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Abstract

The article presents a critical review of evolutionary and new growth theories. The purpose is to discuss the often-made claim that the two approaches, both inspired by Schumpeter's seminal work, are becoming more and more similar in terms of the sources and mechanisms of the growth process on which they focus. According to this argument, some kind of *theoretical convergence* between the two paradigms is taking place. Differently from previous surveys of the field, the article compares evolutionary and new growth theories by focusing on their major theoretical foundations. The discussion leads to the conclusion that the two approaches greatly differ with respect to all of their main theoretical building blocks, and that no convergence between the two paradigms is therefore taking place. This finding should be welcomed by both evolutionary and new growth scholars, because it is the process of interaction and the fruitful exchange of ideas between different approaches that lead to advances in growth theory, not their convergence to a common paradigm.

Key words: Innovation; economic growth; evolutionary economics; new growth theory.

1. Introduction

The crucial role of innovation for economic growth has been increasingly recognised in the last two decades. Taking inspiration from the works of Schumpeter (1934, 1939 and 1943), a surge of interest in the study of innovation and growth started at the beginning of 1980s with the seminal contributions in modern evolutionary economics (Dosi, 1982; Freeman et al., 1982; Nelson and Winter, 1982). The new wave of theorizing was motivated by the unsatisfaction with the stylized view of technological change presented by the Solow model (1956). Sharing a similar criticism, new growth theorists made a great effort to refine the Solovian view by building up models of innovation-driven endogenous growth (Romer, 1986; Lucas, 1988; Aghion and Howitt, 1992).

Evolutionary and new growth theories have rapidly developed in the last two decades. The great surge of interest in the new growth tradition, both in terms of formal endogenous models and of the related econometric work, is well-known, and there already exist various comprehensive surveys of the field (Temple, 1999; Islam, 2003; George, Oxley and Carlaw, 2004). The development of evolutionary economics has also been remarkable, and various critical discussions point to the strong similarities existing between the different strands of research within the evolutionary paradigm (Andersen, 1994; Nelson, 1995; Archibugi and Michie, 1998; Nelson and Winter, 2002).

Both evolutionary and new growth scholars have repeatedly recognised Schumpeter's work as a major source of inspiration. Evolutionary scholars have frequently pointed to the strong connections between Schumpeter and modern evolutionary economics (Hodgson, 1997; Fagerberg, 2003). New growth theorists have also been invoking Schumpeter as their main source of inspiration. Endogenous growth models have increasingly incorporated some of the Schumpeterian ideas on the process of technological competition and innovation-based growth, with the consequence of making the outcomes of the new growth models closer and closer to the ones of evolutionary models (Aghion and Howitt, 1998).

This leads to some major questions: given that the Schumpeterian insights on the process of economic development constitute the main source of inspiration for both evolutionary and new growth theories, how similar are the two approaches? Can we observe *theoretical convergence* between the two, as it is often argued (Heertje, 1993; Romer, 1994; Ruttan, 1997; Sarkar, 1998) on the basis of the Schumpeterian flavour of both theories? These are the questions that this paper intends to answer. The paper carries out a critical survey of evolutionary and new growth theories with the purpose of analysing whether some kind of theoretical convergence is taking place between the two paradigms.

The paper differs from previous critical surveys of the field in two main respects. First, the comparison between evolutionary and new growth theories will not simply be carried out by focusing on the formal growth models developed in the two traditions, but will also include other strands of empirically-oriented and non-formal studies. The latter constitute, in fact, an increasingly important part of growth theorizing, and provide inspiration and new insights for the development of modelling exercises. By enlarging the scope of the comparison, the paper will argue, it is possible to shed new ligths on the similarities and differences between the two theoretical paradigms.

Secondly, the comparison will not be made in terms of the properties and results of evolutionary and new growth models, but it will analyse, at a more general level, the *theoretical foundations* of the two paradigms. By theoretical foundations we mean the theoretical characteristics that may be defined as the major building blocks of growth theorizing. The paper will consider six main theoretical foundations, and analyse them by discussing the following questions:

(1) What is the main level of aggregation on which the theory focuses?

(2) Is it based on the notion of representative agent or on the one of heterogeneous individuals?

(3) What is the mechanism of creation of innovation and new variety?

(4) What is the dynamics of the growth process? How is history conceived?

(5) Is the growth process deterministic or unpredictable?

(6) Does economic growth tend towards equilibrium, or is it a never ending process?

Section 2 will present these six questions in further details, and it will define the main concepts used in the survey. Section 3 will use such theoretical questions as a framework to discuss the basic characteristics of the different streams of evolutionary economics developed in the last two decades, namely the neo-Schumpeterian long wave theory, the technology-gap approach, Nelson and Winter-like evolutionary theorizing, and the national innovation systems framework.[1] In these evolutionary strands of theory, technological change is the main engine of economic growth, which is regarded as a complex process of transformation and qualitative change.[2] The section will suggest that, to a large extent, these approaches share the same theoretical foundations, and may then be regarded as different strands of research within the same evolutionary paradigm. It will also point, though, to the existing tensions and formidable challenges currently faced by evolutionary economics. Section 4 will consider new growth theory by briefly looking at both, formal models and econometric works, and by discussing their theoretical foundations. Finally, section 5 will conclude the survey by pointing out the great differences still existing between evolutionary and new growth theories, and by claiming that no theoretical convergence is taking place between the two paradigms.

2. The theoretical foundations for the study of innovation and growth

This section presents the six theoretical questions that we will use to discuss and to compare evolutionary and new growth theories in the remaining of the paper. We believe that these six aspects constitute the major theoretical foundations for the study of innovation and growth, and thus represent the relevant characteristics that it is necessary to look at in order to compare different approaches. The section defines the main concepts used in the survey, and it briefly points to the origin of each concept in the history of economic thought. The reference to classical authors (e.g. Smith, Marx, Veblen, Schumpeter) will be brief and stylized, as the purpose is not to carry out an articulated discussion of the theoretical origins of modern theories of innovation and growth, but rather to define some important concepts and to introduce the analysis to be developed in the following sections.

2.1 *What is the main level of aggregation?*

A first important distinctive feature of theories of innovation and economic growth is the level of aggregation chosen as fundamental starting point to build up the theory. Three major positions may be distinguished in the history of economic thought:[3]

(i) *Methodological individualism*: this is the approach typical of classical and neoclassical economists, as well as Schumpeter.[4] According to this, the aggregate properties of the economy must be studied by starting from the analysis of the microeconomic behavior of consumers and firms. The whole economic system must be analysed by looking at its component parts, the macroeconomic theory must necessarily be microfounded.

(ii) *Methodological holism* (Hodgson, 1993, p.238): this is the approach typical of Karl Marx, and later frequently adopted in economic sociology and heterodox macroeconomics. [5] Here, it is the social and macroeconomic structure to determine the behaviour of economic agents. The component parts of the economic system can only be studied by analysing the whole, the microeconomic element depends to a large extent on the macroeconomic structure.

(iii) *Non-reductionism*: the previous two positions are both said to be 'reductionist', in that they only consider a one-way relationship between different levels of aggregation: either the micro determines the macroeconomic element, or the latter affects the former. An alternative to these reductionist views, not fully developed yet in modern economic theory, was proposed long ago by Veblen (1899 and 1919).[6] He suggested that important interrelationships exist between the formation of individuals' habits of thought and aggregate institutional regularities. In his view, the macroeconomic and social regularities are determined by the behaviour of individuals, but economic agents are in turn greatly affected by the macro structure in which they live. This temptative description of a co-evolution between different levels of analysis may be labelled 'non-reductionism' (Hodgson, 1993, pp. 246-248), in that there does not exist a single dominant level of aggregation, but each level interacts with the others. As section 3 will point out, modern evolutionary economists frequently call for some form of non-reductionism in the attempt to analyse the co-evolution across different levels of analysis (Dosi and Winter, 2000), although no significant advance in this respect has been obtained yet since the times of Veblen.

2.2 *Representative agent or heterogeneous individuals?*

This question refers to the way in which (micro) economic agents are represented in the theoretical framework. In the history of economic thought, we may distinguish between some major different approaches:

(i) *Neoclassical typological thinking*: this is the position adopted by neoclassical economics since the marginalist revolution, according to which economic agents can be studied by analysing the behaviour of a 'representative agent'. In the simplest and most standard version of the neoclassical metaphor, the economic agent is typically described as a rational maximizer of utility/profits under given constraints and perfect information.

(ii) *Smithian typological thinking*: according to Adam Smith and, later, Herbert Spencer economic agents are genetically similar and homogeneous, but the production process and the division of labour bring differentiation in skills and tasks because individuals learn 'by doing'. Heterogeneity, in this case, is not a precondition but a consequence of the process of economic growth. It is not a genetic attribute of economic agents, but a characteristic acquired during their working life.

(iii) *Marxist typological thinking*: Karl Marx pointed to the existence of a fundamental opposition between two different social classes, the capitalists and the proletarians. These two classes are defined in terms of their relationship to the means of production, and have permanently different interests and purposes. However, within each class, individuals are homogeneous. In other words, Marx implicitly assumes the existence of a duality between social classes at the macroeconomic level, but not heterogeneity of individuals at the microeconomic.

(iv) *Schumpeterian typological thinking*: in Schumpeter (1934 and 1939), the microeconomic description of economic agents is rather peculiar. On the one hand, there is a group of individuals, the entrepreneurs, genetically endowed with special psychological characteristics; they are the ones to determine the growth process, the real source of change. On the other hand, however, all the other economic agents are ordinary and indifferentiated individuals, not dissimilar from the representative agents of neoclassical theory, which react in a deterministic way to the changes of the process over time. This appears as an intermediate position between neoclassical typological thinking and evolutionary biology's 'population thinking'.

(v) *Veblen's population thinking*: heterogeneity of economic agents is an essential characteristic of an evolutionary approach to economic change, an early example being the work of Veblen (1899). Inspired by the developments of evolutionary biology, Veblen believed in the existence of a fundamental element of heterogeneity in individuals' cognitive processes and in the formation of habits of thought, and originally pointed out that this variety is an important precondition for the process of economic growth and social change. Applying the biological metaphor to economics, 'population thinking' means that economic theory cannot ignore the heterogeneity in the population of economic agents, but must necessarily be built on that, as variety is the major source of novelty (innovation) in the process of economic development.[7]

2.3 *What is the mechanism of creation of innovation and new variety?*

In modern theories of innovation and growth, the mechanism through which innovation and new variety are introduced in the economic system is the main source of economic growth, and it thus constitutes a key element in the theoretical framework. Referring to classical authors, we may briefly outline these different mechanisms of technical change:[8]

(i) *Manna from heaven*: The neoclassical representative firm, in its simplest description, is assumed to have perfect and complete knowledge about the best technology available at any given time, and to always be able to adopt it. Technological knowledge is static, perfectly codifiable, and independent of the economic context and situation in which firms make their technological choices. All firms, then, can easily imitate and adopt advanced techniques used by more innovative firms. Knowledge is regarded as a public good, promptly available to all economic agents without further constraints. Technical change, in the most simplified version of the neoclassical metaphor, is exogenous and unexplained.

(ii) *Learning by doing*: this is the mechanism originally suggested by Adam Smith. The production process brings deeper division of labour and increasing specialization, and economic agents learn 'by doing' things and by producing goods during their working activities. Innovation, being a necessary consequence of the productive process, is therefore endogeneous, and mainly incremental and continuous.

(iii) *Labour saving technical change*: this is the mechanism pointed out by Marx, according to which capitalists introduce labour saving technical innovations to decrease labour costs and to expand their profits. However, it remains unclear in the Marxian view how the new technology is invented, selected and adopted by capitalists.[9] The real mechanism of technical change is then exogenous and unexplained.

(iv) *Schumpeterian innovation*: Schumpeter was the first author to use a broad concept of innovation which encompassed technical as well as organizational changes, and to give it a central role in the explanation of economic development. Focusing on radical rather than incremental innovations, he put forward the idea that 'new combinations' are introduced by the entrepreneurs, which are individuals endowed with special psychological traits and creativity (Schumpeter, 1934). Later in his life, he suggested that the innovative process is systematically organized and performed by R&D laboratories within large firms (Schumpeter, 1943), rather than introduced by creative entrepreneurs.

(v) *Veblen's idle curiosity*: Veblen suggests the existence of an important source of variety which continuously opposes to the inertial nature of habits of thought and institutions, namely the "human tendency towards experimentation and creative innovation" (Hodgson, 1993, p.127). Veblen called this tendency 'idle curiosity', and regarded it as a genetic human attitude that is a pre-condition for the process of growth, and not a consequence of it (as in Smith and Spencer). Veblen conceived 'idle curiosity' as analogous to mutations in Darwinian evolutionary biology, and thus as an ongoing and permanent source of change and renewed variety in the economic system.

2.4 *What is the dynamics of the growth process? How is history conceived?*

This characteristic refers to the type of dynamics of the growth process, and it is closely related to the way in which history is conceived in the theoretical framework. A brief look at the history of economic thought suggets that we may distinguish between some major different ways of conceiving economic dynamics:

(i) *Transitional dynamics*: the focus of neoclassical theory is on the static allocation of resources at a given time, and dynamic analysis is conceived as an extension of the equilibrium metaphor to the long run. Economic dynamics is regarded as a process of transition towards a new state of equilibrium. History may therefore be thought of as a process of uniform-speed transitional dynamics towards long run equilibrium, rather than a process of irreversible and qualitative change.

(ii) *Increasing complexity*: this is the position adopted by Adam Smith and Herbert Spencer, which were both deeply interested in issues of transformation and dynamics, rather than resource allocation in a static context. They both argued that socio-economic change proceeds towards an increasing degree of specialization and complexity, and that it is a process of qualitative change. History was then conceived as a (uniform-speed) gradual evolution towards higher states of complexity and differentiation.

(iii) *Revolutionary and dialectic dynamics*: Marx conceived the dynamics of economic and social change as revolutionary, violent and disruptive. Growth is not a slow process of incremental and continuous change, but rather a discontinuous and radical jump from one stage of development to a better one. In his view, history may be conceived as the succession of different phases that proceed in a dialectic and revolutionary manner, until the final state of rest, communism, ultimately sets in.

(iv) *Saltationist dynamics*: Schumpeter argued that "social phenomena constitute a unique process in historic time, and incessant and irreversible change is their most obvious characteristic" (Schumpeter, 1954, p.435). Such a definition of evolution points to the historical dependent unicity and irreversibility of the process of change, which is meant to be qualitative as well as quantitative change. According to him, evolution may be thought of "more like a series of explosions than a gentle, though incessant, transformation" (Schumpeter, 1939, p.102). This 'saltationist' characterization of the process of economic evolution is in many respects similar to Marx, and it is in sharp contrast with the more 'gradualist' character of other classical economists as well as neoclassical economics.

(v) *Gradualist evolutionary dynamics*: gradual, continuous and incremental qualitative change is not only the characterizing element of Smith and Spencer, but also of the evolutionary theory of Veblen. According to him (Veblen, 1899 and 1919), the coexistence of forces driving towards change ('idle curiosity') and inertial forces (the persistence of 'habits of thought' and 'institutions') determines a process of gradual evolution. History is an evolutionary process of qualitative change and cumulative causation.

2.5 *Is the growth process deterministic or unpredictable?*

Another important feature in economic growth theorizing is whether the process described is deterministic and predictable, or rather non-deterministic and unpredictable. Although many intermediate positions could be discussed, it is useful to point out the two major (opposite) views.

(i) *Mechanistic, deterministic and predictable process*: the economic world is understood and represented in terms of cause-effect mechanisms, in which there is no space for purposeful behaviour and free choice. Inspired by the developments of classical physics and astronomy, the mechanistic view in economics has been dominant since the time of classical economists (including Marx), marginalist and neoclassical economics. The mechanistic view implies that, given the initial conditions at the present time and the law of motion of the economic system, any future state can be perfectly foreseen. Mechanicism, therefore, implies determinism and predictability of future economic outcomes.[10]

(ii) *Non-mechanistic, non-deterministic and unpredictable process*: the mechanistic metaphor, according to a different view, is not appropriate to describe the evolution of a complex system. Purposeful behaviour, deliberate choice and creativity of individuals introduce a fundamental element of non-mechanicism and unpredictability in the economic world. This is the view adopted, more or less explicitly, by German Historicists, Old American Institutionalists (e.g. Veblen), and to a certain extent by Schumpeter. In this view, the process of innovation and economic growth is characterized by genuine and pervasive uncertainty, rather than mere computable risk.

This distinction was originally put forward by Knight (1921), according to which "the practical difference between the two categories, risk and uncertainty, is that in the former the distribution of the outcome in a group of instances is known (either through calculation *a priori* or from statistics of past experience), while in the case of uncertainty this is not true, the reason being in general that it is impossible to form a group of instances, because the situation dealt with is in a high degree unique" (Knight, 1921, III.VIII.2). In an economic world characterized by radical uncertainty, rather than computable risk, given the initial conditions at the present state, it is not possible to predict with certainty what the future state of the economic system will be. The economic process is non-deterministic and fundamentally unpredictable.

2.6 *Towards equilibrium or never ending?*

Where does the economic process lead to? Does it tend towards a final state of long run equilibrium, or does it change continuously and go on moving forever without any definite final point? By and large, it is possible to point out two main different views on this fundamental characteristic of economic theory:

(i) *Towards equilibrium*: the process of economic growth tends towards a final state of rest, equilibrium, and greater economic welfare. This was the view adopted, in different forms, by Adam Smith and Herbert Spencer, as well as Marx (for which 'communism' is a final state of rest in which all conflicts and dualisms ultimately cease). The equilibrium view became more explicitly dominant in economics after the marginalist revolution, since the last decades of the nineteenth century. More recently, the neoclassical theory of growth (e.g. Solow, 1956) extended the static concept of equilibrium to the analysis of the dynamics of the long period, by assuming the existence of a ‘steady state’ towards which the economic system will tend in the long run.

(ii) *Never ending process*: the equilibrium view has frequently been criticized outside of the economic mainstream. Economic growth, it has been argued, is a never ending and ever changing process, it does not tend towards a steady state of balanced growth. This is the view expressed in the past, among others, by German Historicists, Schumpeter and Veblen. Using the latter’s words, economic evolution is “a continuity of cause and effect. It is a scheme of blindly cumulative causation, in which there is no trend, no final term, no consummation […], a theory of the process of consecutive change, realized to be self-continuing or self-propagating and to have no final term” (Veblen, 1919, pp. 36-37).

3. Evolutionary growth theorizing

After having defined the main concepts that will be used in this survey, we will now discuss the major strands of research within modern evolutionary economics. This section will consider in turn the main approaches, namely the neo-Schumpeterian long wave theory, the technology-gap approach, Nelson and Winter-like evolutionary theorizing, and the National Innovation Systems framework. Each subsection is composed of two parts: the first presents a brief overview of the approach, while the second part analyses its theoretical foundations by answering the six questions presented in section 2. The discussion will point out that these four approaches share, to a large extent, the same theoretical foundations, so that they may be conceived as different strands of research within the evolutionary economic paradigm. The analysis will also argue, though, that although important advances have been realized in evolutionary economics in the last two decades, there still exist great challenges ahead.

3.1 *Neo-Schumpeterian long wave theory*

The neo-Schumpeterian approach to economic growth takes great inspiration from Shumpeter's book *Business Cycles* (1939), in which the author put forward a theory about the existence of long waves of economic growth. His original point was to focus on the importance of basic (radical) innovations in creating such long waves, because, he argued, they have potentially a deep impact on the whole economy. The Schumpeterian insights on the central role of radical innovations in the macroeconomic growth process did not affect significantly the development of economic thought in the following four decades. Since the mid 1970s, however, there started to be greater criticism on the way in which mainstream economics approached the relationships between technical change and economic growth, and a renewed interest in the central role of innovation as the majour source of economic growth.

The debate started with Kuznets' (1940) review of Schumpeter's *Business Cycles* (1939). His long wave theory, Kuznets argued, did not explain neither the reasons for the timing of occurrence of basic innovations in the depression phase of the wave, nor why they tend to cluster over time. Mensch (1979) put forward the idea that radical innovations tend to cluster in the depression phase of the long wave because this is the time in which the lag between invention and innovation is shortened (so-called 'depression-trigger hypothesis'). A rich empirically oriented literature (among others Kleinknecht, 1981; Van Dujin, 1983) focused on the timing of clustering of basic innovations. The empirical results of these works have been heavily debated. On the whole, as pointed out by Freeman, Clark and Soete (1982), the empirical evidence on the clustering of basic innovations in the depression phase of the wave is rather weak and not conclusive.

After this empirical debate, a second stream of neo-Schumpterian literature flourished during the 1980s, providing a number of concepts and ideas useful to give a stronger theoretical foundation to long wave theory. These more conceptually oriented contributions started with the publication of the book *Unemployment and Technical Innovation* (Freeman, et al., 1982), and was followed by the works of Freeman (1983, 1984 and 1987), Perez (1983, 1985), and Freeman and Louca (2001).

As Perez (1983) points out, the Schumpeterian process of development "unfolds within the economic sphere conceived as a self-regulating organism which provokes its own disturbances (innovations) and absorbs its impacts by constantly striving towards new higher equilibria". The social conditions and institutional framework are excluded from the causation mechanism that drives the primary cycle. This is the reason why she argues that "Schumpeter does lay the foundations for a theory of the cyclical nature of the capitalist economy but not of long waves" (Perez, 1983, p.359). Based on these considerations, neo-Schumpeterian scholars conceive the capitalist system as formed by two related sub-systems: the techno-economic and the socio-institutional. It is the joint evolution of these sub-systems to determine the 'mode of development', and consequently the rise and fall of long waves.

According to this view, it is not important *when* a set of basic innovations is introduced, but rather that these radical innovations are strictly interrelated and pervasive, i.e. that they may drive the growth of many fast growing sectors of the economy. Such a family of interrelated basic innovations may be called 'technological system' (Freeman et al., 1982), 'technological paradigm' (Dosi, 1982), or 'technological style' (Perez, 1983). This concept is arguably quite similar to that of 'general purpose technologies', although the latter is more frequently used in new growth theories (see section 4). When a new technological style arises, there is a big impulse in the techno-economic sub-system to adopt the new best practice technology with high profit prospects. However, the techno-economic system is more ready to accept and adopt changes, while the socio-institutional one may take a longer time before making the changes required by the new technological style. The mismatch between the two sub-systems may retard the large-scale introduction of the new paradigm, precisely because social, organizational and institutional changes are necessary before it can diffuse to the whole economy. As the socio-institutional system evolves, the 'harmonic complementarity' between the two systems gradually restores, and a new mode of development eventually sets in. This may determine a long wave pattern similar to the primary cycle described by Schumpeter (1939): rapid diffusion of the new paradigm, incremental innovations over its 'natural trajectory' (Nelson and Winter, 1977), creative destruction, and consequently the upswing and prosperity phases of the long wave. Later on, increased competition and market saturation, decreasing revenues from the new technologies and decline of profits, which characterize the recession and depression phases of the long wave.

3.1.1 *Discussion*

The first question that our critical review considers refers to the level of aggregation of the approach. In this respect, neo-Schumpeterian long wave theory is a macroeconomic approach to the study of innovation and growth, the focus of the analysis being the evolution of a country (or a group of countries) over time. Great attention is devoted to the study of sectoral differences, focusing in particular on more technologically advanced and fast-growing sectors, which are those that drive the overall growth of the economy. The sectoral analysis, though, is primarily carried out with the purpose of understanding the implications and effects of sectoral patterns on national and international macroeconomic growth. Differently from Schumpeter, then, neo-Schumpeterian theory is not explicitly microfounded. It shows that the main features of Schumpeterian macroeconomics can be obtained without necessarily following methodological individualism.

Consequently, as there is no description of the microeconomic level, the notions of heterogeneity and population thinking are not explicitly considered in this approach. However, the fundamental role of heterogeneity and, more in general, the evolutionary foundation of such an approach, are increasingly recognized by recent long wave studies (Freeman and Louca, 2001). An evolutionary type of modelling in which the interactions of heterogeneous agents determine long wave patterns has already been proposed in the works of Iwai (1984) and Silverberg and Lehnert (1994). The future extension of this class of models could make the evolutionary foundation of neo-Schumpeterian studies more explicit than it is at the present stage.

Similarly to all the other theoretical frameworks considered in this paper, innovation is the main source of economic growth. The historical and institutional context in which technical and organizational innovations take place is considered with great accuracy in neo-Shumpeterian works. On the one hand, the innovative process is exogenous, because it depends on the science and technology system, which is pointed out as important but not explicitly investigated. On the other hand, though, innovation is an endogenous activity, determined by R&D investments of firms and, in a later phase of the long wave, linked to demand and production growth through learning by doing, dynamic economies of scale, and embodied technical progress.

Innovation is arguably the majour source of economic growth in this framework, but this does not justify the often-made claim that neo-Schumpeterian long wave theory is a technological deterministic approach. Such a criticism is based on the fact that when a new technological paradigm emerges, it is the evolution of the techno-economic system to determine the socio-institutional characteristics that are required to compete in the new long wave period. So, transformations in the techno-economic system affect greatly the characteristics of the new mode of development. However, in the downswing phase of the long wave, innovations are more likely to be introduced in the market because firms and consumers are more willing to risk and to try out new solutions. It is in the downswing phase that consumers' expectations, firms' animal spirits, and social and political changes facilitate the introduction and diffusion of a new technological paradigm. Therefore, changes in the socio-institutional system may also affect the techno-economic, so that it is not appropriate to argue that neo-Schumpeterian long wave theory is based on a simple one-sided and technological deterministic view of the process of economic change.

The creation and diffusion of interrelated innovations determine long waves of economic growth, each characterized by an initial speed up (upswing) and then a slowing down phase (downswing). The dynamics of the process is saltationist, disruptive, irregular, and characterized by structural and irreversible change, as in Schumpeter's view. Precise regularity and strict periodicity are not assumed in long wave theory, the process repeats itself over time but in a rather irregular way (Freeman et al., 1982). According to this interpretation of history, the recurrence of long waves does not imply that the waves are all the same. The only recurrent mechanism is the co-evolution between technological and socio-institutional changes and its importance for economic growth, but the precise form that they take in each historical phase is ever changing and always different. Every occurrence is singular and unique in historical time.

A common criticism made to the long wave approach refers to its 'mechanistic' flavour. On the one hand, it is true that, once a new technological paradigm emerges, the long wave process is assumed to follow in a more or less automatic and mechanistic way, closely resembling the Schumpeterian primary cycle. On the other hand, however, in the downswing phase it is not possible to predict which technological and organisational innovations will characterize the following historical phase, and when they will come about. The outcomes of the science and technology system are non predictable with accuracy, and the same is true for the socio-institutional changes that will follow. Considering the whole long wave sequence, then, the process described may certainly be regarded as non-deterministic and non-predictable.

Finally, with respect to the sixth theoretical question that we consider in our discussion, it should be observed that the neo-Schumpeterian process of growth is ever-changing and never-ending, it does not tend towards the steady state. Similarly to Schumpeter, the economic system is never in equilibrium, there are always forces determining further disequilibrating movements. It is innovation that continuously breaks the circular flow of economic activity, and that determines the inherent disequilibrium nature of the economic system.

3.2 *The technology-gap approach*

While neo-Schumpeterian scholars study the process of economic development *within each country*, technology-gap theorists focus on technological and economic differences *between countries*. The approach has originated from the contributions of historically oriented economists, which investigated the process of catching up and overtaking of some advanced (leader) countries in the last two centuries by focusing on the creation of new technologies and on its international diffusion (Veblen, 1915; Gerschenkron, 1962; Habakkuk, 1962; Landes, 1969; Abramovitz, 1986 and 1994, Freeman, 1987). These historical contributions, different as they may be, all point out that two broad sets of factors are necessary for succesful catching-up and rapid growth in the long run: techno-economic and socio-institutional factors. The crucial point is thus that catching up is a complex process, so that its investigation cannot only look at economic factors, but also at the important technological, social and institutional aspects related to the development process.[11]

Originating from these historically oriented studies, a modern strand of technology-gap theory has developed since the 1980s. These more quantitative-oriented applied studies aim at explaining the historical evidence on catching up by adopting a Schumpeterian perspective on the importance of innovation and international diffusion for economic growth. The Schumpeterian idea that firms compete in the market by upgrading their technological capabilities is then applied to the macroeconomic level, where countries are assumed to compete for the economic leadership through their technological capabilities, absorptive capacities and innovating activities. Econometric works in this tradition typically investigate differences in economic growth rates and trade performances by using indicators of national technological activities, such as R&D and patent statistics. The strong correlation generally found between technological and macroeconomic performance (e.g. Fagerberg, 1987 and 1988; Dosi, Pavitt and Soete, 1990) is then taken as an indication of the fundamental role played by the creation and diffusion of technologically advanced products and processes for explaining growth rate differences.

These econometric studies investigate differences in technological and economic performances on large samples of advanced and middle-income countries, so that, compared to the previous historically oriented contributions, the focus shifts from the study of the catching up process of single countries to the analysis of convergence and divergence in the whole sample of countries, carried out through statistical and econometric techniques. The cross-country econometric methodology is thus remarkably similar to that used in the convergence literature in mainstream economics (see section 4).

The theoretical perspective that underlies the applied work in the evolutionary technology-gap tradition, however, is quite different from its neoclassical counterpart. As developed by Cornwall (1977), Abramovitz (1986 and 1994), Fagerberg (1987, 1988 and 1994) and Verspagen (1991 and 1993), the modern technology-gap approach to economic growth assumes that innovation and the international diffusion of new technologies are the main sources of differences in growth rates between countries. Follower countries have a technology-gap (or technological distance) that separates them from the leader country, and they can therefore try to exploit their backward position by imitating and using advanced technologies developed by the leader country, instead of creating them from scratch. The process of imitation and diffusion of new technologies is costly, though, and it requires the existence of social and institutional capabilities that not all the follower countries have (Archibugi and Michie, 1998). This explains why catching up and convergence are not automatic and common outcomes.

Considering the conditions that are necessary for successful imitation and catching up, two broad sets of factors have been stressed. First, following Abramovitz (1994, p.24), it is important to consider the 'technological congruence' of a country. This is defined by various factors: (i) the 'technological interrelatedness', i.e. how much a country is committed to the old technological paradigm, and therefore how difficult is to make the jump into the emerging one; (ii) the country's natural resources and factors endowment; (iii) consumers' demand and tastes; (iv) market size and scale; (v) transportation and infrastructure; (vi) facilities for structural change, i.e. how rapidly the economic system is able to shift resources from the old to the new paradigm; (vii) general macroeconomic conditions and the rate of growth of demand. Second, turning to the broad set of social, cultural and institutional factors, Abramovitz (1994, p.25) defines the 'social capability' of a country, characterized by: (i) its level of education and technical competence; (ii) skills of the entrepreneurial class; (iii) commercial, industrial and financial institutions; (iv) political and social characteristics that influence the risks and incentives of economic activity; (v) science-technology links in firms and public research centres.

Considering them together, techno-economic congruence and social capability differ between countries in each technological paradigm, and these structural differences may explain why some countries manage to succesfully catch up with the technological leader, while some others fall behind. The major difference between this theoretical perspective and technology-gap models in the neoclassical tradition (or North-South models, see Chui et al., 2002) is that the evolutionary view stresses the importance of the social and institutional structure to determine the social capability of a country (Abramovitz, 1986) and its ability to imitate foreign technologies.

3.2.1 *Discussion*

Similarly to the neo-Schumpeterian long wave theory previously discussed, the technology-gap approach is a macroeconomic approach. Applied works in this tradition are not based on the concept of aggregate production function, and the approach is therefore not explicitly microfounded, as there is no description of the behaviour of economic agents that may determine the aggregate outcomes. The Schumpeterian insights on innovation, diffusion and technological competition are transferred from the individual to the aggregate level of analysis: such as firms compete in the market for their market shares and profits, countries compete in the international arena for the technological and economic leadership. The main unit of analysis, then, is the country (some recent works focus on the regional level instead; see Fagerberg and Verspagen, 1996; Cappelen et al., 2003).

As the approach is not microfounded, heterogeneity of individuals and population thinking are not explicitly considered in this framework. It is argued that countries are fundamentally and structurally different, particularly from a social and institutional point of view, but this variety at the macroeconomic level is assumed, and not explained by focusing on the interactions in a population of heterogeneous agents. Some formal evolutionary models (Dosi and Fabiani, 1994; Dosi et al., 1994), however, show that the interactions of heterogeneous agents in an evolutionary framework may generate situations of catching up and falling behind, and reproduce the empirical patterns of convergence and divergence that applied studies have found. More work of this kind is needed in the future. The study of the aggregate properties of microfounded evolutionary models is a fascinating challenge for future research in this field, and it may provide a bridge between the applied work in the technology-gap tradition with the formal analysis of Nelson and Winter-like evolutionary models (discussed in section 3.3 below).

Technological change is the main source of economic growth, but its mechanism, rate and direction are not investigated. Although innovation and diffusion of technologies are conceived as fundamental conditions for catching up, the way in which they are introduced in the economic system is not analysed further. The focus is on the structural and institutional factors that may facilitate or hamper the process of international diffusion, but not on the factors that may explain a differential rate of creation of innovations in different countries. The approach does not shed any new light in this respect.

The dynamics implicitly assumed in technology-gap studies is mainly saltationist. The approach argues in fact that when a new technological paradigm sets in, there is a strong technological push in the economic system, which may turn to have important consequences for the patterns of convergence/divergence. In times of radical changes, leader countries can more easily invest in the new technologies, and are therefore likely to grow faster than follower countries, so that greater divergence between rich and poor countries may follow. After some decades, when catching-up countries start to imitate and use the new technologies in large scale, convergence in the whole sample may be a more common result. So, the dynamics of convergence/divergence between countries does not proceed at uniform speed, but it rather follows the paradigmatic, saltationist and discontinuous character of technological change.

Moreover, the process of catching-up and falling behind is conceived as non-deterministic and non-predictable. The reason is that as technological change is fundamentally an uncertain phenomenon, it is not possible to predict which new technological system will prevail in the future. Therefore, it is hard to predict with accuracy the countries that will be more likely to catch-up in the future, and those that will fall behind. The applied works in this tradition show the changing character of the catching up and convergence process over time. The more recent evidence points out that, while it was relatively easier to imitate and import foreign technologies in the age of Fordism and mass production, the scope for catching up has significantly decreased in the last two decades. The catching up process of follower countries requires now a greater effort for the creation and improvement of national technological capabilities (Fagerberg and Verspagen, 2002). The technology-gap process of growth is then ever-changing and never-ending, it is a process of qualitative change and transformation, rather than a transition towards the steady state.

3.3 *Nelson and Winter-like evolutionary theorizing*

The possible use of the biological-evolution metaphor in economic science was originally suggested by Veblen and Marshall more than a century ago, but the development of modern evolutionary economics is relatively recent, tracing back to Nelson and Winter's (1982) book *An Evolutionary Theory of Economic Change*. Nelson and Winter-like evolutionary theorizing is currently the most influential and rapidly developing branch in the evolutionary economic paradigm.

Three complementary streams of literature have recently extended in various directions Nelson and Winter's theory of economic change: (i) microeconomic evolutionary theory of consumers, firms and organizations, closely connected to cognitive psychology, business and organizational studies;[12] (ii) sectoral studies on the historical evolution of particular industries, and related analyses of industrial dynamics and sectoral systems of innovation;[13] (iii) formal models of economic growth.[14] Although the three streams focus on different aspects of the evolutionary process at various levels of aggregation (firms, sectors and countries, respectively), they all conceive economic evolution as driven by the interactions between heterogeneity, selection and innovation processes. Figure 1 shows a simplified scheme of these interactions.

Heterogeneity (or variety) of economic agents is a fundamental feature of the evolutionary economic world. The latter is characterized by complex evolving knowledge, bounded rational agents and radical uncertainty. In such an uncertain world, individuals follow routines and habits of thought in their economic activities. Routines are regarded as the counterpart of genes in biological evolution. The reason for this analogy is threefold: routines are embodied in the minds and production activities of economic agents; they greatly differ among the various units of the population; and they can be transmitted from one individual to another, so that they may take account of the regularities sustaining stable and inertial patterns of production over time.

Within the same firm, production can be conceived as guided by routines at different levels, driving the standard operating procedures, the investment behaviour, and the deliberate search for new routines or solutions when the old ones prove to give unsatisfactory results in terms of market shares and profits. Routine-guided firms may thus be thought of as the counterpart of phenotypes in biological evolution, because their behaviour is the result of the interactions of their genetic endowment (individual skills and organizational routines) with a given economic and institutional environment.

Since Nelson and Winter (1982)'s seminal work, several evolutionary models of economic growth have tried to formalize this idea of routine-guided heterogeneous firms within a disequilibrium framework. These models assume that firms differ with regards to the techniques that they use (Iwai, 1984; Conlisk, 1989; Silverberg and Lehnert, 1994), their behaviours and strategies (Chiaromonte and Dosi, 1993; Dosi et al., 1994; Fagiolo and Dosi, 2003; Silverberg and Verspagen, 1994a; 1994b; 1996), or the characteristics of the sectors in which they operate (Winter, 1984; Verspagen, 1993). Evolutionary analytical models, therefore, aim at reproducing the idea that the 'routinized' character of the productive process carried out by a population of heterogeneous firms may generate a relatively stable pattern of economic activities and relationships over time. The important point, however, is that such inertial forces and inherent persistency are continuously counteracted by dynamic forces that push the economic system towards evolution, change and transformation. These dynamic forces are technological competition and selection, on the one hand, and innovation on the other.

In the same way as animal species compete for their survival in the natural environment, heterogeneous firms compete in the market by trying to employ more advanced techniques, and to produce at lower costs and better quality than their competitors. The selection mechanism in evolutionary models typically depends on the profits realized by each firm. Firms that are able to obtain high profits increase their market shares; firms with inferior technological capabilities realize lower profits, loose market shares, and will ultimately be driven out of the market. The idea of selection-based growth, put forward in different forms in the past by Schumpeter (1939), Alchian (1951) and Winter (1964 and 1971), is usually represented in recent formal models through the use of replicator (or Lotka-Volterra) equations in which the firm's market share (or production level) is assumed to evolve over time as a function of its technological capability and profitability.

An important qualification, made by the growing number of studies of sectoral patterns of innovation (Pavitt, 1984; Malerba, 2002), is that the competition-selection process works differently in different industries of the economy. Each sector is characterized by the complex interactions between heterogeneous agents, economic structure, institutions and technological characteristics. The latter, in particular, determine the 'technological regime' in which competition and selection take place. The technological regime may be conceived as the technological environment in which innovative activities take place in different industries of the economy. Such an environment differs in terms of technological opportunities, properties of the knowledge base, cumulativeness and appropriability conditions. Formal models and econometric evidence show that the characteristics defining technological regimes may generate the different patterns of industrial dynamics originally identified by Schumpeter (i.e. the so-called Schumpeter Mark I and II; see Winter, 1984 and Malerba, 2005).

Over time, competition and selection tend to consume and to reduce the initial heterogeneity. Without the creation of new variety, the process of evolution would soon come to an end. The fundamental point about the evolutionary economic world is precisely that there is an ongoing introduction of novelty, so that heterogeneity and variety are continuously renewed, and evolution is a never-ending process. In particular, two main different sources of novelty have been stressed in the literature. The first is a kind of 'unintended' innovation, that arises when new routines are created as an automatic and non-deliberate consequence of routinized production within firms. This is for example the case when the firm expands its production scale by hiring additional workers or buying new machines. The additional workers and equipments can never exactly replicate what the old were doing, so that a firm's routines can be randomly modified at any time (Nelson and Winter, 1982, ch. 5). Moreover, the old routines applied to a larger scale can be improved simply because workers learn by doing and by producing. Dynamic economies of scale assume then an important role in an evolutionary environment, as it is for example the case in the model by Silverberg, Dosi and Orsenigo (1988).

A second important source of novelty comes from a deliberate search for new technical solutions whenever the old one does not lead to efficient outcomes and satisficing profits. Nelson and Winter (1982)'s formal model assume that when the profit rate falls below a certain threshold, the firm will engage in a process of search for a better technique by imitating other firms or by creating innovation. Winter (1984) and Malerba (2002) point out that the probability that a firm chooses to imitate or to innovate depends on the characteristics of the technological regime in which it operates, and in particular on the possibility to appropriate the innovation profits, which determines the technological spillovers that is possible to exploit in a given sector of the economy. A later class of evolutionary models (Silverberg and Verspagen, 1994a; 1994b; 1995; 1996), has introduced the idea that firms may change their strategies and routines by learning from past experience, so that evolution does not only imply technological change but behavioural learning as well.

In a nutshell, evolutionary economic theory explains growth in terms of the dynamic interactions between heterogeneity, competition, selection, and innovation, where the latter leads to renewed heterogeneity and thus to perpetuate the growth process. From a theoretical point of view, the evolutionary description of the economic world appears as a novel contribution to growth theory. Its empirical relevance, though, is still difficult to evaluate, and the relationship between formal models and econometric work in this tradition has not been made explicit yet. In particular, what kind of empirical stylized facts may be generated as outcomes of evolutionary models?

Although evolutionary economics has not yet agreed on a standard set of assumptions and results, important empirical trends have been generated as 'emergent properties' of different classes of evolutionary models, i.e.: (i) structural change and creative destruction (like in the studies of industrial dynamics, history-friendly models and recent studies on 'sectoral systems of innovation', see Malerba, 2005); (ii) path-dependency (in models where the coexistence of random events and increasing returns may generate path dependent phenomena of the kind described by David, 1985, and Arthur, 1994); (iii) long waves and fluctuations without fixed periodicity (Silverberg and Lehnert, 1994; Silverberg and Verspagen, 1994a; 1994b; 1995; 1996), reproducing the predictions of the neo-Schumpeterian literature discussed in sec. 3.1; (iv) endogenous specialization patterns and uneven international trade (e.g. Verspagen, 1993); (v) patterns of convergence/divergence between countries at the macroeconomic level (Dosi et al., 1994; Chiaromonte and Dosi, 1993), closely related to the predictions of the technology-gap approach discussed in sec. 3.2. The examples above indicate that an important future challenge for Nelson and Winter-like evolutionary modelling is to reach a closer link between formal models and econometric studies, as this may also provide a more explicit bridge with the other evolutionary traditions considered in this paper.

3.3.1 *Discussion*

Evolutionary models are explicitly microfounded on a population of heterogeneous agents (population thinking). The theory is bottom-up built, it considers necessary to start from the microeconomic level to derive the macroeconomic implications. Aggregate phenomena are defined as 'emergent properties', i.e. "the collective and largely unintentional outcome of far-from-equilibrium micro interactions" (Dosi and Winter, 2000, p. 5). Individuals' skills and firms' routines are the basic units of microeconomic analysis. However, the way in which routines and habits of thought of economic agents may in turn be shaped and affected by the macroeconomic and institutional environment in which they operate has not been made explicit yet. A co-evolution across different levels of analysis is in fact often called for, but not systematically introduced yet in evolutionary modelling. Arguably, future evolutionary models may assume the same non-reductionist character as verbal and non-mathematical studies of evolutionary economic change. Non-reductionism appears therefore as an important challenge for future research in evolutionary economics.

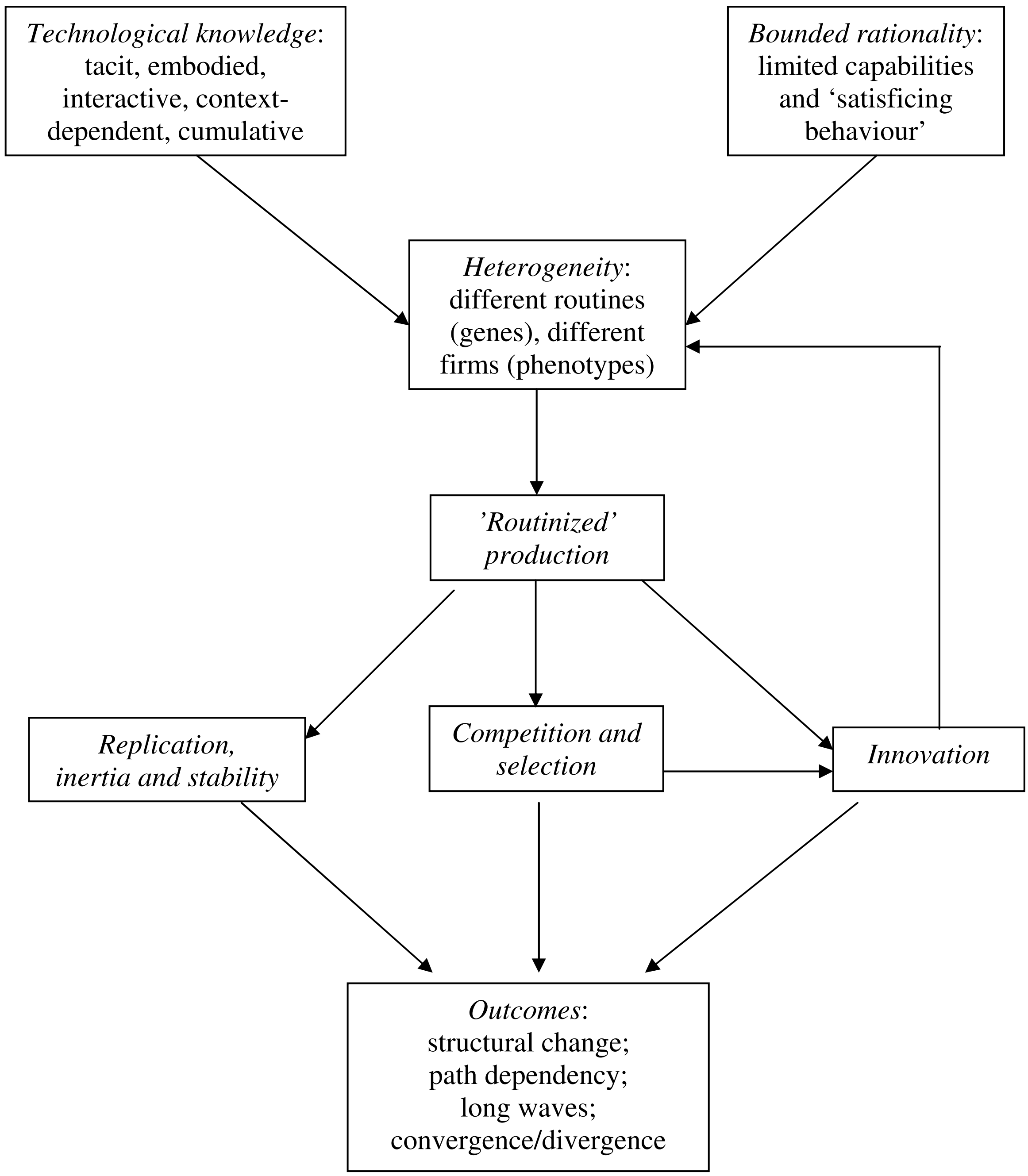
The population of heterogeneous firms is analyzed in terms of the interactions between variety, competition, selection and innovation. The latter is the fundamental source of renewed variety and economic growth, without which evolution would ultimately cease. Novelty can take the form of unintended and automatic consequence of the routinized production, or of deliberate search by firms for new technologies (through innovation and imitation). In both cases, the focus of evolutionary modelling is on an incremental type of innovation, while Schumpeterian radical innovations have not yet found a decisive role in this strand of research.

As a consequence, the dynamics of the economic system is prevailing gradualist, characterized by slow and continuous change and transformation, rather than drastic jumps as in the case of neo-Schumpeterian and technology-gap approaches. History may be conceived as an evolutionary process of gradual and continuous growth and qualitative change, which does not necessarily pass through the succession of different paradigmatic phases. The focus on routinized production and routine-guided innovation gives the theory a bias towards continuity and gradual evolution, in which radical technical and institutional changes can hardly emerge from the inertial quality of routines and habits of thought.

Similarly to the other evolutionary strands of research, economic growth is seen as a non-predictable process, because fundamental sources of uncertainty exist in the economic system. In particular, uncertain and non-deterministic innovative activity is represented in formal models by assuming that the arrival rate of innovation follows a stochastic process (e.g. a Poisson random variable). This formalization, though, appears more suitable to represent an economic environment characterized by computable risk rather than the strong and pervasive uncertainty of the evolutionary world.

The coexistence of random and systematic factors driving economic evolution (Nelson, 1995; Verspagen, 2005), together with the coexistence of inertial and dynamic forces, determine the outcomes of the models: structural change, path-dependency, aggregate growth, endogenous specialization patterns, and convergence/divergence across countries. All of these phenomena are explained as the result of far-from-equilibrium micro interactions. Differently from the neoclassical metaphor of a steady state, then, evolutionary economics theorizes an ever-changing and never-ending process of growth and transformation.

Figure 1. Main relationships in Nelson and Winter-like evolutionary economics



3.4 *The national innovation systems framework*

The previous sections have already made clear that the heart of evolutionary growth theorizing is the investigation of the innovative process. Many feedbacks and complex interactions are involved in the creation of technical and organizational innovations, between individuals within the same firm, between different firms, between producers and users of the new technology, between public and private organizations. Towards the end of the 1980s, it was increasingly recognised that such complex links could not be studied within a linear framework, and a 'systemic' approach to the study of innovation was developed.

Freeman (1987) was the first to use a systemic perspective in his national case study on Japan. The national innovation system (NIS) (defined as "the network of institutions in the public and private sectors whose activities and interactions initiate, modify and diffuse new technologies", Freeman, 1987, p.1), he argued, is arguably the most important factor behind the spectacular economic performance of Japan after World War II. From his neo-Schumpeterian perspective, Freeman conceived the national innovation system as a subset of the 'socio-institutional' one. The case of Japan showed how important it is for a country to have an active and well-organized innovation system.

Conceiving the innovation system in a more narrow way than Freeman, Porter (1990) studied the factors behind the different economic performance of ten industrialized countries. He argued that innovative activities greatly vary in firms of different countries for the existence of differences in the following aspects: (i) factor and resource conditions, including natural resources as well as labor; (ii) demand conditions; (iii) related and supporting industries; (iv) firms' strategies and industry structure. These four elements must be considered together, as a part of an interactive whole. The focus of Porter's analysis is the innovative activity of firms, and the various economic factors that may explain innovative activity and output in different countries.

Porter's strictly economic approach to NIS is different from that of Nelson (1993). In his book containing national case studies of the innovation systems of fifteen different countries, Nelson divided them into three groups: large high-income, smaller high-income and lower-income countries. In the concluding chapter, Nelson (1993, p.518) argues that "it is inevitable that analysis of innovation in a country sometimes would get drawn into discussion of labor markets, financial systems, monetary fiscal and trade policies, and so on. One cannot draw a line neatly around those aspects of a nation's institutional structure that are concerned predominantly with innovation in a narrow sense excluding everything else, and still tell a coherent story about innovation in a broad sense". The fundamental difficulty for these applied studies is precisely the one stressed in the above quotation. It is rather difficult to define neatly which aspects to include or to exclude from the study of an innovation system, as private and public organizations interact within a complex institutional and economic structure. Empirical research has then proceeded in a broad and open way, given that it is hard to find universal and standard criteria to measure and compare the performance of innovation systems in different countries.

The difficulties encountered by applied research suggest that a more structured theoretical framework may be useful for the development of the approach. Closely related to Nelson and Winter-like evolutionary tradition, theoretical research in the NIS field started with the book *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning* (Lundvall, 1992), which studied the microeconomic foundations of the innovative process from an evolutionary and systemic perspective. Innovation is a complex phenomenon of a dynamic, cumulative and rather uncertain nature. It is important to consider such complexities not just from the point of view of the single individual or firm, but rather by focussing on the feedbacks and interactions between the various components of the system. Innovations and learning are collective phenomena, they can hardly be understood without an investigation of the complex interactions between heterogeneous economic agents.

A useful distinction in the systemic theory of innovation is that between 'learning' and 'exploring'. Learning is a fundamental and ubiqutous characteristic of modern knowledge-based economies. It is, first of all, the outgrowth of the productive process, because individuals learn 'by doing' things (Arrow, 1962) and 'by using' technologies (Rosenberg, 1982). But economic agents also learn 'by interacting' with other agents (Lundvall, 1992). While learning is mainly an automatic and unaware consequence of the working activities of individuals, 'exploring' denotes a deliberate and active effort to search for new technical and organizational solutions, new products and processes. Typically, it is the R&D system, and more generally the science and technology system, to perform such an exploring activity in a systematic way. The main economic actors involved in this process are R&D professional laboratories in private firms, and research institutes and Universities in the public domain.

Private and public organizations in the science and technology system, however, are not enough to define an innovation system, as there are important macro aspects that need to be considered as well. In fact, any form of learning and exploring is "anchored in the production structure and in the linkage pattern of the system of production" (Lundvall, 1992, p.17). So, an innovation system approach studies scientific and technological activities within the whole productive system, in which learning continuously takes place. In this respect, there are several factors that directly or indirectly affect the innovative process: the education and training system in private firms and public schools, the role of government in innovation and industrial policies, the general macroeconomic conditions, and consumers' tastes and competencies. This suggests an interesting link in the NIS framework between the micro and the macroeconomic levels of analysis. The innovative behavior of individuals and firms is affected by macroeconomic and structural characteristics, and in turn the patterns of innovative activity determine the evolution of those aggregate features over time.

This implicit interaction between the micro and the macro levels of analysis within an innovation system is not only considered from a strictly economic point of view, but also from an institutional one. Institutions are conceived in a broad way as "sets of common habits, routines, established practices, rules or laws that regulate the relations and interactions between individuals and groups" (Edquist and Johnson, 1997, p.46). They differ from organizations, which are consciously created and have an explicit purpose. Institutions can be thought of as 'rules of the game', while organizations are regarded as 'players'. The fundamental importance of institutions in the innovative process is related to the fact that individuals are not rational agents, but follow habits of thought. Economic agents do not properly *choose* what to do, as it is the case in neoclassical microeconomic theory, but rather follow predetermined rules, routines, habits of thought. When these habits are "common to the generality of men" (Veblen, 1919, p.239), they become 'institutions'. It follows that any kind of human knowledge and innovation is accumulated and stored through habits of thought, routines and institutions. Cognitive, learning and innovative processes at the microeconomic level are shaped by institutions and social structures; in turn, the aggregate level of analysis is continuously affected by individuals' innovative and learning processes, which tend to modify the previously adopted patterns of behavior and habits of thought.

According to this view, institutions have an important function to perform in innovation systems, in that they help economic agents to reduce the uncertainty and complexity of the innovative process. Institutions have a stable character, which sustains and enables individual learning and incremental innovations. At the same time, however, in periods of rapid and radical technological change, there is a pressure for the old habits of thought, routines and institutions to modify and to adapt to the emerging technological paradigm. In such circumstances, some creative destruction of knowledge and institutions is necessary, so that forgetting may be as important as learning (Johnson, 1992). Countries with a higher social and institutional adaptability are more likely to enter quickly into a new techno-economic paradigm, and to have positive economic performance for a prolonged period of time, as shown by the case of Japan (Freeman, 1987).

However, although the role of institutions and their relationship with the innovative process is increasingly pointed out in the NIS approach, it must be recognised that the systemic analysis of institutional transformations is still much less developed than the corresponding analysis of technological change. The main focus of the research has so far predominantly been on the role of innovative activities performed by private and public organizations.

3.4.1 *Discussion*

In general system theory, a system is composed by its components and the relationships between them (Edquist, 2005). What gives an evolutionary flavour to the NIS approach, therefore, is not the use of system theory *per se*, but rather the way in which the components and their relationships are represented. This is discussed as follows.

As regards the relations between micro actors and macro structure, the NIS framework presents an explicit attempt to find a compromise between the two opposite views of methodological individualism and methodological holism. In a non-reductionist fashion, both levels of analysis, micro and macro, are studied in the framework. The innovative activity of private and public organizations is affected and shaped by the production structure, the macroeconomic conditions and the socio-institutional system of the country; in turn, national patterns of innovation and productivity growth are determined by the learning and searching activities of (micro) economic agents. The study of the interactions between micro actors and social structure may constitute an important contribution of the NIS framework to the development of evolutionary growth theorizing. Important insights in this respect could come from a rediscovery of the work of Veblen and old American institutionalism, based on the dynamic relationships between 'habits of thought' and 'institutions' (Hodgson, 1993 and 1998). Such a non-reductionist link between micro and macro levels of the analysis, however, has not been made explicit yet in NIS studies, and needs to be further investigated in future research.

Focusing the attention on the microfoundations of the NIS framework, a fundamental characteristic is the heterogeneity and variety of individuals and organizations (McKelvey, 1997; Saviotti, 1997). If all economic agents had the same learning and innovative capabilities, in fact, innovation could be studied by simply analysing the behavior of a representative agent, and there would be no need of a systemic perspective. But great complexities arise because learning and innovation are interactive activities carried out by heterogeneous agents. NIS is therefore implicitly based on population thinking.

Technical and organizational changes are the result of the complex interactions between private and public organizations, consumers and users of new technologies, macroeconomic structure and institutional framework. Innovation partly depends on learning processes (an inherent consequence of the production process), and partly on exploring activities (a deliberate effort to search for new technical solutions performed by the science and technology system). Therefore, the NIS theory of innovation points to the role played by both, radical and incremental innovations. It presents an explanation of technical and organizational changes that combines the neo-Schumpeterian focus on radical innovations with the evolutionary microfounded theory based on learning and incremental changes.

Consequently, the dynamics of the economic process driven by innovation is in principle consistent with both, a saltationist dynamics as in neo-Schumpeterian and technology-gap approaches, and the more gradualist view typical of Nelson and Winter-like evolutionary studies. Nevertheless, most empirical research has so far focused on the static characteristics of the innovation system in a given period, not on its process of change over time. The analytical-theoretical explanation of the process of evolution of the system over time has not been made explicit yet in the NIS framework. The study of 'complex evolving system' could constitute, according to Metcalfe (2001), a way to give a more precise evolutionary foundation to the NIS approach, and to investigate the dynamic properties of evolving national systems in a more rigorous way.

What is clear is that, similarly to the other strands of research within evolutionary economics, economic change is conceived as a non-deterministic and non-predictable process. The fundamental and permanent source of uncertainty and unpredictability is constituted by the complexities of the innovative process and by the nature of interactive learning between heterogeneous individuals. Relatedly, as in all the other evolutionary perspectives considered so far, it is also clear that the evolution of the innovation system does not tend towards equilibrium, but it is assumed to be a never-ending and always changing process.

4. New growth theory

This section shifts the focus to the other major paradigm in modern theorizing on innovation and growth, namely new growth theory (NGT). The first part of the section describes the main types of analytical models developed in the field in the last two decades, while the second part points to the major strands of applied research related to NGT. There exist already comprehensive overviews of this literature, in relation to both NGT analytical models (Aghion and Howitt, 1998; Chui et al., 2002) and the related applied work (Temple, 1999; Islam, 2003). The reader is referred to these previous works for a more complete discussion of the technical issues involved, and for a more in-depth assessment of the advances obtained in this field.[15] The present section, on the contrary, does not aim at providing a complete survey of NGT. The major purpose here will be to prepare the ground for the discussion of the theoretical foundations of NGT, which will be carried out in the final part of the section. The discussion will analyse the theoretical foundations of NGT by discussing the six major questions that this paper uses as framework of analysis, and this will make it possible to point out the great differences existing between NGT and the evolutionary economic paradigm.

4.1 *New growth models*

New Growth Theory models originated in the second half of the 1980s to overcome the problems left unresolved by the neoclassical model of economic growth (Solow, 1956). Two were the main sources of criticism made to the Solovian view. First, under the assumptions of constant returns to scale of each factor in the production function, and of decreasing marginal productivity of capital over time, the Solow model predicted that economic growth would have ceased in the long run. The only possible source of permanent growth in the steady state was technological change, which was exogenous and unexplained by the model. The latter was then unable to explain why GDP per capita has been continuously growing in most industrialized countries since the Industrial Revolution. Second, as technology was assumed to be a public good, freely available to all countries, the model predicted that poor and rich countries would have all converged to the same level and rate of growth of GDP per capita in the long run (given population and saving rates). This prediction was in contrast with the empirical evidence on the persistence of growth rates differences over long periods of time.

Taking these two problems into account, NGT models developed with the purpose of explaining how technological change can generate sustained growth and persistent differences between countries in the long run. The first generation of models was pionereed by Romer (1986) and Lucas (1988). Their models suggest that technological knowledge may be conceived as a non-rival good. This means that once new knowledge is produced by a firm (or by an economic agent who is accumulating human capital) this may benefit all the other firms as well. The public good characteristic of innovation introduces an important externality in the economic system, and consequently it may explain the existence of increasing returrns to scale in the aggregate production function. Differently from the Solow model, an increase in inputs of production can now have a permanent effect on the rate of growth of output, not only on its level. In the new framework, then, a positive growth rate in the long run can be explained by endogenous technical change, i.e. by the fact that there exist externalities associated to the production of technological knowledge by economic agents.[16] Moreover, an important implication of these models is that endogenous technological change and increasing returns in the aggregate production function may determine persistent differences in economic growth rates between countries, and so tackle the second question left unresolved by the Solovian model. The main problem associated with the first generation of NGT models, however, was that the reason why economic agents may decide to invest in the accumulation of knowledge and human capital was not made explicit. If knowledge is a purely public good, in fact, where do individuals and firms take the incentive to invest in the accumulation of these resources?

This question was considered by a second generation of models (Romer, 1990; Grossman and Helpman, 1990). Still based on the idea that there are important externalities associated to the public good features of knowledge, these models argue that knowledge is an (at least partly) appropriable good, meaning that the fruits of technical progress may be appropriated by the producer in the form of monopoly rents. This idea is formalized by assuming that innovation is created by a separate research sector, whose purpose is to create new blueprints for the production of intermediate capital goods. Once a new blueprint is found, the producer firm can appropriate its invention by patenting it, so that it becomes a monopolist in the production of the new capital good. As a consequence, the assumption of perfect competition is released, as the intermediate goods sector is characterized by monopolistic competition. These models also assume that once a new capital good is produced, it adds to the older ones, which are not instantaneously driven out of the market. Economic growth, then, takes the form of an increasing variety of intermediate goods.

In a nutshell, the appropriability character of technological knowledge explains the microeconomic incentive to invest in innovative activities, and its nonrival feature explains aggregate increasing returns, endogenous growth and differences between countries, as in the previous generation of models. The Romer (1990) and Grossman and Helpman (1990) version of NGT, however, opens up an additional question: is it appropriate to model innovation as a deterministic and certain outcome of the activity of the research sector?

A third generation of NGT models, originating from the works of Aghion and Howitt (1992) and Grossman and Helpman (1991), proposed an answer to this question by pointing to the uncertain nature of innovative activity. Analytical models formalize the uncertainty characterizing the innovative process by assuming that new blueprints are found according to a Poisson stochastic process, whose parameter represents the productivity in the research sector. As the parameter of the stochastic process is known, it is possible to calculate an average arrival rate of innovation, and consequently an average rate of growth of the economy. The second modification introduced by this class of models is that they assume that each new blueprint makes the previous ones instantaneously obsolete, so that the previous monopolists in the intermediate good sector are driven out of the market as soon as an innovation is found. These models drop the idea that there is an increasing variety of coexisting capital goods, and point out that the process of technological competition and economic growth are characterized by Schumpeterian 'creative destruction' (or 'business stealing effect'): the monopoly power associated to a new bluprint is only temporary, and once a new intermediate capital good is introduced, the previous monopolists are driven out of the market.

Combining stochastic innovative activity, creative destruction and aggregate increasing returns, these models predict that economic growth in the long run is a function of three major factors: the amount of labour resources employed in the research sector, the degree of market power in the intermediate capital goods sector, and the productivity in the research sector.

An important empirical fact that these previous generations of endogeneous growth models did not consider is the observation that innovations may have different sizes with different impacts on the economy. The distinction between radical and incremental innovations is an important one in evolutionary economics, and it was originally pointed out in the neo-Schumpeterian long wave strand of research. How can this empirical fact be represented in NGT models? How does the size of innovation matter for endogeneous growth theory?

It is the most recent generation of NGT models (Bresnahan and Trajtenberg, 1995; Helpman, 1998) to put forward an answer to these questions. These works emphasize that innovations may have different sizes: they can be drastic (radical) or incremental. Some drastic innovations, in particular, may have deep impacts on the process of economic growth. According to Helpman (1998, p.13), "a drastic innovation qualifies as a 'general purpose technology' if it has the potential for pervasive use in a wide range of sectors in ways that drastically change their modes of operation". From this definition, it appears that the concept of 'general purpose technologies' (GPTs) is quite similar to that of 'technological paradigm' (Dosi, 1982; Freeman, 1982), which we have previously presented with reference to the neo-Schumpeterian long wave theory (see section 3.1).

In this recent class of NGT models, once a new GPT arrives the radical innovation is not immediately ready to be used in the final goods sector, but it needs to be implemented in the form of a new intermediate capital good (incremental innovation). The arrival of the latter is formalized as a Poisson-distributed random variable, as in the previous Aghion and Howitt (1992) and Grossman and Helpman (1991) models.

After the introduction of the new GPT, labour resources are transferred to the research sector in order to develop the new capital goods and to appropriate the relative monopoly rents, in a phase in which the old technological paradigm still presents higher productivity than the new one. At the aggregate level, this first phase results in a slump of economic activity that may last for a few decades. Later on, once a certain number of intermediate goods embodying the new GPT are found, the profitability of the new methods of production turns out to be more evident to the firms in the final goods sector, and the GPT becomes the new dominant technological paradigm. In this second phase, the new GPT diffuses to the whole economy, and this may sustain the growth of aggregate productivity for the following decades. This two-phase cycle of growth is assumed to repeat over time, and in the long run such a cyclical trend tends towards the steady state.

The stylized description presented above clearly indicates that GPT models propose a formalization of the Schumpeterian theory of long waves. This is an interesting attempt, but modeling exercises of this type should in the future address some major questions: (i) Why does the GPT arrive at a given point in time? Is there any economic or socio-institutional factor affecting the invention of new GPTs? (ii) Is there any economic or socio-institutional factor affecting the rate of diffusion of the new technological paradigm over time and in different countries? These questions suggest possible avenues for future research in this field, and open up a possible ground for further interactions between the evolutionary long wave theory and the GPT modeling tradition.

4.2 *NGT applied research*

The development of new growth models has attracted a great deal of interest of empirically oriented scholars, and a huge amount of applied studies on cross-country differences in economic growth has flourished in the last fifteen years. These works typically take the form of cross-section econometric regressions where the growth of

GDP per capita over time is regressed on its level at the beginning of the period (a proxy for the scope for catching up), and on a set of other structural and economic characteristics, such as, for instance, countries' accumulation of physical capital, and levels of education and human capital.

The so-called convergence debate refers to the two different approaches and interpretations that this type of study may lead to (Temple, 1999; Islam, 2003). One set of econometric works derives growth regressions in the context of the Solow model augmented with human capital (e.g. Mankiw, Romer and Weil, 1992). The convergence property is then interpreted, in a neoclassical fashion, as a result of decreasing marginal product of physical and human capital. Another stream of cross-country applied research, on the contrary, includes additional variables in the specification, such as political conditions, industrial structure, and so on, and interprets the conditional convergence result (or lack of such) in a NGT framework, i.e. as an indication of persistent growth rate differences across countries (e.g. Barro, 1991; Barro and Sala y Martin, 1995). Here, conditional convergence does not depend on different rates of accumulation of physical capital, but rather on the advantages that the international diffusion of technologies may determine for catching up countries.

An important result in the growth regressions literature, though, is that convergence is not a ubiquitous phenomenon, but it depends to a great extent on the countries included in the sample under study. In a seminal paper, Baumol (1986) pointed out the existence of three different convergence clubs in the world economy (OECD countries, centrally planned economies, and less developed countries), and demonstrated that the patterns of convergence greatly differ between these groups. Baumol's idea has been refined in a number of subsequent empirical studies (De Long, 1988; Baumol and Wolff, 1988; Baumol et al., 1989; Baumol, 1994), which have all stressed the great variety of macroeconomic performance in the world economy, and the striking differences between the rapid growth of a restricted group of advanced economies and the static patterns of less developed countries (Pritchett, 1997).

A well-known paper by Durlauf and Johnson (1995) developed this idea further, and classified world countries into four groups according to their initial conditions (i.e. initial levels of GDP per capita and of literacy rate). Their empirical study confirmed the existence of different convergence clubs with markedly different characteristics and growth behaviour. Instead of using the common cross-country regression framework, Quah (1996a; 1996b; 1996c; 1997) studied the dynamics of the distribution of world income, and found evidence of "emerging twin peaks", i.e. the existence of polarization and of increasing differences between rich and poor countries.

These applied works are all the more important in growth theory because, as observed by Temple (1999, p. 150), it is "useful to draw distinctions between types of country. […] It is important to move away from characterizing the 'average' developing country, and work towards a deeper understanding of differences." It is thus increasingly felt in growth theory "the need to acknowledge heterogeneity, and move away from techniques based on 'representative' economies" (ibid., p. 150).

The important challenge that this strand of econometric studies presents for future research in the field is twofold. First, it shows that a wide array of different econometric methodologies may be used to shed new light on the issue of growth rate differences and to complement the traditional cross-sectional approach: panel data methods (Islam, 1995), regression trees and other clustering techniques (Durlauf and Johnson, 1995), and techniques for analysing the dynamics of the whole distribution of world income (Quah, 1996a). Secondly, it suggests the need for further modelling efforts to provide a theoretical explanation for the empirical findings of convergence clubs, polarization and twin peaks. One possible direction would be to extend the multiple equilibria type of models (e.g. Azariadis and Drazen, 1990; Galor, 1996), although the link between this class of model and the NGT empirical work has not been made explicit yet.

One major criticism often made to the new growth empirics is that the various econometric studies are tests of conditional convergence on a large sample of countries, and not of innovation-driven endogenous growth for each single country belonging to the sample (Fine, 2000). They are not estimation of the structural form of the analytical NGT models, but rather tests of its reduced form. As Paul Romer (1994, p.11) argues, "the convergence controversy […] represents a digression from the main story behind endogenous growth theory", and not a direct test of it.

Sharing this point of view, Jones (1995a; 1995b) shifts the attention to the time series implications of new growth models, so originating a new class of empirical tests more directly aimed at testing the predictions of the endogenous formalizations. As mentioned above, NGT models predict a positive relationship between the amount of labour resources employed in the research sector and the rate of economic growth. Jones shows, however, that this prediction is in contrast with the empirical evidence, which indicates that the steady rise of R&D intensity since the 1960s has not been associated to increasing but to constant or decreasing economic growth rates.

This finding has recently inspired a new type of empirical tests of NGT models, which focuses on the time series dimension of the growth process, and on the 'scale effects' implications of the analytical models (Jones, 1999; Greiner, Semmler and Gong, 2005). This new direction of research is promising, although various methodological and data-related problems may hamper the diffusion of this type of time series tests (Temple, 1999 and 2003; Islam, 2003). An interesting connection that would enrich even further this line of empirical research could be the one between time series endogenous tests and the recent class of GPT models, investigating the empirical relevance of the two-phases long wave cycle generated by the emergence of a new GPT.

4.3 *Discussion*

NGT models and the related empirical works are based on the concept of aggregate production function, meaning that the approach is macroeconomic but implicitly microfounded. Economic agents are represented as rational maximizers of an intertemporal profit or utility function. Moreover, they are conceived as fundamentally homogenous. The use of the 'representative agent' metaphor makes it possible to study the effects of the microeconomic behaviour on the macroeconomic level of analysis by using relatively simple analytical and formal models. The approach is thus based on typological thinking, which implies a less realistic description but a greater analytical power of NGT models as compared to evolutionary studies.

When NGT models formalize the ideas of 'variety of capital goods' and 'product differentiation' (Romer, 1990; Grossman and Helpman, 1990), these are rather different from the way in which heterogeneity and variety are conceived in evolutionary economics. In NGT, variety is a consequence of innovative and learning activities of economic agents (reminding somewhat of the 'increasing complexity' of the growth process described by Adam Smith and Herbert Spencer), not an essential precondition of the process of economic growth (as in evolutionary economics).

In NGT models, innovation is a major source of economic growth. Technological knowledge is formalized as a non-rival and partly appropriable economic good produced by a separate research sector. Innovation may be explained by two kinds of complementary mechanisms: learning by doing in relation to the accumulation of knowledge and human capital (emphasized by Romer, 1986 and Lucas, 1988), and 'exploring' through the R&D activity of private firms (emphasized since the model of Romer, 1990). More recently, GPT models enlarge the set of possible mechanisms explaining technological innovation and productivity growth by assuming that *radical* innovations may have particularly deep and pervasive impacts on the economy. At the present stage of development of these models, however, the arrival of a new GPT is exogenous, serendipitous, and not linked to any economic or socio-institutional factor. A field for further modeling exercises would be to endogeneize the arrival of radical innovations by following some of the insights coming from the neo-Schumpeterian long wave literature (Freeman et al., 1982; Freeman and Louca, 2001; see section 3.1). An interesting possibility, in particular, would be to model the 'depression-trigger hypothesis' by linking the rate of arrival of radical innovations to economic factors such as demand and profitability conditions in the downswing phase of the long wave cycle.

Learning by doing and exploring activities by the R&D sector determine a gradualist type of dynamics, following which the economic system smoothly proceeds towards the steady state. History, then, may be conceived as a uniform-speed transitional dynamics, rather than an evolutionary process of transformation and qualitative change. Such a gradualist view, however, may be modified in the future by the advances of the recent generation of GPT models. In this case, innovations are mainly radical and may determine saltationist dynamics and long run fluctuations. The temptative combination of gradualist and saltationist dynamics in GPT models appears to be a novel element in NGTs, and needs to be further explored in the future.

Another important theoretical feature of NGT models is the way in which uncertainty is introduced in modeling exercises. These, in fact, represent innovation as an uncertain outcome of R&D activities by assuming that its arrival rate follows a Poisson stochastic process with given parameter. This formalization suggests that the process of growth is not characterized by ‘strong’ and radical uncertainty as in evolutionary economics (Dosi, 1982), but rather by ‘computable risk’. In fact, although a stochastic element exists in the model, it is still possible to predict on average the rate of arrival of innovations, and consequently that of economic growth. The recent class of GPT models does not constitute an exception in this respect: the two-phase cycle repeats mechanically over time, and no strong uncertainty is present in the succession of the deterministic and predictable long waves. The way in which uncertainty is represented in NGT models implies a stylized description of the growth process, but its advantage is certainly the greater tractability and stronger analytical power of NGT models as compared to evolutionary works. In an emerging class of models of economic dynamics, namely *chaos models*, a deterministic system may, due to the high sensitivity in initial conditions, generate radically uncertain outcomes (Boldrin and Woodford, 1990; George and Oxley, 1999). This type of models presents a peculiar combination of neoclassical characteristics (the description and microfoundations of the deterministic system) and evolutionary outcomes (uncertain and disequilibrium behaviour). This class of models has not been applied yet to the study of innovation and growth, but its wider use in future modeling and empirical exercises may possibly constitute a bridge between the evolutionary and NGT research traditions.

Finally, the economic process represented by NGT, in formal models as well as in empirical works, tends towards a steady state of balanced growth, which may differ across countries. Differently from evolutionary economics, the impact of innovation on economic growth is therefore analysed in a dynamic equilibrium setting. In GPT models too, the economic fluctuations determined by the stochastic arrival of innovations do not permanently deviate from the long run equilibrium trend. Temple (2003) has recently argued, however, that the steady state metaphor should not be taken too literally by growth researchers, as its major purpose is to provide an analytical tool for the tractability of formal models, and not a prediction to be tested by empirical studies. Yet another challenge for future research, then, would be to shift the focus from the long run properties of the growth models towards the process of transitional dynamics, which is all the more important in terms of welfare and policy implications (George, Oxley and Carlaw, 2004).

Table 1. The theoretical foundations of evolutionary and new growth theories.

	New Growth Theories	**Evolutionary theories**
What is the main level of aggregation?	Aggregate models based on neoclassical microfoundations ('methodological individualism')	Towards a co-evolution between micro and macro levels of analysis ('non-reductionism')
Representative agent or heterogeneous individuals?	Representative agent and typological thinking	Heterogeneous agents and population thinking
What is the mechanism of creation of innovation?	Learning by doing and 'searching' activity by the R&D sector; Radical innovations and GPTs	Combination of various forms of learning with radical technical and organizational innovations
What is the dynamics of the growth process? How is history conceived?	History is a uniform-speed transitional dynamics	Towards a combination of gradualist and saltationist dynamics: history is a process of qualitative change and transformation
Is the growth process deterministic or unpredictable?	'Weak uncertainty' (computable risk): stochastic but predictable process	'Strong' uncertainty: non deterministic and unpredictable process
Towards equilibrium or never ending?	Towards the steady state	Never ending and ever changing

5. Conclusions

The article has presented a critical survey of two major modern approaches to the study of innovation and economic growth, evolutionary and new growth theories. The purpose has been to discuss the often made claim that the two approaches, both inspired by Schumpeter's seminal works, are becoming more and more similar in terms of the sources and mechanisms of the growth process on which they focus. According to this argument, some kind of theoretical convergence between the two paradigms is taking place.

The article has argued that a comprehensive comparison of these different growth theories cannot simply be done by pointing to their common Schumpeterian features, as it is frequently done, or by looking at the properties and results of modeling exercises. The comparison needs to be made at a more general level of analysis, that is by investigating the theoretical foundations of the different approaches. By theoretical foundations we mean the theoretical characteristics that may be considered as the main building blocks of each growth paradigm.

Following this idea, section 2 has presented the six theoretical questions that we have used as a framework to compare the two approaches. It has defined the main concepts used in the survey, and it has briefly pointed to the origin of each concept in the history of economic thought. Section 3 has analysed the basic foundations of different streams of modern evolutionary economics, namely the neo-Schumpeterian long wave theory, the technology-gap approach, Nelson and Winter-like evolutionary theorizing, and the national innovation systems framework. The section has shown that these recent streams of evolutionary economics share the same theoretical foundations, so that they can be regarded as different strands of research within the same (broadly defined) evolutionary

paradigm. However, the discussion has also pointed to some existing tensions and to the great challenges ahead for the evolutionary economic paradigm.
Section 4 has turned the attention to new growth theory, and it has briefly discussed the main generations of analytical models, as well as the major developments in the applied tradition. The section has shown that the theoretical foundations of new growth theory greatly differ from those of the evolutionary approach. The main differences between the two growth paradigms can be summarized as follows (see table 1).

(1) The aggregate properties of new growth models are derived from the analysis of the behaviour of rational economic agents, and the related cross-country econometric work is set up in a production function framework. Both of them are thus implicitly based on methodological individualism. On the contrary, evolutionary studies point to the theoretical advantages of a non-reductionist theory where the micro and macro levels of analysis co-evolve and interact with each other. This attempt is often called for, but it is nonetheless difficult to make operational, and the different strands of evolutionary research have not yet reached a clear and common position in this respect.
(2) 'Typological thinking' and 'representative agent' are conceived as useful principles in new growth theory, as they increase the analytical tractability of formal models, thus strengthening their conceptual power. In NGTs, the notion of heterogeneity is not an essential intrinsic characteristic of individuals, firms, sectors and countries, but rather a consequence of the productive process, close in spirit to the metaphor of increasing complexity associated with the growth process described in the past by Adam Smith and Herbert Spencer. In evolutionary economics, on the other hand, heterogeneity of economic agents, routines and habits of thought assumes a fundamental role in the construction of the theory, which is then close to a Veblerian type of population

thinking. The latter increases the realism of the description of the growth process, but presents formidable challenges for modeling exercises.

(3) Although innovation is the main source of economic growth in both equilibrium and evolutionary views, the underlying concept of knowledge is rather different. In new growth theory, knowledge is conceived as a non-rival and partly appropriable economic good. Evolutionary theories, though, point out that knowledge is a more complex entity, which cannot be analysed in purely economic terms. According to evolutionary scholars (Nelson and Winter, 1982), knowledge is often tacit, and not always codified and codifiable. It is embodied in the routines of individuals and organizations, and not stored in a book of blueprints. It is interactive, collective and systemic, and not simply the result of individual learning. It tends to be highly dependent and strongly rooted in a given organizational and institutional context, and not separable from it. On the whole, the mechanisms of creation of innovation look similar in evolutionary and new growth theories, but the conceptual foundation behind them is rather different.

(4) NGT models conceive history as a uniform-speed transitional dynamics towards the steady state, not as a process of qualitative change and transformation. Evolutionary economics, on the contrary, searches for a combination of saltationist and gradualist dynamics, and stresses the role of qualitative change and permanent transformation of the growth process. In both paradigms, however, it is difficult to combine gradualist and saltationist features in a single theoretical framework, and this presents interesting challenges for future research.

(5) The new growth world is characterized by 'weak' uncertainty and computable risk, as implied by the use of random variables to formalize the arrival of innovation in the analytical models. The growth process is hence stochastic but predictable. On the other hand, the evolutionary growth process unfolds in an economic environment marked by

‘strong’ uncertainty and unpredictability. This is clearly argued by a large set of appreciative and non-formal type of studies, while evolutionary modeling exercises do not significantly differ from new growth models in this particular respect. The tension between appreciative and formal types of evolutionary studies poses a crucial challenge for future developments of the evolutionary paradigm.

(6) In NGTs, economic growth tends towards the steady state in the long run. The steady state metaphor, in this context, should be interpreted as a useful tool that increases the tractability and analytical power of formal models, rather than a prediction to be confronted with empirical evidence. The growth path described by evolutionary theories, on the contrary, is an ever changing and never ending process of change and transformation, much closer in spirit to the disequilibrium economic world theorized in the past by Veblen and Schumpeter.

In a nutshell, new growth theory combines ideas from classical authors such as Smith and Schumpeter, and interpret them in a dynamic equilibrium framework, where rational choices of economic agents lead to steady state outcomes in a stochastic way. Evolutionary economics draws inspiration from various classical authors, such as Marx, Veblen and Schumpeter, and interpret their insights in an evolutionary disequilibrium context, where interactions among routine-guided and boundedly rational heterogeneous agents determine an unpredictable and endless process of qualitative change and transformation. The former paradigm points to the advantages that formal modelling may lead to in terms of increased analytical simplicity and greater power of generalization. The latter stresses the new insights that a more realistic description of the growth process makes it possible to obtain.

On this ground, the often-claimed convergence between evolutionary and new growth theories cannot be simply justified in terms of their common Schumpeterian features. The analysis carried out in this paper leads to the conclusion that evolutionary and new growth theories greatly differ with respect to all of their theoretical foundations. No theoretical convergence between the two paradigms is taking place.

This finding should be welcomed by both evolutionary and new growth scholars, as it is not theoretical convergence that determines advances in growth theory, but rather the continuous process of interaction and give-and-take between the two paradigms. Although no theoretical convergence is taking place, in fact, there exists an intense exchange of ideas and a fruitful interaction between the two approaches. On the one hand, evolutionary economics greatly benefits from the development of NGTs. The unsatisfaction with the stylized and formal type of analysis of the development process offered by endogenous growth models has proved to be a fundamental motivation to induce evolutionary economists to provide more realistic descriptions and to search for new empirical insights.

On the other hand, new growth theories benefit from the development of evolutionary economics, as the latter provides new insights on the complexities associated with the innovative process and its impacts on economic performance. The re-interpretation of some of these evolutionary insights in a dynamic equilibrium framework has in fact led to the refinement of NGT models and to new empirical applications. Three specific examples may illustrate this point. The first refers to the evolutionary strand of long wave theory flourished in the 1980s (section 3.1). This type of historical and descriptive research has later been formalized by the recent class of GPTs models, where the evolutionary insights on radical innovations, technological paradigms and Schumpeterian long waves have been re-interpreted in an endogenous growth framework. The second example relates to the technology-gap approach (section 3.2). These type of empirical studies, flourished during the 1980s, were originally quite close to an evolutionary and disequilibrium interpretation of the growth process. But a later strand of econometric work in NGT applied a similar idea on the relevance of innovation and the international diffusion of new technologies, and interpreted it in the context of a micro-founded dynamic equilibrium setting. Finally, a third type of interaction between the two paradigms refers to the idea of variety of macroeconomic behaviour. While this has been a major point motivating evolutionary research since its outset (e.g. in the literature on national systems of innovation, see section 3.4), mainstream growth theory did not initially acknowledge this as a major point for building up analytical models and untertaking empirical research. In the last decade, however, NGT has increasingly focused on the great variety of growth behaviour in the world economy, and investigated the existence of different convergence clubs through multiple equilibria models as well as a wide array of non-parametric econometric techniques.

In all these examples, the insights provided by evolutionary research have proved to be a crucial motivation to develop successive waves of new growth models, where the latter have re-interpreted the evolutionary insights in a mainstream dynamic equilibrium framework based on neoclassical microfoundations. The outcomes of these NGT models reproduce the same stylized facts pointed out by evolutionary studies, but, admittedly, the theoretical structure underpinning them is fundamentally different from the conceptual framework originally proposed by evolutionary theories. So, the cases mentioned above do not represent examples of theoretical convergence between the two paradigms, but they rather indicate the existence of interactions between radically different economic worlds.

The interactions between these alternative paradigms have been quite important for the development of the field in the last two decades, and they will go on playing a relevant role in the future. The crucial point is that such fruitful exchange of ideas between evolutionary and new growth theories takes place precisely because the two approaches are so different. Therefore, it is the inherent difference between the two that stimulates advances in growth theory, not their convergence to a common paradigm. The day in which different paradigms will have converged to a single framework, growth theory will cease to be such a dynamic and fascinating field of research. This day is still distant in the future.

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Notes

1. Following Witt (1991), Nelson (1995), and Fagerberg (2003), we will use the label 'evolutionary economics' to indicate the whole set of approaches that will be discussed in section 3. Section 3.3, however, will focus on the more narrow set of evolutionary approaches directly linked to Nelson and Winter (1982)'s influential theory of economic change, that we will label 'Nelson and Winter-like evolutionary theorizing'.
2. There are some other important disequilibrium views (such as the Austrian School, Post-Keynesian, and Institutional economics) that are indirectly related to the development of modern evolutionary economics, but lay outside of the scope of this survey, so that they will not be considered further.
3. A more detailed discussion of the relevance of different levels of aggregation in economic theory can be found in Hodgson (1993, ch.15).
4. It is well known that Schumpeter was the first to use the expression 'methodological individualism'.
5. See Swedberg and Granovetter (1992).
6. See also Hodgson (1998).
7. An extended discussion of the concept of 'population thinking' can be found in Andersen (1994) and Hodgson (1993).
8. Freeman (1994) and Dosi (1997) present critical surveys of the different mechanisms of technical change in economic theory.
9. A critical discussion of the role of technical change in the theory of Karl Marx can be found in Elster (1983) and Hodgson (1993).
10. See Hodgson (1993, ch.14) for a critical discussion of this issue. The brief characterization of a mechanistic, deterministic and predictable economic process pointed out here is admittedly simplistic. There exists a class of models of economic dynamics, so-called *chaos models* (Boldrin and Woodford, 1990; George and Oxley, 1999), where a deterministic system, due to the high sensitivity in initial conditions, may lead to stochastic behaviour and uncertain outcomes. However, chaos models have not been widely applied yet to the study of innovation and growth, and a discussion of them goes therefore beyond the scope of this survey.
11. The historically oriented literature on catching-up and growth has been recently surveyed by Fagerberg and Godinho (2005).
12. Pavitt (2005) has recently considered some of the most important contributions in this now huge literature.
13. An overview of the main findings of the recent studies of sectoral systems of innovation can be found in Malerba (2005).
14. For a previous discussion of evolutionary models of economic growth, with special emphasis on diffusion models, see Sarkar (1998).
15. Several comprehensive surveys related to NGT have recently been presented in this *Journal*, in relation to different aspects of growth theory, such as the role of trade for the growth process (Lewer and Van den Berg, 2003), the effects of inflation (Temple, 2000; Gillman and Keyak; 2005) and of financial liberalization (Auerbach and Siddiki, 2004), and the role of fiscal policies (Zagler and Durnecker, 2003). Measurement and empirical issues have also been discussed, particularly in relation to different measures of human capital (Wobmann, 2003; Gibson and Oxley, 2003) and of TFP (Carlaw and Lipsey, 2003). For a detailed discussion of these contributions, see George, Oxley and Carlaw (2004).
16. New growth models are in fact also referred to as *endogenous growth models*, due to the endogenous nature of technological change. All the models reviewed in this section share this characteristic, as they all focus on innovation as the main engine of growth. However, there exist other classes of endogenous growth models that emphasize other sources of economic dynamics than technological change (see previous note). In this type of models, which we do not consider in this survey, it is the long run growth rate, rather than innovation, that constitutes the endogenous feature of the formalization.

References

Abramovitz, M. (1986) Catching-up, forging ahead and falling behind. *Journal of Economic History* 46, 385-406.

— (1994) The origins of the postwar catch-up and convergence boom. In Fagerberg, J., Verspagen, B. and von Tunzelmann, N. (eds.) *The Dynamics of Technology, Trade and Growth*. Aldershot: Edward Elgar.

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

— (1998) Endogenous Growth Theory. Cambridge, MA: MIT Press.

Alchian, A. A. (1951) Uncertainty, Evolution, and Economic Theory. *Journal of Political Economy* 58**,** 211-222.

Andersen, E. S. (1994) Evolutionary Economics, Post-Schumpeterian Contributions, London: Pinter.

Archibugi, D. and Michie, J. (1998) Technical change, growth and trade: new departures in institutional economics. *Journal of Economic Surveys* 12 (3), 313-332.

Arrow, K. (1962) The economic implications of learning by doing. *Review of Economic Studies* 29, 155-173.

Arthur, W. B. (1994) Increasing Returns and Path Dependence in the Economy. Ann Arbor, MI: University of Michigan Press.

Auerbach, P. and Siddiki, J.U. (2004) Financial liberalisation and economic development: an assessment. *Journal of Economic Surveys* 18(3), 231-265.

Azariadis, C., Drazen, A. (1990) Threshold externalities in economic development. *Quarterly Journal of Economics* 1990, 501-526.

Barro, R. (1991) Economic growth in a cross-section of countries. *Quarterly Journal of Economics* 106, 407-443.

Barro, R. and Sala Y Martin, X. (1995) Economic Growth. Boston: McGraw-Hill.

Baumol, W. J. (1986) Productivity growth, convergence and welfare: what the long-run data show. *American Economic Review* 76 (5), 1072-1085.

— (1994) Multivariate growth patterns: contagion and common forces as possible sources of convergence. In: W. J. Baumol, R. R. Nelson, E. N. Wolff, (eds.) *Convergence of Productivity: Cross-National Studies and Historical Evidence*, Oxford.

Baumol, W. J., Wolff, E. N. (1988) Productivity growth, convergence and welfare: reply. *American Economic Review* 78 (5), 1155-1159.

Baumol, W. J., Batey Blackman, S. A., Wolff, E. N. (1989) *Productivity and American Leadership: the Long View*. Cambridge, Mass.: MIT Press.

Bresnahan, T. and Trajtenberg, M. (1995) General purpose technologies: ‘engines of growth’?. *Journal of Econometrics* 65, 83-108.

Boldrin, M. and Woodford, M. (1990) Equilibrium models displaying endogenous fluctuations and chaos. *Journal of Monetary Economics*, 25, 189-222.

Cappelen A., Castellacci, F., Fagerberg J. and Verspagen, B. (2003) The impact of regional support on growth and convergence in the European Union. *Journal of Common Market Studies* 41 (4), 621-644.

Carlaw, K.I. and Lipsey, R.G. (2003) Productivity, technology and economic growth: what is the relationship?. *Journal of Economic Surveys* 17(3), 457-495.

Chiaromonte, F. and Dosi, G. (1993) Heterogeneity, competition, and macroeconomic dynamics. *Structural Change and Economic Dynamics* 4, 39-63.

Chui, M., Levine, P., Murshed, S.M. and Pearlman, J. (2002) North-South models of growth and trade. *Journal of Economic Surveys* 16(2), 123-165.

Conlisk, J. (1989) An aggregate model of technical change. *Quarterly Journal of Economics* 104, 787-821.

Cornwall, J. (1977) Modern Capitalism, its Growth and Transformations. London: Martin Robertson.

David, P. (1985) Clio and the economics of QWERTY. *American Economic Review* 75, 332-337.

De Long, J.B. (1988) Productivity growth, convergence and welfare: comment. *American Economic Review* 78 (5), 1138-1154.

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

— (1997) Opportunities, incentives and the collective patterns of technological change. *Economic Journal* 107, 1530-1547

Dosi, G. Pavitt, K. and Soete, L. (1990) The Economics of Technical Change and International Trade, London: Harvester Wheatsheaf.

Dosi, G. and Fabiani, S. (1994) Convergence and divergence in the long-term growth of open economies. In G. Silverberg and L. Soete (eds.) *The Economics of Growth and Technical Change: Technologies, Nations, Agents*. Aldershot: Edward Elgar.

Dosi, G., Fabiani, S., Aversi, R. and Meacci, M. (1994) The dynamics of international differentiation: a multy-country evolutionary model. *Industrial and Corporate Change* 3, 225-241.

Dosi, G. and Winter, S. (2000) Interpreting economic change: evolution, structures and games. *LEM Working Paper* 2000/08.

Durlauf, S. N., Johnson, P. A. (1995) Multiple regimes and cross-country growth behaviour. *Journal of Applied Econometrics* 10, 365-384.

Edquist, C. (2005) National systems of innovation. In J. Fagerberg, D. C. Mowery and R. R. Nelson (Eds.) *The Oxford Handbook of Innovation*, Oxford: Oxford University Press.

Edquist, C. and Johnson, B. (1997) Institutions and organizations in systems of innovations. In C. Edquist (ed.) *Systems of Innovation: Technologies, Institutions and Organisations*. London and Washington: Pinter.

Elster, J. (1983) Explaining Technical Change. Cambridge, MA: Cambridge University Press.

Fagerberg, J. (1987) A technology gap approach to why growth rates differ. *Research Policy* 16, 87-99.

— (1988) International competitiveness. *Economic Journal* 98, 355-374.

— (1994) Technology and International differences in growth rates. *Journal of Economic Literature* 32, 1147-1175.

— (2003) Schumpeter and the revival of evolutionary economics: An appraisal of the literature. *Journal of Evolutionary Economics* 13, 125-159.

Fagerberg, J. and Verspagen, B. (1996) Heading for Divergence? Regional Growth in Europe Reconsidered. *Journal of Common Market Studies* 34, 431–448.

— (2002) Technology-gaps, innovation-diffusion and transformations: an evolutionary interpretation. *Research Policy* 31, 1291-1304.

Fagerberg, J. and Godinho, M. M. (2005) Innovation and Catching-up. In J. Fagerberg, D. C. Mowery and R. R. Nelson (Eds.) *The Oxford Handbook of Innovation,* Oxford: Oxford University Press.

Fagiolo, G. and Dosi, G. (2003) Exploitation, exploration and innovation in a model of endogenous growth with locally interacting agents. *Structural Change and Economic Dynamics* 14 (3), 237-273.

Fine, B. (2000) Endogenous growth theory: a critical assessment. *Cambridge Journal of Economics* 24, 245-265.

Freeman, C. (1983) Long Waves in the World Economy. Butterworth, Kent.

— (1984) Prometheus unbound. *Futures* October 1984, 490-500.

— (1987) Technology Policy and Economic Performance: Lessons from Japan. London: Pinter.

— (1994) The economics of technical change. *Cambridge Journal of Economics* 18, 463-514.

Freeman, C., Clark, J. and Soete, L. (1982) Unemployment and Technical Innovation. London: Pinter.

Freeman, C. and Louça F. (2001) As Time Goes by: From the Industrial Revolutions to the Information Revolution. Oxford: Oxford University Press.

Galor, O. (1996) Convergence? Inferences from theoretical models. *Economic Journal* 106, 1056-1069.

George, D. and Oxley, L. (1999) Robustness and local linearisation in economic models. *Journal of Economic Surveys* 13(5), 529-550.

George, D., Oxley, L. and Carlaw, K. (2004) Surveys in Economic Growth: Theory and Empirics. Blackwell Publishing.

Gerschenkron, A. (1962) Economic Backwardness in Historical Perspective. Cambridge, MA: Harvard University Press.

Gibson, T.L.J. and Oxley, L. (2003) Cost- and income-based measures of human capital. *Journal of Economic Surveys* 17(3), 271-307.

Gillmann, M. and Kejak, M. (2005) Contrasting models of the effect of inflation on growth. *Journal of Economic Surveys* 19(1), 113-136.

Greiner, A., Semmler, W., Gong, G. (2005) *The Forces of Economic Growth: A Time Series Perspective*. Princeton: Princeton University Press.

Grossman, G.M. and Helpman, E. (1990) Comparative advantages and long run growth. *American Economic Review*. 80, 796-815.

— (1991) Quality ladders in the theory of growth. *Review of Economic Studies* 58, 86-91.

Habakkuk, H.J. (1962) American and British technology in the Nineteenth Century. Cambridge, MA: Cambridge University Press.

Heertje, A. (1993) Neo-Schumpeterians and economic theory. In Magnusson (ed.) *Evolutionary Approaches to Economic Theory*. Dordrecht: Kluwer.

Helpman, E., ed. (1998) General Purpose Technologies and Economic Growth. Cambridge, MA: MIT Press.

Hodgson, G. (1993) Economics and Evolution: Bringing Life Back into Economics. Cambridge, MA: The MIT Press.

— (1997) The evolutionary and non-Darwinian economics of Joseph Schumpeter. *Journal of Evolutionary Economics* 7(2), 131-145.

— (1998) The Approach of institutional economics. *Journal of Economic Literature* 36, 166-192.

Islam, N. (1995) Growth empirics: a panel data approach. *Quarterly Journal of Economics* 110, 1127-1170.

— (2003) What have we learnt from the convergence debate?. *Journal of Economic Surveys* 17(3), 309-362.

Iwai, K. (1984) Schumpeterian dynamics. An evolutionary model of innovation and imitation. *Journal of Economic Behavior and Organization* 5, 159-190.

Johnson, B. (1992) Institutional learning. In Lundvall, B-Å. (ed.) *National Systems of Innovation: Towards a theory of Innovation and Interactive Learning*. London: Pinter Publishers.

Jones, C. (1995a) R&D based models of economic growth. *Journal of Political Economy* 103, 759-784.

— (1995b) Time series tests of endogenous growth models. *Quarterly Journal of Economics* 110, 495-525.

— (1999) Growth: with or without scale effects?. *American Economic Review* 89, 139-144.

Kleinknecht, A. (1981) Observations on the Schumpeterian swarming of innovations. *Futures* 13, 293-307.

Knight, F. H. (1921) Risk, Uncertainty and Profit. Boston, MA, Houghton Mifflin.

Kuznets, S. (1940) Schumpeter's business cycles. *American Economic Review* 30, 257-271.

Landes, D. (1969) The Unbound Prometeus. Technological Change and Industrial Development in Western Europe from 1750 to the Present. Cambridge, Cambridge University Press.

Levine, R. and Renelt, D. (1992) A sensitivity analysis of cross-country growth regressions. *American Economic Review* 82(4), 942-963.

Lewer, J.J., and Van den Berg, H. (2003) How large is international trade's effect on economic growth?. *Journal of Economic Surveys* 17(3), 363-396.

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

Lundvall, B-Å. (1992) National Systems of Innovation: Towards a theory of Innovation and Interactive Learning. London: Pinter Publishers.

Malerba, F. (2002) Sectoral systems of innovation and production. *Research Policy* 31 (2), 247-264 .

— (2005) How innovation differ across sectors and industries. In J. Fagerberg, D. C. Mowery and R. R. Nelson (Eds.) *The Oxford Handbook of Innovation*, Oxford: Oxford University Press.

Mankiw, N., Romer, D., and Weil, D. (1992) A contribution to the empirics of economic growth. *Quarterly Journal of Economics* 107, 407-437.

McKelvey, M. (1997) Using evolutionary theory to define systems of innovation. In Edquist, C. (ed) *Systems of Innovation: Technologies, Institutions and Organisations.* London and Washington: Pinter.

Mensch, G. (1979) Stalemate in Technology: Innovations Overcome the Depression. New York: Ballinger.

Metcalfe, S. (2001) Institutions and economic progress. *Industrial and Corporate Change* 10, 561-586.

Nelson, R.R. (1993) National Innovation Systems: A Comparative Analysis. New York and Oxford: Oxford University Press.

— (1995) Recent evolutionary theorizing about economic change. *Journal of Economic Literature* 33, 48-90

Nelson, R. and Winter, S. (1977) In search of a useful theory of innovation. *Research Policy* 6, 36-76.

— (1982) An Evolutionary Theory of Economic Change. Cambridge: The Belknap Press of Harvard University Press.

— (2002) Evolutionary theorizing in economics. *Journal of Economic Perspectives* 16 (2), 23-46.

Pavitt, K. (1984) Sectoral patterns of technical change: towards a taxonomy and a theory. *Research Policy* 13, 343-373.

— (2005) Innovation processes. In J. Fagerberg, D. C. Mowery and R. R. Nelson (Eds.) *The Oxford Handbook of Innovation*, Oxford: Oxford University Press.

Perez, C. (1983) Structural change and assimilation of new technologies in the economic and social systems. *Futures* October 1983, 357-375.

— (1985) Microelectronics, long waves and world structural change: new perspectives for developing countries. *World Development* 13, 441-463

Porter, M. (1990) The Competitive Advantage of Nations. London: Macmillan.

Pritchett, L. (1997) Divergence, big time. *Journal of Economic Perspectives* 11 (3), 3-17.

Quah, D. T. (1996a) Twin peaks: growth and convergence in models of distribution dynamics. *Economic Journal* 106, 1045-1055.

— (1996b) Convergence empirics across economies with (some) capital mobility. *Journal of Economic Growth* 1 (1), 95-124.

— (1996c) Empirics for economic growth and convergence. *European Economic Review* 40, 1353-1375.

— (1997) Empirics for growth and distribution: stratification, polarization, and convergence clubs. *Journal of Economic Growth* 2, 27-59.

Romer, P. (1986) Increasing returns and long-run growth. *Journal of Political Economy*, 94, 1002-1037.

— (1987) Crazy explanations for the productivity slowdown. In Fischer, S. (ed.) *NBER Macroeconomics annual*. Cambridge, MIT Press.

— (1990) Endogenous technological change. *Journal of Political Economy* 98, 71-102.

— (1994) The origins of endogenous growth. *Journal of Economic Perspectives* 8(1), 3-22.

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

Ruttan, V. (1997) Induced innovation, evolutionary theory and path dependence: sources of technical change. *Economic Journal* 107, 1520-1529.

Sarkar, J. (1998) Technological diffusion: alternative theories and historical evidence. *Journal of Economic Survey* 12 (2), 131-176.

Saviotti, P. (1997) Innovation systems and evolutionary theories. In Edquist, C. (ed) *Systems of Innovation: Technologies, Institutions and Organisations.* London and Washington: Pinter.

Schumpeter, J. (1934) The Theory of Economic Development. Cambridge: Harvard University Press.

— (1939) Business Cycles. Philadelphia: Porcupine Press.

— (1943) Capitalism, Socialism and Democracy. New York: Harper.

— (1954) History of Economic Analysis London: Routledge.

Silverberg, G., Dosi, G. and Orsenigo, L. (1988) Innovation, Diversity and Diffusion: A Self-Organisation Model. *Economic Journal* 98, 1032-54.

Silverberg, G. and Lehnert, D. (1994) Growth fluctuations in an evolutionary model of creative destruction. In Silverberg, G. and Soete, L. (ed) *The Economics of Growth and Technical Change. Technologies, Nations, Agents*. Aldershot: Edward Elgar.

Silverberg, G. and Verspagen, B. (1994a) Learning, Innovation and Economic Growth: A Long-Run Model of Industrial Dynamics. *Industrial and Corporate Change* 3**,** 199-223.

— (1994b) Collective Learning, Innovation and Growth in a Boundedly Rational, Evolutionary World. *Journal of Evolutionary Economics* 4, 207-226.

— (1995) An Evolutionary Model of Long Term Cyclical Variations of Catching Up and Falling Behind. *Journal of Evolutionary Economics* 5, 209-227.

— (1996) From the Artificial to the Endogenous: Modelling Evolutionary Adaptation and Economic Growth. In E. Helmstädter and M. Perlman (eds.) *Behavorial Norms, Technological Progress and Economic Dynamics: Studies in Schumpeterian Economics*, Ann Arbor, MI: University of Michigan Press.

Solow, R. (1956) A contribution to the theory of economic growth *Quarterly Journal of Economics* 70, 65-94.

Swedberg, R. and Granovetter, M. (1992) Introduction. In Granovetter, M. and Swedberg, R. (ed.), *The Sociology of Economic Life*. Westview Press.

Temple, J. (1999) The new growth evidence. *Journal of Economic Literature* 37, 112-156.

— (2000) Inflation and growth: stories short and tall. *Journal of Economic Surveys* 14(4), 395-426.

— (2003) The long-run implications of growth theories. *Journal of Economic Surveys* 17(3), 497-510.

Van Duijn, J.J. (1983) The Long Wave in Economic Life. London: Allen and Unwin.

Veblen, T. (1899) The Theory of the Leisure Class: An Economic Study of Institutions. New York: Macmillan.

— (1915) Imperial Germany and the Industrial Revolution. New York: Macmillan.

— (1919) The Place of Science in Modern Civilisation and Other Essays. New York: Huebsch.

Verspagen, B. (1991) A new empirical approach to catching up or falling behind. *Structural Change and Economic Dynamics* 2, 359-380.

— (1993) Uneven Growth Between Interdependent Economies: Evolutionary View on Technology-gaps, Trade and Growth. Aldershot: Avebury.

— (2005) Innovation and Economic Growth. In J. Fagerberg, D. C. Mowery and R. R. Nelson (Eds.) *The Oxford Handbook of Innovation,* Oxford: Oxford University Press.

Winter, S. (1964) Economic 'natural selection' and the theory of the firm. *Yale Economic Essays* 4, 225-272.

— (1971) Satisficing, selection and the innovating remnant. *Quarterly Journal of Economics* 85, 237-261.

— (1984) Schumpeterian Competition in Alternative Technological Regimes. *Journal of Economic Behavior and Organization* 5, 137-158.

Witt, U. (1991) Reflections on the present state of evolutionary economic theory. In G. Hodgson and E. Screpanti (eds.), *Rethinking Economics: Markets, Technology and Economic Evolution.* Aldershot: Edward Elgar.

Wobmann, L. (2003) Specifying human capital. *Journal of Economic Surveys* 17(3), 239-270.

Zagler, M. and Durnecker, G. (2003) Fiscal policy and economic growth. *Journal of Economic Surveys* 17(3), 397-418.