

Theoretical Models of Heterogeneity, Growth and Competitiveness

Insights from the Mainstream and Evolutionary Economics Paradigms

Fulvio Castellacci



Norsk Utenrikspolitisk Institutt
Norwegian Institute of International Affairs

NUPI Working Paper 763

Department of International Economics

Utgiver: Norwegian Institute of International Affairs
Copyright: © Norwegian Institute of International Affairs 2009
ISBN: 978-82-7002-245-8

Any views expressed in this publication are those of the author. They should not be interpreted as reflecting the views of the Norwegian Institute of International Affairs. The text may not be printed in part or in full without the permission of the author.

Visiting address: C.J. Hambros plass 2d
Address: Postboks 8159 Dep.
0033 Oslo
Internet: www.nupi.no
E-mail: pub@nupi.no
Fax: [+ 47] 22 36 21 82
Tel: [+ 47] 22 99 40 00

Theoretical Models of Heterogeneity, Growth and Competitiveness

Insights from the Mainstream and Evolutionary Economics Paradigms

Fulvio Castellacci

Department of International Economics,
Norwegian Institute of International Affairs (NUPI)
E-mail address: fc@nupi.no

[Abstract] This paper presents a survey of theoretical models of heterogeneity, growth and competitiveness. We compare two main theoretical traditions, evolutionary economics and mainstream heterogeneity models, in order to investigate whether the incorporation of heterogeneous agents has made the recent wave of mainstream models more similar to the evolutionary modelling style and results. The results of our survey exercise can be summarized as follows. On the one hand, we observe some increasing similarities and converging aspects between the evolutionary and the mainstream approaches to the study of heterogeneity. On the other hand, however, there are still some fundamental differences between them, which mainly relate to the distinct set of theoretical assumptions and methodological frameworks in which these heterogeneity models are set up and rooted. In short, the evolutionary approach emphasizes the complexities of the growth process and makes an effort to provide a realistic description of it, whereas the mainstream approach does instead follow a modelling methodology that emphasizes the analytical power and tractability of the formalization, even if that implies a somewhat simplified and less realistic description of the growth process.

* This paper has been produced as part of the BITE project. The research grants obtained from the Norwegian Research Council and the P.M. Røwdes Stiftelse are gratefully acknowledged. The paper *will be published as a chapter of the* International Handbook of Economic Integration, Jovanovic, M. (Ed.), Edward Elgar, 2010, forthcoming.

1. Introduction

The introduction of *heterogeneity* in economic models represents an exciting new development that has recently attracted increasing attention in the fields of growth theory, international economics and industrial organization. This recent wave of models describe, in a nutshell, an economic environment where heterogeneous agents (firms) compete with each other and where the competition and market selection process drives the process of creative destruction and aggregate growth.

This recent analytical development is not only relevant because it explains a host of empirical stylised facts on firm heterogeneity and industry dynamics, but also for the profound interest it has from a theoretical point of view. By explicitly introducing micro-level heterogeneity, these recent models go beyond the neoclassical standard assumption of a representative agent and increase substantially the realism of the economic description.

The original impulse to the development of this type of models can be traced back to Nelson and Winter's (1982) evolutionary economics theory. Nelson and Winter's seminal work formulated a model that was explicitly based on a dynamic process of interaction between heterogeneous agents, market competition and selection, technological innovation and aggregate growth. This opened up the wave to a series of later refinements and extensions of this type of evolutionary economics models (Lipsey et al., 2005; Verspagen, 2005).

At the same time as this evolutionary strand of modelling research was developing, the heterogeneity issue did also attract substantial attention within the economics mainstream. Different branches of growth research saw the flourishing of models that introduced firm heterogeneity, competition and selection features within a mainstream economic environment characterized by agents' rationality and equilibrium dynamics. Some of the seminal works in this tradition were in particular presented for the study of industrial dynamics (Hopenhayn, 1992; Luttmer, 2007), international trade and industry growth (e.g. Melitz, 2003) and macro growth (Azariadis and Drazen, 1990; Galor, 2005).

These recent theoretical developments raise one major question. Mainstream economic models of trade and growth are now increasingly based on the heterogeneity-competition-selection metaphor, which by and large follows the same logic proposed by evolutionary economics

models. Does this mean that mainstream heterogeneity models have progressively become more similar to those developed in the evolutionary field? In other words, can we observe a process of theoretical convergence between these two modelling traditions?

This is the question investigated in this paper. The work intends to carry out a survey of evolutionary and mainstream heterogeneity models in order to investigate whether the two approaches are gradually becoming more similar to each other and possibly converging to a single unified framework. We will carry out this task by reviewing different strands of modelling research and, for each of them, we will present a simple description of its main set of assumptions and results and highlight its basic analytical structure.¹

The paper is structured as follows. Section 2 will start by presenting Nelson and Winter's (1982) model and the subsequent extensions and refinements in the field of evolutionary economics. Section 3 will then shift the focus to mainstream (equilibrium) models, and present a summary view of some key models in the areas of industrial dynamics (section 3.1), international trade and industry growth (section 3.2) and macro growth models with multiple equilibria (section 3.3). Section 4 will explicitly point out similarities and differences between the evolutionary and the mainstream approaches to the study of heterogeneity. Section 5 will summarize the results of the discussion and draw some implications for future research in the field.

2. Evolutionary models of industrial dynamics and growth

Modern evolutionary economics originates from Nelson and Winter's (1982) seminal 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 economics theoretical paradigm. Section 2.1 presents the main ideas of Nelson and Winter's original model of industrial dynamics and growth, and section 2.2 will then describe more recent de-

¹ The type of overview analysis that is carried out in this paper is related to two different works previously presented by the same author. Castellacci (2007) discusses the process of theoretical convergence between evolutionary and new growth theories. On the other hand, Castellacci (2008) does instead compare empirical works in the evolutionary and mainstream traditions and the related policy implications. The present paper differs from these previous works in two important respects: first, it explicitly focuses on *theoretical* models; secondly, it specifically studies recent models in which *heterogeneity* is the key feature of the formalization.

velopments in this tradition and summarize the general structure of evolutionary economics models.

2.1 Nelson and Winter's (1982) evolutionary growth model

This seminal model aims at reproducing the long-run trend and aggregate time series of the US economy for the last few decades. However, differently from Solow's (1957) seminal contribution, Nelson and Winter's model intends to reproduce the same macroeconomic trends by starting from a description of the microeconomic environment that is in sharp contrast with the standard neoclassical characterization. Their evolutionary model does in fact set up an economy that is composed of a population of heterogeneous firms, each of which, being characterized by bounded rationality and satisficing behaviour, follows routines and habits of thought rather than maximizing an intertemporal profit function. Besides, microeconomic agents operate in an economic environment that is characterized by fundamental uncertainty and an out-of-equilibrium dynamics. In such a complex environment, it is therefore not possible to solve the model analytically by means of steady-state conditions; the model's properties are for this reason explored through computer simulations.

The analytical structure of the model is sketched in figure 1. The formalization assumes that firms produce a homogenous product. The enterprises differ in terms of the amount of capital used in the production process, as well as the technique that they use, which is summarized by a two-dimensional vector whose elements are the input coefficients describing the use of capital and labour for any given amount of output.² In any period t , given the firms' decisions regarding the amount of investment and the technology to be used, the aggregate (industry-level) output and labour demand are set and, hence, the wage rate. The aggregate wage level then determines the profitability of each enterprise and its market share. Firm's profitability is a key aspect of the model, since it determines both the investment done by an enterprise as well as its technological activities.

The model in fact assumes that, if the profitability of a firm is below a given threshold, the enterprise decides to *search* in the technology space for a better technique in order to strengthen its market performance in the next periods. The search activity may take two different forms: innovation or imitation. Regarding the former, the probability to innovate is as-

² Besides the incumbents' activities, new firms may also enter the market and, if they decide to do so, their initial capital stock level is randomly drawn from a uniform distribution.

sumed to be inversely related to the distance between the technique that the firm is currently using and the new technology. The model's parameter *ease of innovation* measures this probability and shows how changes in this variable affect the aggregate dynamics of the model. On the other hand, the probability to imitate is a function of the total output produced through this new technique in a given period, i.e. its size and relevance in the economy. The model's parameter *emphasis on imitation* measures the relative importance of imitation versus innovation strategies adopted by firms and its aggregate effects on the economy.

Besides allowing for the existence of firm-level heterogeneity in terms of technological and economic behaviour, the model also introduces the possibility of cross-industry differences and sector-specific characteristics by assuming the existence of two distinct regimes of technological change.³ On the one hand, the *science-based regime* is an environment where the technological dynamics is driven by an exogenous flow of opportunities driven by advances in the scientific frontier. Innovative firms, in this context, try to keep pace with this moving frontier and latent productivity dynamics. On the other hand, the *cumulative technology regime* is one in which innovation takes an incremental form building up on firms' previous technological capabilities, and where the growth of productivity is endogenous instead of being driven by the exogenous dynamics of scientific opportunities.

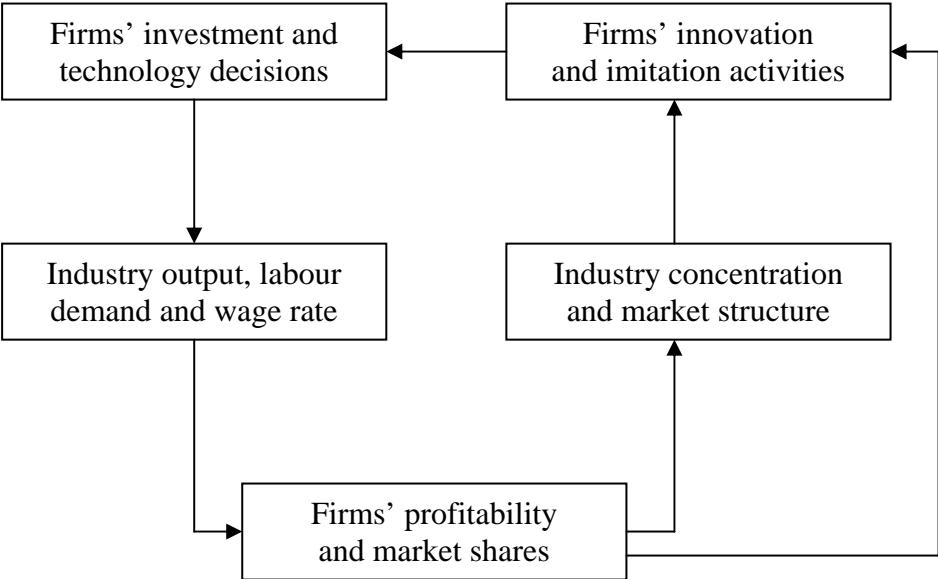
All in all, the analytical structure of Nelson and Winter's model depicted in figure 1 shows the existence of a dynamic process of interaction between different levels of analysis: the micro behaviour determines industry outcomes and the latter, in turn, shape agents' technological and investment decisions that will determine the macro outcome in the next period. This micro-macro-micro interaction ultimately leads to a stochastic dynamic model that follows an out-of-equilibrium path. The analytical complexity of this path makes it necessary to study the model's properties and outcomes by means of computer simulations.

The simulation analysis carried out by Nelson and Winter is rich and multifaceted, spanning various chapter of their book. In a nutshell, two key results that it is worth emphasizing here are the following: (1) an increase in the *ease of innovation* parameter (or, similarly, in the exogenous growth rate of latent productivity in the science-based regime) leads to a more

³ This extension is introduced in Part V of Nelson and Winter's book, which basically extends the model previously developed in Part IV by focusing more closely on the effects of different technological regimes and market structure dynamics.

rapid growth of productivity at the aggregate level; (2) relatedly, an increase in the *emphasis on imitation* parameter leads to a less concentrated market. The reason for this latter result is twofold: first, laggard firms rapidly tend to become as productive and profitable as the leading firms in the industry; secondly, there is a greater rate of entry in the market, and hence a stronger selection effect that fosters the aggregate growth rate.

Figure 1: The analytical structure of Nelson and Winter’s (1982) model



2.2 Later developments: the general structure of evolutionary economics models

Three complementary streams of literature have recently extended in various directions Nelson and Winter’s theory of economic change: (1) microeconomic evolutionary theory of consumers, firms and organizations, closely connected to cognitive psychology, business and organizational studies; (2) sectoral studies on the historical evolution of particular industries, and related analyses of industrial dynamics and sectoral systems of innovation; (3) formal models of economic growth.⁴ Although the three streams focus on different aspects of the evolutionary process at various levels of aggregation (firms, sectors and countries, respectively), what they have in common is that they all conceive economic evolution as driven by the interactions between heterogeneity, selection and innovation processes. Figure 2 shows a simplified scheme of these interactions, i.e. a sort of stylized view of the general structure of

⁴ For an overview of these strands of research, see Castellacci (2007).

current evolutionary models and, more generally, of the interpretation of the evolutionary metaphor in economics.

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.

Developing Nelson and Winter (1982)'s seminal formalization, several evolutionary models of economic growth have later refined 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 behaviour 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 macro 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. As in Nelson and Winter's model, 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, cumulateness 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 Schumpeter, 1934 and 1943; Winter, 1984; 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, which 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. 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).

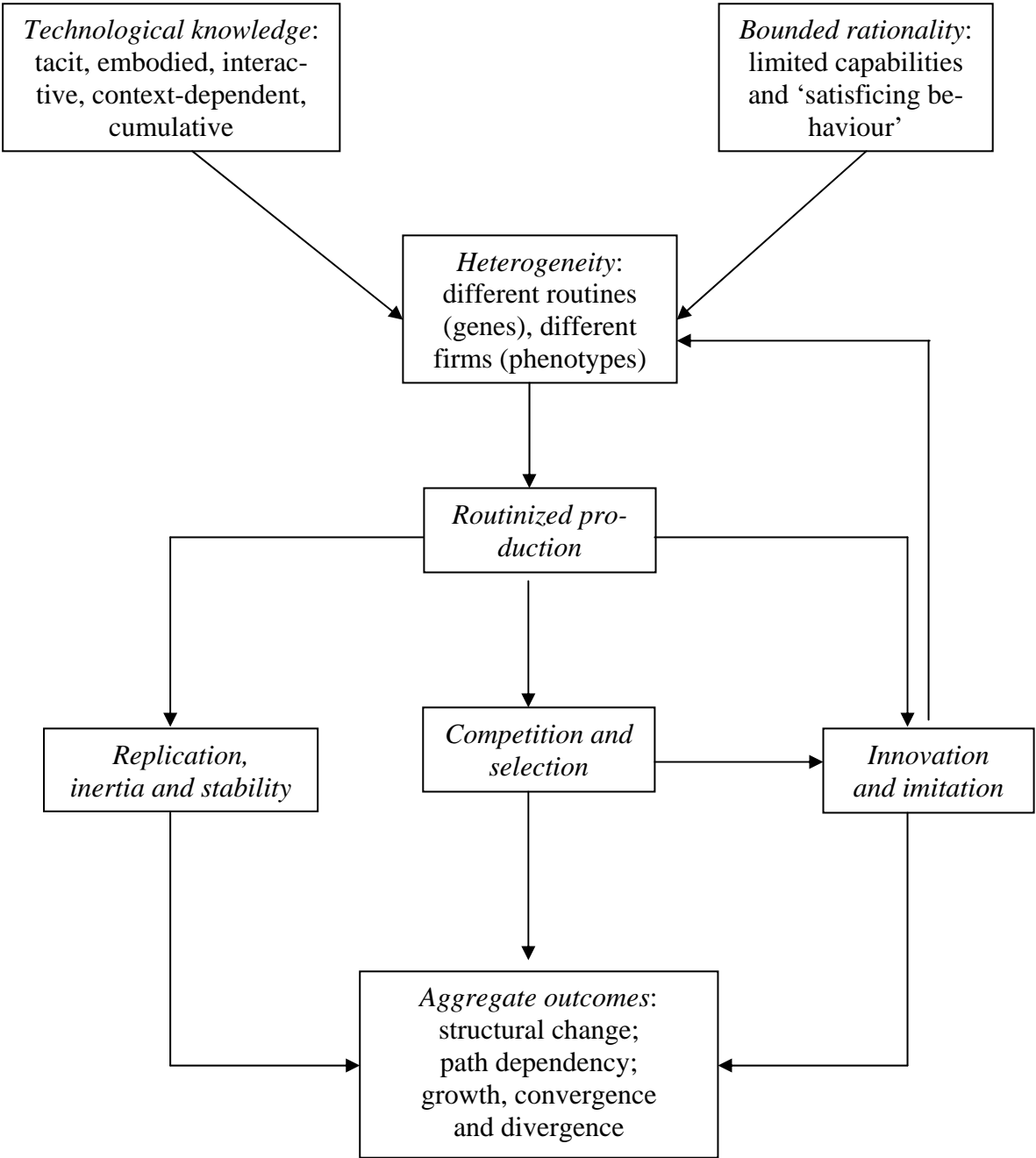
A second important source of novelty comes from a deliberate search for new technical solutions whenever the old one does not lead to efficient outcomes and satisficing profits. As pointed out in section 2.1, Nelson and Winter (1982)'s model assume that when the profit rate falls below a certain threshold, 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. 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, and in particular: (1) 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); (2) 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); (3) long waves and fluctuations without fixed periodicity (Silverberg and Lehnert, 1994; Silverberg and Verspagen, 1994a; 1994b; 1995; 1996); (4) endogenous specialization patterns and international trade patterns (e.g. Verspagen, 1993); (5)

convergence and divergence between countries at the macroeconomic level (Dosi et al., 1994; Chiaromonte and Dosi, 1993).

This recent theoretical tradition does therefore challenge the conventional economics view based on the assumption of a representative rational agent operating in an equilibrium framework. By emphasizing the key role of heterogeneity for economic dynamics, evolutionary models are explicitly microfounded on a population of heterogeneous agents (so-called *population thinking*), where individuals' skills and firms' routines are the basic units of microeconomic analysis. The theory is bottom-up built, and 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: 5). Economic growth is seen as a non-predictable process, because fundamental sources of uncertainty exist in the economic system, and macro phenomena are explained as the result of out-of-equilibrium micro interactions. Differently from the neoclassical metaphor of a steady state, evolutionary economics theorizes an ever-changing and never-ending process of growth and transformation.

Figure 2: The general structure of evolutionary economics models (source: Castellacci, 2007)



3. Mainstream models of heterogeneity, growth and competitiveness

The challenge launched by evolutionary models provided mainstream economics with an important novel view. The concept of agents' heterogeneity, in particular, represented an interesting new theoretical idea that was at odds with the traditional economics notion of a representative agent, but that was indeed appealing since it could increase the realism of economic dynamics models. This new idea has therefore recently attracted a great deal of scholarly attention within the mainstream. In the last few years, a new set of theoretical models have introduced firm heterogeneity and used it to explain a variety of interrelated issues such as industry dynamics and growth, international trade and competitiveness, and macroeconomic growth and poverty traps.

This section briefly reviews these recent models and studies their analytical structure. In particular, we consider three distinct classes of models, which focus respectively on industry dynamics (section 2.1), international trade (section 2.2) and macroeconomic growth and convergence (section 2.3). Although these three classes of models are rooted in distinct (though related) branches of economics research, what they have in common is that they all introduce the notion of heterogeneity and make it a key feature of the theoretical set up. The other key common feature is that, in all of these models, heterogeneity is analysed within a mainstream framework characterized by agents' rationality and equilibrium dynamics, thus providing a view that is eventually quite distinct from the disequilibrium features of evolutionary models.

3.1 Firm heterogeneity, industrial dynamics and growth

This type of models focuses on the process of industry dynamics and growth and studies how this is affected by the existence of firms characterized by heterogeneous productivity levels. A few key empirical stylized facts motivate models in this tradition:⁵ (1) there exists large productivity differences between firms (and plants) within each industry; (2) these productivity differences are persistent over time; (3) the size distribution of firms within each sector is highly and persistently skewed;⁶ (4) despite these persistent features, however, many industries experience a substantial turnover process, and the rate of entry, exit and market reallocations constitute an important factor for the aggregate growth of an industry. Taken together,

⁵ See Sutton (1997), Caves (1998) and Bartelsman and Doms (2000) for comprehensive overviews of the empirical literature underlying the class of models considered in this section.

⁶ This is the so-called Gibrat's law, or *law of proportionate effects*. For a survey of empirical studies of this phenomenon, see Sutton (1997).

these empirical stylized facts suggest that firm heterogeneity is a persistent feature of industrial sectors and a key factor explaining their dynamics.

An early seminal model incorporating some of these features is the classical work of Jovanovic (1982). In his model, firms draw their productivity from a (time-invariant) probability distribution, but do not have full information about their costs and productivity levels before entering the market and starting the production process. The enterprises will only be able to observe their productivity levels at the end of each period. Given their market performance and differential productivity levels, a selection process will then lead to the growth of more productive firms and the shrinking and exit of other less productive enterprises. Jovanovic's formalization is also known as a "passive learning" type of model, because firms do not actively invest to improve their information about their ex-ante productivity prospects, nor do they try to enhance the latter by means of innovation and imitation investments.

Hopenhayn (1992) extends Jovanovic's model by providing a steady-state analysis of the dynamics of heterogeneous producers within an industry. Hopenhayn's model describes a perfectly competitive industry that is composed of a continuum of firms producing a homogeneous product. As in Jovanovic, firms are subject to stochastic productivity shocks, hence they face uncertainty regarding their productivity levels in any given period. These shocks follow a Markov process that is assumed to be independent across firms in the same market. Incumbents must pay a fixed production cost in each period, and new entrants must also pay a fixed (sunk) cost before entering the market.

In such a context, enterprises whose productivity is below a given threshold level must exit the market, whereas other more productive firms will grow. On average, the aggregate productivity of the industry can be summarized by a parameter that describes the statistical distribution of firms' productivity shocks. This implies that the model is analytically tractable and can be solved by means of steady-state analysis: the formalization is stochastic at the micro level but follows a deterministic path at the aggregate (industry) level.

The steady-state analysis of this model leads to two main firm-level results: (1) the size of a firm is an increasing function of the productivity shocks it experiences; (2) the distribution of firms' shocks increases with the age of the firm. Consequently, older enterprises will have a higher survival probability, as well as larger size and profitability. At a more aggregate level,

a key implication of the model refers to the entry cost parameter. A decrease of the entry cost (i.e. lower entry barriers) will make it easier for newcomers to enter the market, and provide a serious threat to the profitability of incumbents. Hence, the process of competition and selection that drives the industry dynamics will be stronger, and there will therefore be a higher rate of turnover and turbulence in the market. This interaction between firm heterogeneity, selection and aggregate (industry) outcomes is a key characteristic of the class of models considered in this sub-section, which does also inspire the trade models reviewed in section 3.2.

“Passive learning” models of this kind have then been refined by a related set of models that introduce the possibility that firms may actively invest in R&D in order to improve their productivity and profitability levels over time and that, for this reason, are also known as “active learning models”. The seminal contribution here is the one of Ericson and Pakes (1995), which has recently been refined and extended by Luttmer (2007). Luttmer’s model is in many respects similar to Hopenhayn (1992), but it differs from it in two main respects: (1) the description of the industry context; (2) the introduction of imitation as an active strategy that new entrants can use to learn from incumbents.

Luttmer’s (2007) industry is characterized by monopolistic competition where firms produce a continuum of differentiated goods. In any period, incumbents must pay a fixed production cost, whereas new entrants incur a sunk entry cost. Similarly to the models described above, the productivity of each incumbent firm is randomly drawn from a probability distribution, and this is assumed to evolve over time independently of other firms’ productivity dynamics. The productivity of new entrants does also grow over time. The first part of the model assumes this growth rate to be exogenous, while in the second part this is made endogenous and dependent on the rate of imitation.

In the exogenous growth version of the model, a decrease in entry costs (and fixed production costs) leads to a stronger selection effect. This means that a greater number of new firms enter the market, the average firm size in the industry decreases whereas the aggregate productivity level grows. This also implies an increase in the number of variety of differentiated goods in the economy and, hence, a greater welfare for the consumers.

On the other hand, the endogenous growth version of the model assumes that, after paying the entry cost, new entrants can imitate an incumbent by drawing from a productivity distribution.

Imitation is assumed to be imperfect, in the sense that there will always be a gap between the incumbent's and the new entrant's productivity. In this imitation-augmented version of the model, the selection effect becomes stronger and more effective, because new entrants have now an additional source of productivity growth that will accelerate the aggregate growth rate of the industry. In particular, the selection effect and industry growth will be stronger the greater the imitation ability of new entrants.

On the whole, the analytical structure of both passive and active learning models is schematically represented by the diagram in figure 3. In a nutshell, these models are characterized by the combination of two distinctive features: the uncertainty and heterogeneous productivity of firms, and the presence of fixed (sunk) costs that incumbents and new entrants incur before entering the market. These two features lead to a partition of firms into different groups according to their market performance and, hence, the aggregate outcomes in terms of selection effect and industry growth. In sum, the model is described by a micro-to-macro causation mechanism characterized by micro-level uncertainty that leads to a macro-level deterministic dynamics.

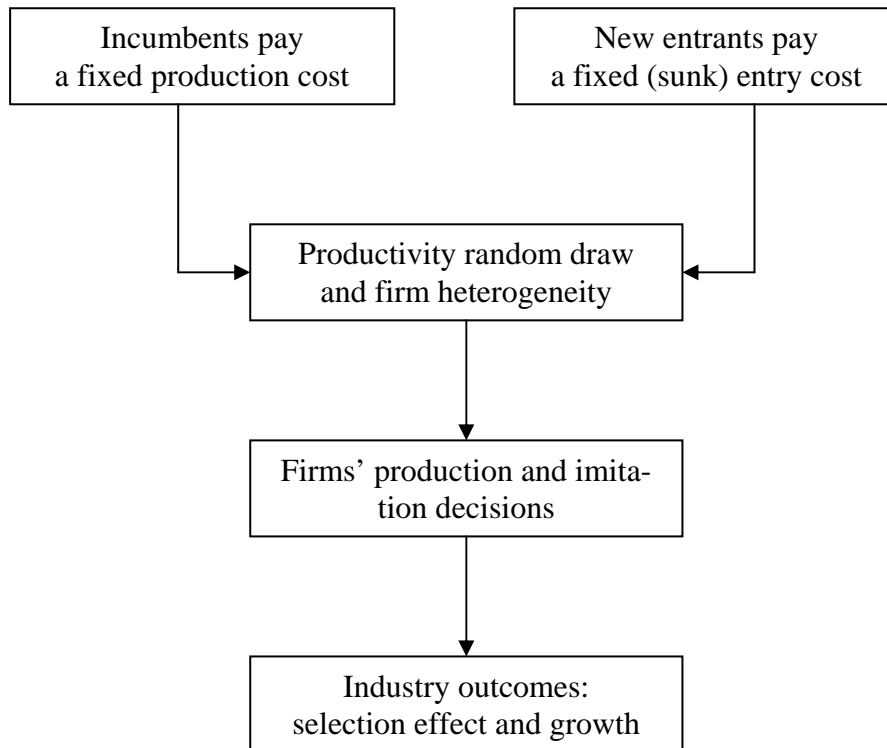
A different but related type of heterogeneity model is the one presented by Aghion et al. (2005). This work is rooted in a somewhat distinct branch of industrial economics, i.e. the traditional literature on competition and innovation, which investigates the relationships between industry-level competition conditions and firm-level innovative activities. Aghion et al. (2005)'s model provides a Schumpeterian interpretation of this literature that is particularly relevant for our discussion because it does also assume a specific form of firm-level heterogeneity that leads to a process of competition, selection and industry growth.

Aghion et al. (2005) assume the existence of two types of enterprises in the industry, each one producing a specific good that is not perfectly substitutable with the other firm's product. Hence, the industry is characterized by a duopoly with a competition process between a leader and a follower firm, rather than a continuum of heterogeneous producers as in the models previously described. The two firms differ in terms of the technology they use and, hence, their unit costs of production. A key model's parameter describes the magnitude of the technology gap between the two firms: the parameter is close to 0 in *leveled* sectors, where neck-to-neck firms are very close to each other and the technology gap is therefore small; by contrast, *unleveled* industries are characterized by a larger gap between leader and follower.

Firms may invest in R&D in order to improve their productivity and market position, and innovations arrive randomly following a Poisson stochastic process. Leader and follower enterprises are also assumed to differ in terms of the amount of resources they decide to invest in R&D, and these innovation intensity levels are affected by the degree of product market competition in each industry. The latter is defined in this model as the degree of substitutability between the goods produced by the two firms (where a value of 0 of this model's parameter defines a minimum degree of competition in which there is no substitution between the two goods, while a value of 1 refers to an industry with perfect substitutability and, hence, perfect competition).

The steady-state analysis of the model points out the effects of changes in the degree of product market competition on innovation, and shows how these differ in distinct industry contexts. In leveled industries where firms compete neck-to-neck, an increase in the degree of competition leads to a positive effect on innovation, so-called escape-competition effect. By contrast, in unleveled sectors where the technological distance between leader and follower is larger, an increase in the degree of competition turns out to have a negative effect on the innovation rate (Schumpeterian effect) because of the impacts it has on the laggard firm's expected returns and incentives to innovate. Combining together these contrasting effects, the model shows the existence of an inverted U-shape relationship between competition and innovation. All in all, industry growth in this model is driven by the innovative investments carried out by leader and follower firms, rather than by the process of reallocations and the related selection effect that was the crucial feature of the other models presented in this section.

Figure 3: The analytical structure of models of firm heterogeneity and industry dynamics (e.g. Hopenhayn, 1992; Luttmer, 2007)



3.2. Firm heterogeneity, international trade and industry growth

This second class of mainstream heterogeneity models is rooted in a recent strand of research within international economics, and focuses on the effects that international trade has on industry growth. The key mechanism through which international trade spurs the dynamics of industries is in these models driven by a process of competition among heterogeneous firms and the consequent market turbulence, reallocations and selection effects. Thus, despite being rooted in a different branch of economics research, the close relationship between this class of models and the one described in section 3.1 is quite evident.

The original motivation for the flourishing of this recent set of heterogeneity models is the desire to refine new trade theory models and make them more in line with a host of firm-level empirical stylized facts. New trade theory models (e.g. Helpman and Krugman, 1985) describe an environment characterized by product differentiation and monopolistic competition. Product variety within each sector explains trade between countries with similar factor compositions and, hence, intra-industry trade (which was not explained by the standard trade

model). However, new trade models assume homogeneity of technology and firm productivities, leading to the implication that all firms within each industry should be able to export to all countries (Helpman, 2006). This assumption contrasts sharply with empirical evidence, though.

Three important empirical stylized facts are at odds with new trade models: (1) in each industry, only a small fraction of firms export, whereas the others only produce for the domestic market; (2) exporters are different from non-exporters: they are larger, more capital and skill intensive, and more productive; (3) there exists a substantial process of turnover and reallocation among plants and firms within each sector, and this selection effect, that is stronger in an open competitive market, is an important driver of aggregate growth for the industry. It is this set of empirical observations on the dynamics of enterprises within each industry that has stimulated the flourishing of the new class of heterogeneity models, where the effects of international trade on industry growth are explained by the dynamics of firms in the market.⁷

Melitz (2003)'s model represents the cornerstone of this type of approach. Its analytical structure and main idea is quite similar to Hopenhayn's formalization (1992; see section 3.1 of this paper), although Melitz's model has a different description of the industry context and an explicit focus on international trade. It is a model of monopolistic competition with heterogeneous producers, and a key characteristic driving its outcomes is the combination of firm-specific productivity levels and fixed (sunk) export costs. In every industry, enterprises produce a differentiated product. The productivity level of each firm is determined as a random draw from a probability distribution, and it is for simplicity assumed to be time-invariant. Similarly to the models described in section 3.1, firm heterogeneity is therefore presented in a simple and analytically tractable way, since the productivity distribution may easily be summarized by an average productivity parameter. The aggregate (industry) outcomes can then be studied analytically by means of this average productivity and the firms' export sunk costs.

In particular, given the productivity distribution and the level of sunk costs, firms in each industry are partitioned into three distinct groups: (1) those whose revealed productivity level does not enable to cover the fixed production costs, and which therefore decide not to produce (not even for the domestic market); (2) those whose productivity is below a minimum thresh-

⁷ For comprehensive surveys of the theoretical and empirical literature in this recent strand of international economics, see Helpman (2006), Greenaway and Kneller (2007) and Bernard et al. (2007).

old level that is required to export, and that hence produce only for the domestic market; (3) those for which the revealed productivity level is above this threshold required to enter foreign markets, and that therefore decide to sell both to the domestic and to the international market.

Given these productivity threshold levels and the resulting partition of firms, industry outcomes are then determined, i.e. the number of firms in each of the three groups and the aggregate productivity of the industry (a weighted average of individual producers' productivities). In the steady-state equilibrium, there is a constant rate of entry of new firms and exit of incumbents, so that the number of firms in each of the three groups is assumed to remain stable over time.

The key result of Melitz (2003) model refers to the impacts of trade liberalization. This leads to two related effects. First, there is a reduction in trading costs and entry barriers, so that a greater number of enterprises export. Secondly, in the domestic market, there is an increase of competition due to the entry of productive foreign firms. This raises the demand for labour by more productive firms and, hence, pushes up real wages. As a consequence of this labour cost increase, less productive domestic firms must exit the market. The aggregate implication is therefore that there is a higher average productivity in each industry due to this reallocation mechanism according to which more productive firms enter the market and progressively get stronger, whereas less productive units shrink and eventually exit the industry. In sum, industry dynamics is driven by this reallocation and selection mechanisms, while for simplicity there is no productivity growth or technological change led by individual firms' innovation or imitation activities.

Bernard et al. (2003) present a model that, despite having a slightly different description of the industry set up than Melitz, develops however a quite similar idea. Bernard et al. (2003)'s model introduces Bertrand competition into the Ricardian framework (instead of monopolistic competition as in several other trade models). The industry is characterized by imperfect competition with variable mark ups. Firms differ in terms of their efficiency levels, which are determined stochastically as the realization of a random draw from a Pareto distribution. Producers who draw a greater efficiency level are able in this context to charge a lower price and sell more, both in the domestic market and abroad.

The model points out three channels through which openness and international trade may sustain the productivity growth of the industry. First, the price of intermediate inputs decreases relatively to wages, due to the availability of cheaper imports that substitute domestically produced inputs, and it hence spurs price competitiveness. Secondly, there is entry (exit) of plants whose productivity is higher (lower) than the industry average. Thirdly, there is a process of reallocation of production among incumbents with different efficiency levels and a related change in firms' market shares towards the more productive units.

Melitz and Ottaviano (2008) introduce an interesting new element in this class of models. Their model postulates that firms' profits and mark ups are affected by the size of the market, because the latter determines the degree of competition in the industry, i.e. the number of firms in the sector and the related market share distribution. This idea is interesting because it highlights the fact that the competition and selection mechanism driving aggregate productivity growth is endogenously dependent on market size. In other words, the firm-level dynamics is shaped by the industry-level context, and this opens up for the possibility to analyze a greater variety of sector-specific conditions in future works.

In the first part of their model, Melitz and Ottaviano (2008) develop a closed economy version of their model, in which the cut-off cost level (or productivity threshold) is a function of market size and, hence, of the degree of competition in the market. Larger markets are characterized by a tougher competition and selection process (i.e. a lower cut-off cost threshold level) and therefore a higher average productivity in the industry. Firms are on average bigger and have higher profits, although they charge lower prices and lower mark ups.

In the second part of the exercise, the open economy model, it is shown that the cost cut-off level is lower in an open economy industry than in the corresponding closed sector. The entry of foreign firms in the domestic market increases competition, the less productive firms are driven out of the market, and the average productivity in the industry does therefore increase. The mechanism leading to market reallocations and growth is slightly different from Melitz' original model: it is driven by increased product market competition rather than by a change of the relative prices of factors (inputs' price versus labour cost). All in all, the effect of changes in the market size parameter is the same as in the closed economy version of the model: a larger market determines an increase in the economy's welfare because it leads to a

lower industry cost cut-off level, higher aggregate productivity and product variety, and lower mark ups and prices.

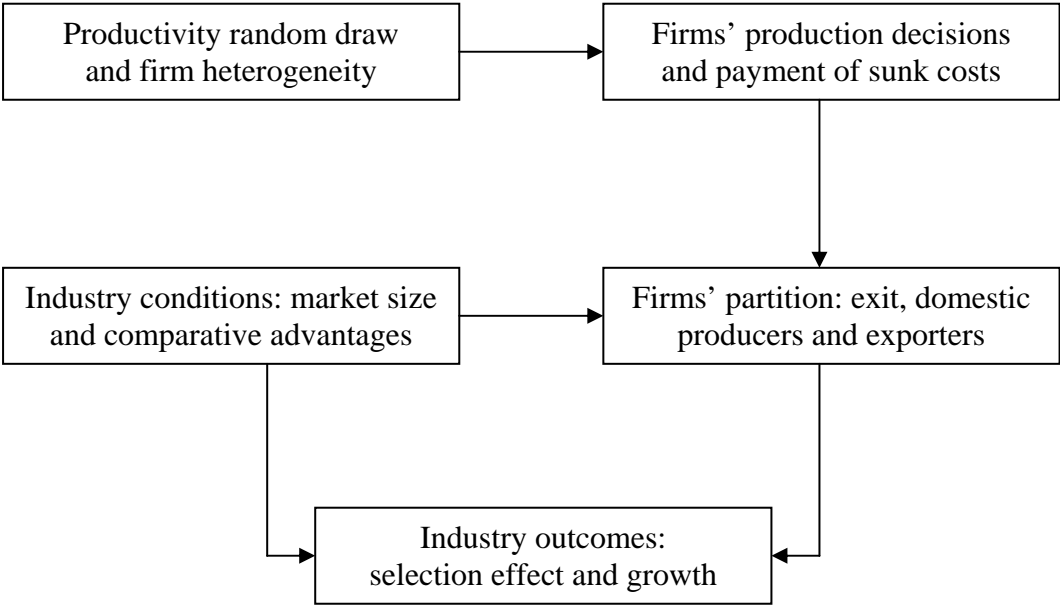
Bernard, Redding and Schott (2007) present a model that integrates new trade theory (e.g. Helpman and Krugman, 1985) with the new strand of research on firm heterogeneity. Their model retains some of the standard conditions of the Heckscher-Ohlin and new trade theory frameworks by assuming that there are factor intensity differences across sectors as well as factor abundance differences across countries. These generate endowment-driven comparative advantages (i.e. explaining why countries export more in industries where they have a comparative advantage) as well as horizontal product differentiation (explaining within industry trade). Adding firm heterogeneity to this standard context makes it possible to explain, in addition, the process of self-selection driven by trade costs and productivity differences within each sector.

The logic of the model is simple and appealing. When trade liberalization increases in such an industry context, the existence of comparative advantages and sectoral differences leads to a different response of heterogeneous firms to economic globalization. Export opportunities rise relatively more in the comparative advantaged industry, which therefore experiences a greater flow of entry of productive firms and exit of less productive enterprises. The reallocation and selection effects in this industry are therefore stronger than in a corresponding comparative disadvantaged sector, and the industry productivity growth rate will therefore be higher in the former than in the latter. In other words, the contemporaneous existence of firm heterogeneity and trade costs “magnifies” differences across industries and countries due to the effects of comparative advantages.

Summing up, figure 4 presents a simplified view of the analytical structure of this class of models. This structure is rather similar to the one of models of industrial dynamics and growth previously considered in section 3.1 (see figure 3). There is, however, an interesting difference. As presented in this section, trade models have recently introduced the idea that sector-specific conditions (e.g. market size, degree of competition, comparative advantages) may affect the micro-dynamics of trade and growth. This implies that there exists a process of interaction between different levels of analysis, which goes from the macro (industry) to the micro, and then back to the determination of macro outcomes. This is interesting because it

makes the analytical structure of these mainstream models in some respects more similar to the one of evolutionary economics models described in section 2.

Figure 4: The analytical structure of models of firm heterogeneity international trade and industry growth (e.g. Bernard et al., 2007; Melitz and Ottaviano, 2008).



3.3. Macro growth models with multiple equilibria and poverty traps

The third class of heterogeneity models that we consider in this section have a sharply distinct focus from those discussed in sections 3.1 and 3.2, as they aim at explaining the process of growth and convergence at the macroeconomic level, rather than focusing on the dynamics of industries. However, what they have in common with the other models is that they also introduce heterogeneity as a key feature of the theory, and use it to explain cross-country differences in long-run performance.

The convergence idea has for a long time attracted a great deal of attention in growth theory. A recent development in growth empirics investigates the extent and reasons of cross-country heterogeneity in the convergence process. In particular, the convergence clubs hypothesis is the strand of growth empirics that studies how the growth and convergence process differs across country clubs. The main idea of this type of studies is that countries that differ in terms of initial conditions will converge to different steady states (Galor, 1996). Empirical evidence

does in fact show that, in a large sample of rich and less developed economies it is easy to identify different country groups, where the convergence mechanism characterizes some of them but not others.

After the pioneering study of Baumol (1986), the convergence clubs hypothesis received a great deal of attention. The seminal paper by Durlauf and Johnson (1995) identified the existence of multiple regimes in a large cross-section of countries and demonstrated the non-linearities associated with the growth and convergence process. In a nutshell, the main result of this research strand is that countries are able to catch up if their initial development level is above a minimum threshold level. Above this threshold, middle-income countries tend to converge fast and progressively slow down as they get closer to the frontier. Below this minimum threshold level, the absorptive capacity is too low to enable the catch up process and, as a consequence, less developed economies frequently experience a stagnant performance and an enlargement of the gap *vis-à-vis* the more advanced country group.

These empirical findings on polarization and non-linearities in the growth process have inspired a class of theoretical models that seek to understand the underlying mechanisms explaining the emergence and diverging performance of country clubs. What are the factors that determine the minimum threshold level that it is necessary to catch up, and how do they relate to other characteristics of national economies?

A seminal study in the field is the multiple equilibria model proposed by Azariadis and Drazen (1990). This formalization augments the neoclassical growth model with a new feature that produces multiple growth paths, namely threshold externalities in the accumulation of human capital. The threshold property and non-linearity of the model are explained by the mechanism through which individual agents accumulate human capital. Individual investments in education are assumed to depend on two factors: the time invested in human capital formation by each individual, and the private yield on education. The latter factor, in turn, is assumed to be a positive function of the average (aggregate) level of human capital in the economy. This formalization generates threshold externalities because, over a certain threshold level of aggregate human capital, the individual incentives to invest in education are increasing rapidly, whereas below this given threshold low private yields determine a stagnant dynamics of aggregate human capital and, hence, economic growth. In this model, different

initial conditions in terms of human capital levels may therefore explain diverging long-run dynamics of national economies.

Galor and Moav (2000) present a model where non-linearities in the growth process are determined by the interaction of human capital and technological change. The basic idea is that an increase in the rate of technical progress tends to raise the relative demand for skilled labour and, hence, to increase the rate of return to individual investments in education. The subsequent increase in the supply of educated individuals, in turn, acts to push technological change further. It is such dynamic interaction between the processes of skill formation and technological upgrading that is at the heart of the cumulativeness of aggregate growth trajectories.

A related idea is proposed by Galor and Weil (2000) and Galor (2005), whose “unified growth theory” models seek to explain the long-run transition of national economies from older to more advanced stages of development. These models identify three main development stages – a ‘Malthusian’, ‘post-Malthusian’ and a ‘modern growth regime’ – and study the mechanisms explaining the transition across these long-run phases. In particular, a key insight of these works is the observation that during the post-Malthusian phase a demographic transition occurred. The faster pace of technological change progressively increased the returns to human capital accumulation. This determined a change in parental attitude towards children’s education, favouring a shift from quantity to quality, i.e. a higher preference for a fewer number of well-educated children. The resulting slowdown in population growth, in combination with the acceleration in human capital and technological accumulation, thus led many economies into a modern growth regime characterized by stable growth of per capita incomes. In this development stage framework, the existence of different country clubs is explained as the outcome of different timing of transitions experienced by national economies in the shift from the post-Malthusian to the modern growth regime.

The model by Galor and Tsiddon (1997) is also consistent with this view, but it refines the multiple equilibria analysis by studying the interactions between technological progress, intergenerational earnings mobility and economic growth. This is an overlapping-generations model where economic agents live two periods, in the first of which they must decide in what sectors to work and the level of education they seek to achieve in the future. Differently from the previous models, economic agents’ human capital dynamics depends here on two main

factors: their individual ability and their parental sector of employment (since empirical evidence indicates that earnings possibilities for a worker are higher if there is a close match with the parents' sector of employment). In periods of sustained technological progress, individual ability stands out as the more crucial factor for a worker's success, and high-skills agents tend to cluster in more technologically advanced sectors. This introduces greater intergenerational mobility in the economic system, and the concentration of talented individuals in high-tech branches fosters technological change and human capital even further. The cross-country implication of this cumulative dynamics is that initial differences in human capital endowments (and in the distribution of human capital across sectors) may lead to diverging dynamics of national economies.

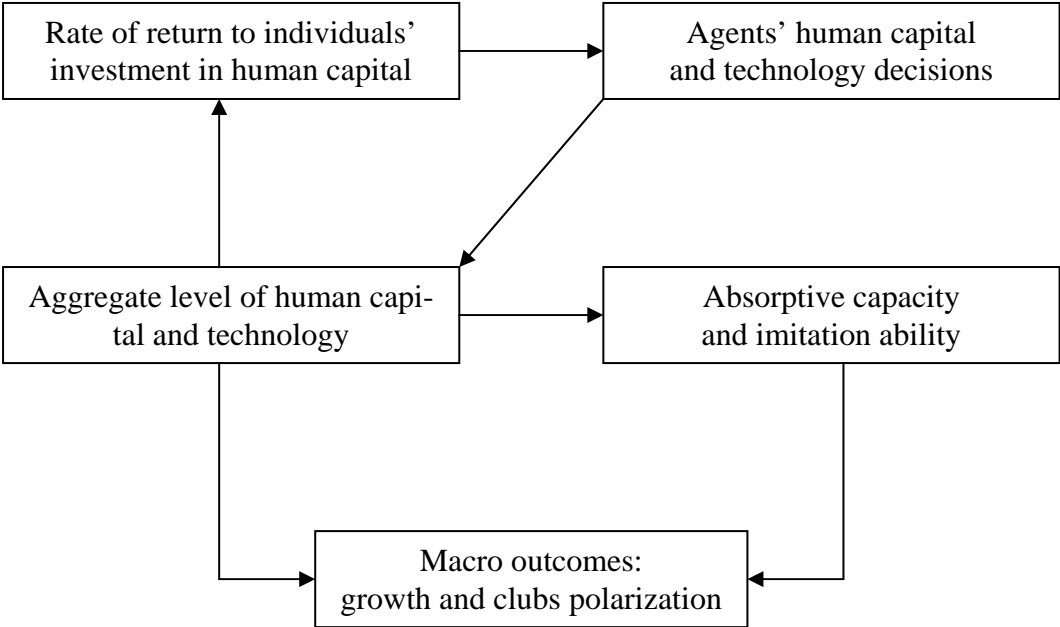
A different explanation for the existence of multiple growth paths is provided by Durlauf (1993) and Kelly (2001). These formalizations focus on the dynamics of industrial sectors and the importance of intersectoral linkages to sustain the aggregate dynamics of the economic system. The main idea of Durlauf's (1993) model is that when intersectoral linkages among domestic industries are sufficiently strong, the growth of leading sectors propagates rapidly to the whole economy, whereas if such technological complementarities are not intense enough the aggregate economy follows a less dynamic growth path. Kelly (2001) refined this framework by building up a Schumpeterian quality-ladder model in which economies evolve by continuously producing new goods and progressively becoming more complex over time. Intersectoral linkages tend to become more complex and intense as new products are introduced in the economy, and threshold externalities thus emerge as the result of different degrees of complexity that characterize different groups of national economies.

Howitt (2000) and Howitt and Mayer-Foulkes (2005) refine the Schumpeterian growth model by arguing that cross-country differences in the rates of return to investments in human capital may shape the dynamics of absorptive capacity and thus generate three distinct convergence clubs: an *innovation*, an *implementation* and a *stagnation* group. The first is rich in terms of both innovative ability and absorptive capacity. The second is characterized by a much lower innovative capability, but its absorptive capacity is developed enough to enable an imitation-based catching up process. The stagnation group is instead poor in both aspects, and its distance *vis-à-vis* the other two groups tends to increase over time. Recently, Acemoglu et al. (2006) refined the club model by arguing that a crucial source of dynamics for countries in the *innovation* group is constituted by the availability of a skilled pool of managers and entrepre-

neers. The competition and selection process through which skilled managers emerge represents a crucial growth mechanism for countries that are already close to the technological frontier.

In summary, figure 5 presents a simplified view of the type of macro models considered in this sub-section. An interesting feature emerging from this diagram is the process of interaction between aggregate characteristics of countries (e.g. their level of human capital and technology) and the micro-level behaviour of economic agents (e.g. their investments in human capital or technological accumulation). This interaction between different levels of analysis is what explains the existence of threshold externalities and the cumulative dynamics experienced by the growth process: above a given threshold level, the cumulative interaction between agents' investments and macro dynamics will lead countries to a virtuous growth path; by contrast, economies below this threshold level will fall behind and persistently stay in a poverty trap.

Figure 5: The analytical structure of macro models with multiple equilibria and poverty traps (e.g. Galor, 2005; Howitt and Mayer-Foulkes, 2005).



4. Evolutionary and mainstream heterogeneity models: are they converging?

Despite being rooted in different strands of research and theoretical traditions, all of the models reviewed in this paper have an important common feature: they introduce heterogeneity as a key characteristic explaining the process of market competition and selection and the consequent outcomes in terms of aggregate growth. So, the original idea of the evolutionary economics metaphor – based on the interaction between heterogeneity, competition and selection – has now become an important cornerstone of recent mainstream models of trade, industrial dynamics and growth.

This leads to the question: since these different classes of models are all based on a similar type of evolutionary logic, can we then conclude that evolutionary and mainstream heterogeneity models are progressively becoming more similar to each other and gradually converging to a common theoretical and modelling paradigm?

We discuss this question in the present section. We compare various aspects of the modelling strands considered throughout the paper in order to point out increasing similarities between the evolutionary and the mainstream approaches to the study of heterogeneity as well as fundamental differences that seem more difficult to reconcile. Table 1 provides a summary of this discussion: its upper part focuses on converging aspects whereas its lower part points out non-converging features and persistent differences between the two theoretical paradigms.

Let us first consider the points in the upper part of table 1. By pointing them out as *converging aspects and increasing similarities*, we do not mean to imply that the various modelling strands are based on exactly the same logic and the same process of interaction between heterogeneity and the competition and selection process. As clear from the discussion carried out in sections 2 and 3, there are indeed some specific differences among these various classes of models. However, we regard these differences as *non-fundamental*: they refer to the focus of the models and the story these tell, but not the underlying analytical structure of the formalization and the philosophy and methodology that underlies the theoretical framework.

More specifically, it is interesting to compare the evolutionary models of industrial dynamics and growth (first column in table 1) with the three strands of mainstream heterogeneity mod-

els (the remaining three columns). Evolutionary models describe an economic environment characterized by heterogeneous firms, sectors and countries, which compete with each other in order to increase their profitability and market shares. The key strategy economic agents use in the competition process is to foster their technological capabilities, either by innovating or by imitating existing advanced knowledge. Such a technology-based competition and selection process leads to the aggregate dynamics of the system (industry or country). Evolutionary models also point out the importance of the interaction among different levels of analysis: micro agents affect macro outcomes and the latter, in turn, shape microeconomic behaviour and strategies.

Presented in such a simple way, the similarities between evolutionary models and recent mainstream heterogeneity models are apparent. The models reviewed in section 3 are in fact also based on the idea that economic units (firms, sectors, countries) are fundamentally different from each other, going beyond the representative agent assumption that was typically made by the standard neoclassical model type. The competition and selection process among these heterogeneous units does also constitute an important part of the story described by these formalizations. In all of these works, there is some type of threshold level that determines the selection process. In models of industrial dynamics and trade and industry growth (see sections 3.1 and 3.2 respectively), the threshold is determined by a combination of entry barriers (sunk costs) and the heterogeneity of individual producers. In the macro growth strand reviewed in section 3.3, the threshold is instead identified as a minimum level of absorptive capacity (i.e. human capital and technological capability) above which agents (countries) grow in a cumulative way and catch up with the technological and economic frontier.

An interesting difference between these three classes of mainstream heterogeneity models is represented by the key mechanism explaining growth and the dynamics of the system. Most of the models considered in section 3.1 and 3.3 point to technological innovation and imitation as the fundamental driving forces, whereas models of international trade (section 3.2) emphasize selection and reallocation mechanisms, rather than technology, as the crucial factors explaining aggregate dynamics. However, we do not regard this as a fundamental difference: it is a difference of emphasis and focus of the models, not of their underlying logic and structure. In fact, it is intuitively reasonable to argue that these two distinct growth mechanisms – market reallocations and innovation-driven productivity growth – may be considered to be complementary aspects of the growth process. It is therefore likely to expect that future

models in this tradition will be able to combine together technological and market dynamics as two interacting mechanisms driving the growth of the system.

Last but not least, another aspect of increasing convergence between evolutionary and mainstream heterogeneity models refers to the interaction among different levels of analysis. Some of the recent mainstream strand of research considered in this paper (see in particular sections 3.2 and 3.3) present models in which the aggregate context and specific conditions (industry- or country-level) affect individual agents' behaviour and strategies, and these micro-level choices determine, in turn, the macro dynamics of the system and the model's outcomes. Such a macro-micro-macro interaction process may explain a cumulative type of dynamics and non-linearities in the growth process.

At the same time as pointing out converging aspects and increasing similarities between evolutionary and mainstream heterogeneity models, however, it is also important to outline other important aspects where the two theoretical traditions have not yet shown any sign of convergence. The lower part of table 1 focuses on what we consider to be more *fundamental differences* between the two approaches, i.e. theoretical aspects where the differences between the two paradigms are less likely to become smaller over time because they refer to substantially different modelling philosophies and methodologies.

As discussed in section 2, evolutionary economics models describe an environment where heterogeneous agents have bounded rationality and satisficing behaviour, and hence act following routines and habits of thought rather than maximizing a utility or profit function. The economic environment is characterized by radical and persistent uncertainty. There is a stochastic element in each period, and the fact that the random draw is repeated over time makes it impossible to predict average outcomes of the dynamic process (e.g. Nelson and Winter). Given the complexities associated with microeconomic heterogeneity and radical uncertainty, the dynamics of the system cannot be assumed to be on a stable equilibrium path. Evolutionary models reject the steady-state metaphor and emphasize the out-of-equilibrium features of the system dynamics. This approach has one important methodological implication: the stochastic and non-linear dynamic model typically presented by evolutionary models is too complex to be analytically tractable, and it must therefore be solved through the use of computer simulation analysis.

By contrast, the recent strands of mainstream modelling works that incorporate heterogeneity are based on a quite different set of theoretical assumptions and conceptual pillars. Their theoretical foundation is, in many respects, still based on the standard neoclassical economics metaphor. Micro agents are described as rational maximizers of a utility or profit function, and the economic environment presents a simplified and analytically tractable form of uncertainty: the micro behaviour is stochastic but the resulting aggregate dynamics is deterministic, and it can therefore be predicted on average. This is possible because these models assume that a stable equilibrium dynamics will prevail in the long run, and thus they can be analytically solved by studying the steady-state conditions that characterize the model in the long run.

In summary, the recent strands of mainstream models considered in this paper (section 3) lead to a substantial step forward as compared to previous neoclassical model approaches, since they provide a more realistic description of the economic environment by introducing the notion of heterogeneity as a new conceptual pillar of the formalization. However, this is done within a theoretical context that is still rooted in a standard neoclassical framework, so that the overall result of this type of exercises is ultimately quite different from the theoretical framework proposed by evolutionary models.

Table 1: A comparison between evolutionary and mainstream models of heterogeneity

Evolutionary models of industrial dynamics and growth	Mainstream I: Industrial dynamics models	Mainstream II: Trade and growth models	Mainstream III: Macro growth models
--	---	---	--

Converging aspects and increasing similarities

Heterogeneity of what?	Firms' routines and technologies; Industries' technological regimes; Countries' absorptive capacities	Firms' productivity levels; Product differentiation; Industries' concentration levels	Firms' productivity levels; Product differentiation; Industries' size and comparative advantages	Countries' initial conditions (in- come per capita, human capital and absorptive capacity)
Entry barriers	Entry is stochastic but not costly (not a key feature of these models)	Fixed entry costs	Fixed export costs	A minimum level of human capital and/or absorptive capacity
Selection mechanism	Firms' technology-driven competi- tiveness and profitability	A productivity threshold partitions firms into two distinct groups	Productivity thresholds partition firms into three distinct groups	Threshold externalities in human capital and technological dynamics
Technological innovation	Science-based innovation, incre- mental innovation, imitation	Innovation and imitation (<i>active learning</i>)	No focus on the innovation- productivity link so far	Interactions between human capital and technological dynamics
Key engines of aggregate growth	Innovation and imitation	Selection effects; innovation and imitation	Selection and reallocation effects fostered by trade liberalization	Human capital, innovation and imitation
Interactions between dif- ferent levels of analysis	Micro-macro-micro	Micro-to-macro	Macro-micro-macro	Macro-micro-macro

Non-converging aspects and fundamental differences

Agents' rationality	Bounded rationality and satisficing behaviour	Rational profit maximizers	Rational profit maximizers	Rational profit maximizers
Uncertainty	Stochastic element in each period: models' results cannot be predicted	Micro behaviour is stochastic but macro dynamics is deterministic	Micro behaviour is stochastic but macro dynamics is deterministic	Micro behaviour is stochastic but macro dynamics is deterministic
Dynamics	Disequilibrium	Steady-state equilibrium	Steady-state equilibrium	Steady-state equilibrium
Analytical tractability	Complex dynamic models solved through computer simulations	Analytically tractable models	Analytically tractable models	Analytically tractable models

5. Conclusions

The paper has carried out a survey of theoretical models of heterogeneity, growth and competitiveness. We have compared two main theoretical traditions, evolutionary economics and mainstream heterogeneity models, in order to investigate whether the incorporation of heterogeneity features has made the recent wave of mainstream models more similar to the evolutionary modelling style and results. Section 2 has focused on evolutionary economics, the tradition that has originally pointed out the importance of heterogeneity, selection and competition to understand market dynamics, structural changes and productivity growth. Section 3 has then shifted the focus to three related model classes rooted in the mainstream tradition, which study respectively the processes of industrial dynamics (section 3.1), international trade and industry growth (section 3.2) and the growth and catching up of national economies (section 3.3).

The results of our survey and comparison exercise have been pointed out in section 4, and can be summarized as follows. On the one hand, we observe some interesting similarities and converging aspects between the evolutionary and the mainstream approaches to the study of heterogeneity. On the other hand, however, there are still some fundamental differences between them, which mainly relate to the distinct set of theoretical assumptions and methodological framework in which these heterogeneity models are set up and rooted. What are the implications of our results for future research in this field?

First, the fact that there are increasing similarities and converging aspects between the two modelling paradigms is certainly a good thing, as it shows that research in this field has indeed made a substantial progress in the last few years. Mainstream heterogeneity models have recently taken up the challenge originally provided by evolutionary economics to the standard neoclassical framework based on the notion of a representative agent, and incorporated the heterogeneity feature within an equilibrium set up. This has implied an increase in the realism of mainstream models while at the same time keeping their clarity and analytical tractability unaltered.

However, this interesting development also raises one major challenge ahead. Since evolutionary and mainstream heterogeneity models are progressively becoming more similar in terms of the story they tell and the results they point out, which of them represent the *real*

theory explaining industry dynamics and growth? In fact, empirical research in this field has not yet undertaken the task of a systematic assessment and test of the relative merits and drawbacks of evolutionary *vis-à-vis* mainstream models. The two theoretical traditions are to a large extent developing as two separate branches of economics research, whereas it would be useful and appealing to carry out a more systematic comparison of the empirical power of the models developed in the two different approaches, comparing not only the models' outcomes but also their different underlying assumptions. This could be a new exciting development for research in this field.

Secondly, our discussion has also made clear that, despite the increasing similarities, there still exist some fundamental differences between models in the two theoretical traditions. These differences refer mostly to some key assumptions upon which the models are built, and which point out the different philosophy and methodology underlying the two competing frameworks. In a nutshell, evolutionary models describe an economic environment characterized by bounded rational agents, radical uncertainty and out-of-equilibrium dynamics, whereas mainstream heterogeneity models are still in many respects rooted in a neoclassical framework characterized by agents' rationality and a deterministic and equilibrium dynamics. The former approach emphasizes the complexities of the growth process and makes an effort to provide a realistic description of it; the latter does instead follow a modelling methodology that emphasizes the analytical power and tractability of the formalization, even if that implies a somewhat simplified and less realistic description of the growth process.

Our paper points out these theoretical and methodological differences between these two approaches, but does not intend to take a position in favour of one or the other. By contrast, our results imply that these differences between competing research paradigms have actually constituted a powerful stimulus to the development of this field of research in the last few years. Theoretical and methodological pluralism has been a positive factor for the progress of growth research, and it should therefore be supported further in the future.

References

- Acemoglu, D., Aghion, P. and Zilibotti, F. (2006): "Distance to frontier, selection and economic growth", *Journal of the European Economic Association*, 4 (1): 37-74.
- Aghion, P., Bloom, N., Blundell, R., Griffith, R. and Howitt, P. (2005): "Competition and innovation: An inverted U relationship", *Quarterly Journal of Economics*, 120 (2): 701-728.
- Alchian, A. A. (1951): "Uncertainty, Evolution, and Economic Theory", *Journal of Political Economy* 58: 211-222.
- Arthur, W. B. (1994): *Increasing Returns and Path Dependence in the Economy*. Ann Arbor, MI: University of Michigan Press.
- Azariadis, C. and Drazen, A. (1990): "Threshold Externalities In Economic Development", *Quarterly Journal of Economics*, 105(2): 501-526.
- Bartelsman, E. J. and Doms, M. (2000): "Understanding productivity: lessons from longitudinal microdata", *Journal of Economic Literature*, 38 (3): 569-594.
- Baumol, William J. (1986): "Productivity Growth, Convergence, and Welfare: What the Long-Run Data Show", *American Economic Review*, 76: 1072-1085.
- Bernard, A., Jensen, B., Redding, S. and Schott, P. (2007): "Firms in international trade", *Journal of Economic Perspectives*, 21 (3): 105-130.
- Bernard, A., Redding, S. and Schott, P. (2007): "Comparative advantage and heterogeneous firms", *Review of Economic Studies*, 74 (1): 31-66.
- Castellacci, F. (2007): "Evolutionary and new growth theories. Are they converging?", *Journal of Economic Surveys*, 21 (3): 585-627.
- Castellacci, F. (2008): "Innovation and the competitiveness of industries: Comparing the mainstream and the evolutionary approaches", *Technological Forecasting and Social Change*, 75: 984-1006.
- Caves, R. (1998): "Industrial organization and new findings on the turnover and mobility of firms", *Journal of Economic Literature*, 36: 1947-1982.
- Chiaromonte, F. and Dosi, G. (1993): "Heterogeneity, competition, and macroeconomic dynamics", *Structural Change and Economic Dynamics* 4: 39-63.
- Conlisk, J. (1989): "An aggregate model of technical change", *Quarterly Journal of Economics* 104: 787-821.
- David, P. (1985): "Clio and the economics of QWERTY", *American Economic Review* 75: 332-337.
- Dosi, G., Fabiani, S., Aversani, R. and Meacci, M. (1994): "The dynamics of international differentiation: a multi-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. (1993): "Nonergodic economic growth", *Review of Economic Studies*, 60: 349-366.
- Durlauf, S. N., Johnson, P. A. (1995): "Multiple regimes and cross-country growth behaviour", *Journal of Applied Econometrics* 10: 365-384.
- Ericson, R. and Pakes, A. (1995): "Market perfect industry dynamics: A framework for empirical analysis", *Review of Economic Studies*, 62: 53-82.
- 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.
- Galor, O. (1996): "Convergence? Inferences from theoretical models", *Economic Journal*, 106: 1056-1069.

- Galor, O. (2005): "From Stagnation To Growth: Unified Growth Theory", in P. Aghion, S.N. Durlauf (eds.), *Handbook of Economic Growth*, vol. 1A, London: Elsevier.
- Galor, O. and Moav, O. (2000): "Ability-biased technological transition, wage inequality, and economic growth", *Quarterly Journal of Economics*, 115: 469-498.
- Galor, O. and Weil, D. (2000): "Population, technology and growth: from Malthusian stagnation to the demographic transition and beyond", *American Economic Review* 110: 806-828.
- Galor, O. and Tsiddon, D. (1997): "Technological progress, mobility and growth", *American Economic Review*, 87: 363-382.
- Greenaway, D. and Kneller, R. (2007): "Firm heterogeneity, exporting and foreign direct investment", *Economic Journal*, 117: 134-161.
- Helpman, E. (2006): "Trade, FDI and the organization of firms", *Journal of Economic Literature*, 44 (3): 589-630.
- Helpman, E. and Krugman, P. (1985): *Market Structure and Foreign Trade: Increasing Returns, Imperfect Competition and the International Economy*, MIT Press, Cambridge, MA.
- Hopenhayn, H. (1992): "Entry, exit and firm dynamics in long run equilibrium", *Econometrica*, 60 (5): 1127-1150.
- Howitt, P. (2000): "Endogenous growth and cross-country income differences", *American Economic Review*, 90 (4): 829-846.
- Howitt, P. and D. Mayer-Foulkes (2005): "R&D, implementation and stagnation: a Schumpeterian theory of convergence clubs", *Journal of Money, Credit and Banking* 37 (1): 147-177.
- Iwai, K. (1984): "Schumpeterian dynamics. An evolutionary model of innovation and imitation", *Journal of Economic Behavior and Organization*, 5: 159-190.
- Jovanovic, B. (1982): "Selection and evolution of industries", *Econometrica*, 50: 649-670.
- Kelly, M. (2001): "Linkages, thresholds, and development", *Journal of Economic Growth*, 6: 39-53.
- Lipsey, R.G., K. Carlaw and C. Bekar (2005): *Economic Transformations: General Purpose Technologies and Long Term Economic Growth*, Oxford: Oxford University Press.
- Luttmer, E. (2007): "Selection, growth, and the size distribution of firms", *Quarterly Journal of Economics*, 123 (3): 1103-1144.
- Malerba, F. (2002): "Sectoral systems of innovation and production", *Research Policy* 31 (2): 247-264 .
- Malerba, F. (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.
- Melitz, M. (2003): "The impact of trade and intra-industry reallocations and aggregate industry productivity", *Econometrica*, 71 (6): 1695-1725.
- Melitz, M. and Ottaviano, G. (2008): "Market size, trade and productivity", *Review of Economic Studies*, 75: 295-316.
- Nelson, R. and Winter, S. (1982): *An Evolutionary Theory of Economic Change*, Cambridge: The Belknap Press of Harvard University Press.
- Pavitt, K. (1984): "Sectoral patterns of technical change: towards a taxonomy and a theory", *Research Policy*, 13: 343-373.
- Schumpeter, J. (1934): *The Theory of Economic Development*, Cambridge: Harvard University Press.
- Schumpeter, J. (1939): *Business Cycles*, Philadelphia: Porcupine Press.
- Schumpeter, J. (1943): *Capitalism, Socialism and Democracy*, New York: Harper.

- 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.
- Silverberg, G. and Verspagen, B. (1994b): "Collective Learning, Innovation and Growth in a Boundedly Rational, Evolutionary World", *Journal of Evolutionary Economics*, 4: 207-226.
- Silverberg, G. and Verspagen, B. (1995): "An Evolutionary Model of Long Term Cyclical Variations of Catching Up and Falling Behind", *Journal of Evolutionary Economics* 5: 209-227.
- Silverberg, G. and Verspagen, B. (1996): "From the Artificial to the Endogenous: Modelling Evolutionary Adaptation and Economic Growth", in E. Helmstädter and M. Perlman (eds.) *Behavioral Norms, Technological Progress and Economic Dynamics: Studies in Schumpeterian Economics*, Ann Arbor, MI: University of Michigan Press.
- Solow, R. (1957): "Technical change and the aggregate production function", *Review of Economics and Statistics*, 39:312-320.
- Sutton, J. (1997): "Gibrat's legacy", *Journal of Economic Literature*, 35: 40-59.
- Verspagen, B. (1993): *Uneven Growth Between Interdependent Economies: Evolutionary View on Technology-gaps, Trade and Growth*, Aldershot: Avebury.
- Verspagen, B. (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.
- Winter, S. (1971): "Satisficing, selection and the innovating remnant", *Quarterly Journal of Economics*, 85: 237-261.
- Winter, S. (1984): "Schumpeterian Competition in Alternative Technological Regimes", *Journal of Economic Behavior and Organization*, 5: 137-158.