the profitability of the whole economy.

The authors show the rate of technological change, r, is the following

$$v = \sum_a \frac{\partial r a}{\partial t}\Big|_w \frac{K_a}{K} + (s + h)\sum_a (r_a - r)^2 \frac{K_a}{K} \tag{8}$$

Two components can be distinguished: the first provides the weighted average of the rate of technical progress for each technique α and can be referred as disembodied technical change (i.e. accounting for the mere occurrence of innovation); the second, which represents the "diffusion" term or technological change embodied in new investments, gives us the covariance of the deviation of the rate of return with respect to the distribution K_a/K. If there is a wide distribution of the rates of return of different techniques, the contribution of the diffusion terms to the overall rate of technical change will be high. In fact, in this case there will be a large number of entrepreneurs spread across the spectrum of rate of return. Thus, the number of entrepreneurs moving to new techniques will be high. This implies a rapid diffusion and a high rate of embodied technological progress. Conversely, a sharp distribution of the rates of return of different techniques will reduce the contribution of the diffusion term to the overall rate of technical change. As the number of entrepreneurs moving to the new technique will be small. Therefore, aggregate economic growth is related to the variation across technologies and their levels of diffusion. In turn, this implies that technological progress embodied in new investment increases the diffusion process of new techniques and accelerate aggregate growth.

5. The evolutionary contributions to growth theory

Evolutionary growth theory emerges as an attempt to overcome the limits of neoclassical growth theory as formalised in 1957 Solow's model. Although the Solow's model accounting for technical change explained the stylised facts, the main problem appeared to be the impossibility to distinguish between a move along the production function (due to the increase of one kind of capital) and a shift in the production function (due to the increase of another kind of capital). This distinction may be regarded as the distinction between innovation and routine operations in evolutionary economics, which completely lack in neoclassical growth theory due to their assumptions.[xii]

The development of traditional growth theory along these unsatisfactory lines may be attributed to the detachment between formal and appreciative theory (Nelson and Winter, 1982). The latter tends to be close to empirical work and is about what the analyst think is going on. Therefore, it can be usually expressed in terms of storytelling. The former appeals to data for support as its main scope is to set up an abstract structure enabling to explore, find and check proposed logical connections (Nelson and Winter, 1982, Nelson, 1998). If economic theorising is going well, then empirical facts influence appreciative theory, and appreciative theory provides grounds for formal theory. However, according to these authors, in the history of economic thought what seems to be happened is that formal theory and appreciative theory developed separately with formal theory sourcing aspects of appreciative theory which could have been straightforward formalised according to the available mathematical tools and leaving the rest on a side. In fact, as argued by Nelson and Winter (1982), and Nelson (1994), while in the 1950s and 1960s neoclassical theory was concerned with bringing together bodies of formal theory into a specific growth context and with formalising appreciative ideas in a naïf form, appreciative theory embarked into an analysis of micro aspects of technology (e.g. Scherer, 1965, Schmookler, 1966), whose results started questioning some of the fundamentals of neoclassical economics such as perfect information, economic rationality and the maximisation rule. This detachment marked a twofold development of the analysis on economic growth: an analysis of economic growth at macro level concerned with formalisation and an analysis of economic growth at micro level more concerned with empirical evidence. The reasons for this disjunction have been identified in the lack of analytical tools to model non-competitive general equilibrium as well as in the scarce attention given to appreciative theorising by formal economists. The outcome of appreciative theorising showed that significant inter-industry and inter-sectoral differences were associated with differences in rates of growth of total factor productivity reflecting differences in the rate of technological change. These results largely confirmed Schumpeter (1942) argument on the centrality of the firm in the capitalist economic development. However, as argued by Nelson and Winter (1982), and Nelson (1994, 1998), both formal and appreciative theories were about the immediate determinants of growth (under Abramovitz's words) in the sense that growth has been understood as a function of change in these immediate determinants without going to explore what is behind them. This was clear in the 1970s, when a persuasive explanation for the uneven performance among nations (i.e. the slowdown of the American economy, and the contemporary rise of Japan and many European countries) was still lacking.

In the attempt to provide a more realistic analysis of growth than the one provided by the orthodox tradition, the evolutionary perspective provides some major contributions to growth theory. First of all, due to its microfounded character evolutionary theory treats the micro processes as fundamental and the macro processes as aggregates. This implies that macro phenomena are the results of underlying micro phenomena, which play a major role in explaining aggregated processes. Conversely, neoclassical theory has focused on the macro phenomena neglecting the microeconomic details, thus loosing significant elements of the analysis. This different approach has allowed evolutionary theory to emphasise the significance of firm- and sector-level analysis, where technologies and industries co-evolve. In fact, the great emphasis placed on these micro phenomena has allowed evolutionary theory to deal with structural change issues more realistically. The adoption of an aggregated (Cobb-Douglas) production function - whose theoretical use is widely known to be logically faulty (see, for example Harcourt, 1972) - prevents neoclassical as well as new growth theory from understanding the effects of important distributive changes that affect overall growth rates. The key difficulty lies in the fact that the overall growth rate of aggregate output and labour productivity depends on the cross-sectoral variations in the rates of output growth and level of labour productivity (Cornwall and Cornwall, 1994). By treating the economy as a homogenous whole, new growth theory assumes that each sector experiences the same changes in productivity growth. This does not allow to capture the fact that rising productivity growth in only one sector impacts on average productivity growth according to the output share of the affected sector and to any resulting inter-sectoral labour reallocation. Evolutionary analysis overcomes the limits of the orthodox theory conducting a microeconomic analysis through the use of an evolving Leontief technology (as in the Nelson and Winter's model discussed in section 2), originally adopted at aggregate level in the Harrod-Domar model. In that case, the Leontief production function created the knife-edge problem due to the high number of exogenous parameters. In the case of the Leontief technology this problem is solved as innovation provides the flexibility needed to avoid the knife-edge problem in the economy (Andersen, 2001). In fact, within this context a disequilibrium on the labour market yields active search by firm towards new methods of production which employ more intensively the most abundant factors of production. This provides a more rigorous frame than the aggregate neoclassical production function to analyse economic growth.

Along these lines, the evolutionary perspective has contributed to a more realistic theorising on growth by adopting a behavioural approach in explained the decision-making process of the firm. In this perspective, firms take their decisions on the grounds of some observable rules of thumb, which, taken as given, bridge environmental stimuli with corporate responses. This allows to build up a more realistic growth theory by comparison with the neoclassical and new growth theory, where the rules concerning the firm's decision process are deducted from maximisation. The adoption of a behavioural approach also enhances the explanatory power of evolutionary growth theory when considering the highly uncertain environment in which the firm operates. When taking their decisions, firms know nothing about the possible alternatives and potential outcomes of success. Therefore, they are far to face "large, well defined production sets that extend beyond the experiences range of operation" (Nelson and Winter, 1982) as in the orthodox approach. Conversely, firms proceed by trials and errors through searching processes.

A further contribution of evolutionary theory lies in the introduction of a dynamic concept of competition understood as evolving competitive advantage, which does not relies on equilibrium analysis as in the orthodox theory. The latter understands competition as circumstances where no relative competitive shifts or profits can be realised and assumes that the system must be near or in this state. Instead, in the evolutionary perspective competitions is defined in terms of conditions continuously changing over time in response to the strategies pursuit by firms and feedbacks from the rest of system. Therefore, evolutionary theory focuses on the rates of growth of the scale of production of competing commodities rather than on the simple scale of production (Metcalfe and Gibbons, 1989).

In this context, the recognition of the proprietary aspects of technological change (against the traditional conception of knowledge as a public good) has been identified has a major element in understanding macroeconomic growth. The possibility of appropriating technological innovation generates differences in growth rates between firms and at aggregated level, as shown by the models dealing with technological diffusion discussed above. In this as well as in other respects, evolutionary theory anticipated and, somehow, stimulated new growth theory. The recognition by NGT of the proprietary aspect of technology - due to the profitability of R&D investments enabling the firm to appropriate a portion of the increase in productivity - and market imperfections as well as of externalities from R&D investments or from education (Lucas, 1988) and spillovers generating economies of scale (Romer, 1986) can be seen as a consequence of heterodox developments. Similarly, the rise of an evolutionary alternative explanatory scheme has also promoted the flourishing of neo-Schumpeterian models within the NGT realm as in the case of Aghion and Howitt’s 1992 model, which treat technological change in terms of a process of ‘creative destruction’. Therefore, the main differences between these and the neoclassical models lie in more realistic assumptions of the former over the latter. Nonetheless, the recognition of these phenomena as important determinants of growth cannot be regarded as a novelty when considering that applied theory have long before emphasised these aspects (as discussed above). However, as remarked by Aghion and Howitt (1994), new growth theory models still have some limitations owning to the reliance upon rational expectations - the assumption of perfect-information is relaxed only by treating uncertainty about the future in terms of a correctly specified probability distribution of possible future events - and the lack of attention to institutions and transaction costs. Endogenous growth models have taken into account the uncertainty that surrounds technical change, but without recognising that continuing technical advance implies a continuing state of disequilibrium. This is mainly due to the optimisation character of economic agents of the models. Therefore, although technical advance is regarded as the main source of economic growth, its concept is understood as involving moving equilibria, whose paths are foreseen by the involved actors.

6. Conclusions

This paper reviews selected evolutionary models proposing an alternative view to mainstream growth theory. The models discussed can be framed in a wider attempt to build up an economic theory capable of explaining macroeconomic patterns on the grounds of microeconomic assumptions more realistic than those made by orthodox theory. A major element of these models is the explicit assumption of bounded rationality, as actors behave on the grounds of their routines and they kwon nothing about what is optimal. Similarly, the evolutionary character of these models is given by the fact that firms select technologies by deciding which to introduce and which not as well as by deciding which one takes on aboard. In turn, on the grounds of their fitness firms are selected in the market. Based on a theory of firms' technological change, evolutionary growth models seems to unpack the immediate source of growth by providing some insights on the nature of technology, the processes driving technological change and the factors influencing the behaviour and effectiveness of the firms.

In Nelson and Winter’s (1974, 1982) model, firms are the central actors, as they are understood as the carriers of ‘technologies’ in the form of particular capabilities developed through routines over time. Search behaviours for improvement is defined in terms of R&D (other authors prefer the term ‘learning’). Different degree of corporate fitness are defined on the grounds of these search process - as firms doing more profitable R&D will grow relative to their competitors. Similarly, search processes bring firms together - as what the firm does depends on what its competitors are doing. Firms in an industry operate in an exogenously given determined environment. The model defines a dynamic stochastic system, which can be model as a complex Markov process. That is at a given point in time all firms are characterised by their stock of capital and their chosen technology; and their decision rules on input employed and output produced depend upon the market conditions of the previous period. The market determines the price. Then each firm's profitability is determined on the ground of the technology, and the investment rule defines the extent of expansion or contraction of each firm. Search routines focus either on the firms' behaviour or on the firms' capabilities and stochastically propose modifications, which may or may not be adopted. Ended this iteration, the system is ready for a new one. This model is a growth model in the sense that successful technological innovations allow capital stock formation and firm growth by generating profits. This outweighs any decline in employment per unit of labour associated with productivity growth, resulting in an increase in demand for labour and in real wage rate. The increase in labour productivity, real wages, and capital intensity (the latter due to the adoption of capital using and labour saving technology appeared by chance during the search process) hold down the rate of return on capital. If profits rate rises, the high profits will induce an investment boo, which will increase capital stock and drive capital return down.

Further developments of the evolutionary perspective focusing on the diffusion issues have been accounted by variants of Nelson and Winter's model, which eliminate the stochastic elements in the introduction of new technologies and replaced it either by two technologies (as in Silverberg, Dosi and Orsenigo's model) or by a given set of technologies, each of which can improve at different rates (as in Soete and Turner's model). In the latter case, industry productivity is the result of the improvement in individual technologies as well as of the use of the more productive relative to the less productive. In terms of growth, the major conclusion of the model is that aggregate economic growth is related to the variation across technologies and their levels of diffusion. In the former, some firms take advantage on their competitors, as, being able to recognise the better technology, they can invest in using and learning it. Firms can also employ both technologies by using the profit derived from the prevailing technology to invest in experience with the current inferior technology that is potentially the best. In terms of growth, the rate of internal and external learning and their interplay determines corporate expansion (contraction), which in turn promotes macroeconomic growth.

The microfounded character of these models has allowed evolutionary theory to avoid the critiques moved to neoclassical and NGT analysis based on macro aggregates. Moreover, the adoption of an approach based on observable patterns of behaviour rather than on a priori theoretical assumptions as well as of the proprietary aspect of technology makes the evolutionary setting more realistic, thus enhancing its explanatory power. If these features are specific to an evolutionary approach, some of them have been also incorporated in NGT as a result of the recognition of their relevance for the understanding of economic growth (i.e. appropriability of research and development outcomes (Romer, 1990), R&D externality (Romer, 1986, etc…). Similarly, the understanding of technological change as a "creative destruction" process has given rise to a neo-Schumpeterian stream of models developed within NGT (Aghion and Howitt, 1992, etc…). Nonetheless, although the neo-Schumpeterian endogenous models have partially attempted to account for the limits of orthodox growth theory, they still rely heavily on the traditional neoclassical assumptions.

References

Andersen, E. S. (2001) "Toward a Multiactivity generalisation of the Nelson-Winter model". Paper presented at the 2001 Nelson and Winter Conference, Aalborg.

Aghion, P. and Howitt, P. (1992) "A model of growth through creative destruction". *Econometrica*, Vol. 60, pp. 323-351.

Aghion, P. and Howitt, P. (1994) "Endogenous technical change: the Schumpeterian perspective". Pasinetti, L. L. and Solow, R. M. (eds.) *Economic Growth and the Structure of Long-Term Development*. (Houndmills and London; Macmillan).

Alchian, A. A. (1950) "Uncertainty, evolution and economic theory". *Journal of Political*

Economy, LVIII, pp. 211-221.

Atkinson, A. B. and Stiglitz, J. E. (1969) “A new view of technological change”. *The Economic Journal*, Vol. 69, pp. 573-578.

Cantwell, J. A. (1989) “Introduction”. Cantwell, J. A. *Technological Innovation and Multinational Corporation*. (Oxford; Basil Blackwell).

Cantwell, J. A. (1991) “The theory of technological competence and its applications to international production”. McFetridge D. (ed.) *Foreign Investment, Technology and Economic Growth*. (Calgary; The University Calgary Press).

Cantwell, J. A. (1994) Introduction”. Cantwell J. A. (ed.) *Transnational Corporation and Innovatory Activities*. (London and New York; Routledge).

Cantwell, J. A. (1998): “Innovation in the global economy”. Archibugi, D., Howells, J. and Michie J. (eds.): *National Systems of Innovation or the Globalisation of Technology?*. (Cambridge; Cambridge University Press).

Cohen, W. M. and Malerba, F. (2000) “Is tendency to variation a chief cause of progress?”. Paper presented at the 2001 Nelson and Winter Conference, Aalborg.

Cornwall, J. and Cornwall, W. (1994) “Growth theory and Economic Structure”. *Economica*, Vol. 61, pp. 237-251.

Dosi, G. (1982) “Technological paradigms and technological trajectories”. *Research Policy*, Vol. 11, pp. 147-162.

Dosi, G. and Malerba, F. (1996) “Organisational learning and institutional embeddedness”. Dosi, G. and Malerba, F. (eds.) *Organisation and Strategy in the Evolution of the Enterprise*. (London; Macmillan Press).

Dosi, G. and Nelson R. R. (1994) “An introduction to evolutionary theory in economics”. *Journal of Evolutionary Economics*, Vol. 4, No. 3, pp. 153-172.

Foster, J. (1996) “Analytical foundation of evolutionary economics”. *University of Queensland Department of Economics Discussion Papers*, No. 198.

Freeman, C. (1982) The *Economics of Industrial Innovation*. (London; Francis Pinter).

Harcourt, G. C. (1972) *Some Capital Controversies in the Theory of Capital*. Cambridge, Cambridge University Press.

Hayek, F. A. (1948) “The meaning of competition” in *Individualism and Economic Order*

(Chicago; Chicago University Press).

Hodgson, J. (1997) "On the evolutionary of Thorstein Veblen's evolutionary economics". *Cambridge Journal of Economics*, Vol. 22, pp. 415-431.

Iwai, K. (2000) "A contribution to the evolutionary theory of innovation, imitation ad growth". *Journal of Economic Behavior and Oerganization*, Vol. 43, 167-198.

Kaldor, N. (1957) "A model of economic growth". *Economic Journal*, Vol. 67, pp. 591-624.

Kelm, M. (1996) "Schumpeter's theory of economic evolution: a Darwinian interpretation". *ESRC Centre for Business Research Working Papers*, No. 34, University of Cambridge.

Kline, S. J. and Rosenberg, N. (1986) "An overview of innovation". Landau, R. and Rosenberg, N. (eds.) *The Positive Sum Strategy*. (Washington; National Academy Press).

Loasby, B. J. (1991) *Equilibrium and Evolution. An exploration of connecting principle in economics*. (Manchester and New York; Manchester University Press).

Lucas, R.E. (1988) "On the mechanics of economic development". *Journal of Monetary Economics*, Vol. 22, pp. 3-42.

Metcalfe, S. (1998) "Evolutionary concepts in relation to evolutionary economics". *CRIC Working Papers* No. 4 (University of Manchester).

Metcalfe, S., Fonseca, M. D. and Ramlogan, R. (2000) "Innovation, growth and competition: evolving complexity or complex evolution?". Paper presented at the "Complexity and Complex systems in Industry Conference", University of Warwick, September.

Metcalfe, S. and Gibbons, M. (1989) "Technology, variety, and organisation". *Research on Technological Innovations & Management and Policy*, Vol. 4, JAI Press, pp. 153-193.

Nelson, R. R. (1973) "Recent exercises in growth accounting: new understanding or dead end?". *American Economic Review*, Vol. 63, No. 3, pp. 462-468.

Nelson, R. R. (1992) "What is 'commercial' and what is 'public' about technology, and what should be?". Rosenberg, N., Landau, R. and Mowery, D. C. (eds.) *Technology* *and the Wealth of Nations*. (Stanford; Stanford University Press).

Nelson, R. R. (1994) “What has been the matter with neoclassical growth theory”. Silverberg, G. and Soete, L. (eds.) *The Economics of Growth and Technical Change*. (Aldershot; Eward Elgar).

Nelson, R. R. (1996) *The Source of Economic Growth*. (Cambridge; Harvard University Press).

Nelson, R. R. (1998) “The agenda for growth theory: a different point of view”. *Cambridge Journal of Economics*, Vol. 22, pp. 497-520.

Nelson, R. R. and Sampat, B. N. (1999) “Making sense of institutions as a factor shaping economic performance”. Columbia University, mimeo.

Nelson, R. R. and Winter, S. G. (1974) “Neoclassical vs. evolutionary theories of economic growth: critiques and prospectus”. *Economic Journal*, Vol. 84, pp. 886-905.

Nelson, R. R. and Winter, S. G. (1977) “In search of a useful theory of innovation”. *Research Policy*, Vol. 6, pp. 37-76.

Nelson, R. R. and Winter, S. G. (1982) *An Evolutionary Theory of Economic Change.* (Cambridge, Mass.; Harvard University Press).

Nelson, R. R., Winter, S. G. and Schuette, L. H. (1976) “Technological Change in an evolutionary model”. *Quarterly Journal of Economics*, Vol. 90, pp. 90-118.

Perez, C. (1985) “Microelectronics, long waves and world structural change: new perspective for developing countries”. *World Development*, Vol. 13, pp. 441-463.

Romer, p. (1986) “Increasing returns and long run growth”. *Journal of Political Economy*, Vol. 94, pp. 1032-1037.

Romer, P. (1990) “Endogenous technological change”. *Journal of Political Economy*, Vol. 98, No. 5, pp. 71-102.

Rosenberg, N. (1982) *Inside the Black Box: Technology and Economics*. (Cambridge; Cambridge University Press).

Scherer; F. M. (1965) “Firm size, market structure, opportunity, and the output of patented inventions”. *The American Economic Review*, Vol. LV, No. 5, Part 1, pp. 1097-1125.

Schmookler, J. (1966) *Invention and Economic Growth*. (Cambridge Mass; Harvard University Press).

Schumpeter, J. A. (1942) *Capitalism, Socialism and Democracy*. Zuffi, E. (1970) (Milano; Etas/Kompass).

Silverberg, G., Dosi, G. and Orsenigo, L. (1988) "Innovation, diversity, and diffusion: a self-organising model". *Economic Journal*, Vol. 98, pp, 1032-1054.

Soete, L and Turner, R. (1984) "Technological diffusion and the rate of technological change". *Economic Journal*, Vol. 94, pp. 612-623.

Solow, R. (1957) "Technical Change and the Aggregate Production Function". *Review of Economics and Statistics*, Vol. 39, pp. 312-320.

Winter, S. G. (1971) "Satisficing, selection and the Innovating Remnant". *Quarterly, Journal of Economics*, Vol. 85, pp. 237-261.

Notes

[i] Recently attempts have been made to formalise the links between the micro and macro aspects of growth following an evolutionary logic. Among others, Iwai (2000) has shown that as far as the state of technology will forever retain a feature of disequilibrium, the economic will keep generating positive profits. Therefore, unlike in the neoclassical version the industry will never settles down to an equilibrium state of uniform technology, rather it would keep innovating, generating new profits and, in turn, economic disequilibrium.

[ii] Following Nelson and Winter (1982) "the orthodoxy … represents a modern formalisation and interpretation of the broader tradition of Western economic thought whose line can be traced from Smith to Ricardo through Mill, Marshall, and Walras. Further, it is a theoretical orthodoxy, concerned directly with the methods of economic analysis and only indirectly with any specific questions of substance".

[iii] Alchian's 1950 article already emphasised the limits of the orthodox approach due to the assumption of perfect-information.

[iv] Loasby (1991) argues that the coordination of the growth of knowledge depends on rational structures and rational procedures rather than rational choice. In that "different structures and different procedures lead to different results" (Ibid., 103).

[v] It should be emphasised that in the literature (Kelm, 1996, Foster, 1996) it has been remarked that the application of the Darwinian theory to the process of economic evolution does not consist of the identification of spurious analogies between biological and economic phenomena. Rather, Darwinian theory provides the possibility to obtain a general model that explains a process of endogenous change by the interaction of several mechanisms (i.e. information storage, endogenous change, and selection retention). Moreover, it is worth noting that the interpretation of Schumpeter as a Darwinian is rather debated in the literature (see Hodgson, 1997).

[vi] Cohen and Malerba (2000), among others, argue that technological diversity stimulates innovation.

[vii] As broadly discussed by Cantwell (1998), imitation also presumes firm-specific capabilities (see also Freemanís (1982) discussion on the rise of Japan).

[viii] In a pioneering article, Dosi (1982) defines a technological paradigm as "a model of solution of *selected* technological problems based on *selected* principles derived from the natural science and on *selected* material technologies" (*Ibid.*, 152). Each paradigm shapes and constrains the rates and direction of technological change regardless of market inducements.

[ix] As far as institutions are concerned, Nelson and Sampat (1999) propose the concept of "social technologies" that have come to be regarded by the relevant social group as standard at a given point in time

[x] Metcalfe et al. (2000) demonstrate the interdependence between selection and development processes.

[xi] Since the 1950s considerable empirical work has been done under the guide of the "growth accounting" framework implicit in the neoclassical model. This stream of empirical research has proceeded by dividing up the sources of growth adding new variables by comparison with the original model in order to reduce the "residual" (i.e. capture large part of technical change). However, as argued by Nelson (1973, 1996), the sources of economic growth are linked one another by a strong complementarity, which make impossible to divide up the credit for growth. In fact, the increase of an input augments the marginal contribution of all others to output. In this sense, growth is super-additive as the increase in output from a rise in inputs is greater than the sum of the increase in output due to a growth in input, calculated one by one, holding other inputs constant (Nelson, 1996).

[xii] Dissatisfaction about the representation of technological change as a shift in the production function came before the systematic attempt of organising an evolutionary theory as an alternative to the orthodox tradition as illustrated by Kaldor's (1957), and Atkinson and Stiglitz's (1969) articles.