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## A Comprehensive Review of the Microeconomic Foundations of Economic Growth

This review provides a summary of the main findings of the literature review (which, as supporting document for the text "Strategies of Economic Growth and Catchup", is attached separately ). The section then provides a brief discussion of key theories and concepts that we drew from the literature

### Summary Findings from the Literature

Technological innovation has an important role to play both as part of the competitive process and as a driver of economic growth and development. However, perhaps surprisingly, for a long time innovation was considered a field where economists, as opposed to other scientists and engineers, only viewed this as a 'black box'.. The forces underlying the process of technological change were believed to be substantially independent of economic incentives and mostly affected by the exogenous evolution of scientific knowledge and its technological applications.

It has been only recently, mainly over the last two decades, that the economic forces behind technological innovation have started to be investigated in more detail within mainstream economics. As a result, a wide variety of theories and models, sometimes very diverse in spirit, describing the economics of innovation are now available. All these theories share the common aim of providing a conceptual foundation for understanding how innovation affects the economy, how economic forces affect the emergence of technological changes, and the decision-making processes through which technological innovation occurs.

We have made no attempt to provide the most representative and comprehensive summaries of each strand of literature; this is not our goal. Rather it is to give a sufficient summary to enable subsequent identification of how the study can be taken forward to develop analytical tools for assessing market dynamics in competition policy investigations.

This section provides a brief summary of some key elements of the different strands of literature overviewed in much of this work.

### Industrial organization

Studies of dynamic competition within economics have developed from once inherently static neoclassical economic theories to modern analyses of innovation and dynamic competition.

Nonetheless, a strong relationship with neoclassical economics remains in the general methodological approach adopted in these theories, which are characterized by the analysis of equilibrium models where fully rational economic agents make optimizing choices.

Generally, traditional models of innovation focus on the study of firms' incentives to invest resources in Research and Development (R&D) activities. Game-theoretical models developed in the industrial organization literature have investigated firms' R&D decisions in strategic environments. (Endogenous growth models, discussed in the next sub-section, have developed the study of market dynamics in models that explain the relationship between firms' investments, innovation and economic growth.)

Game-theoretical models suggest that there are two main forces that underlie firms' investment in R&D: the search for higher profits and the threat posed by falling behind potential innovating rivals. Game theoretical models study these forces in a variety of market situations and address issues such as the interplay between innovation and market structure, the dynamics of competition and the nature of the relationship between intensity of competition and innovation.

These models provide a rich picture of what the possible strategies and industry equilibria in dynamic markets can be. However, general predictions, that can be considered appropriate across all situations and industries, are scarce. On one hand, this is a result that seems to stress the lack of predictive power of these models, i.e. (almost) everything can be rationalized; on the other hand, however, the variety of results seems well to fit with the variety of observed behaviours and "equilibria". There is no general model that can uncritically be applied to any case: the understanding of the specific characteristics of the single situation needs to underpin any appropriate choice of a modelling framework.

Despite the absence of general results, these models are certainly useful tools to understand firms' incentives to invest in R&D activities in strategic environments and to suggest what main factors may be central in shaping the nature of dynamic competition. For instance, these models suggest that:

- In order to understand R&D investments in strategic environments it is necessary to understand how innovation may affect profits both of successful and non-successful innovators. The first perspective captures the idea that firms want to innovate to increase their profits; the second captures the idea that firms want to innovate to maintain competitiveness.

- The relationship between concentration of an industry and its rate of technological innovation is certainly complex and in general not a causal one: both should be thought of as the outcomes of the operation of market forces and exogenous factors such as the nature of demand, technological opportunity and the conditions governing appropriability.

- Dynamic competition may be characterized by persistent dominance of the incumbent leader or by action-reaction whereby incumbents are overtaken by a rival whose incumbency is itself then short-lived. The nature of market dynamics depends on a number of factors, such as the type of innovation, i.e. drastic or non-drastic, the uncertainties involved in R&D activities, the nature of patent protection and of knowledge spill-overs, the intensity of product market competition, etc.

- When the relationship between competition and innovation is investigated, it is necessary to be clear what the notion of intensity of competition describes and how this relates (or does not relate) to market structure. Indeed a market where competition is tougher may be more concentrated simply because inefficient firms cannot survive. There may be a trade-off between the intensity of static competition and innovation. In general, the relationship between intensity of competition and innovation need not be monotonic at all.

Endogenous growth models have recently developed along the earlier game theoretical literature on innovation in the context of studies that seek to explain the relationship between innovation and economic growth. These models suggest that innovation, resulting from intentional R&D investments by profit-maximizing firms or simply by unintentional learning-by-doing, is a fundamental driver of economic growth in the long run.

Early Schumpeterian endogenous growth models stressed the importance of ex-post rents for innovation: competition would have a detrimental effect on innovation by decreasing the rents that an innovator would be able to appropriate. More recent models have emphasized another mechanism by which competition affects innovation: tougher competition may increase the incentives of firms to innovate in order to escape from fierce competition. These recent studies suggest that the relationship between competition and innovation may not well be monotonic and that instead, one should expect an inverse-U shaped relationship: when competition is low, an increase in competition would foster innovation; the reverse would happen when competition is fierce.

The result that competition may be conducive to innovation is also obtained in studies where the traditional behavioral assumption of profit-maximizing firms is relaxed. When principal-agent considerations are introduced to explain managers' behaviors, another mechanism by which competition may favor innovation is suggested: the speed of innovation may be retarded by the slack of managers who tend to avoid private costs associated with innovation. When competition intensifies, the higher threat of bankruptcy may force managers to speed up the process at which new ideas are adopted. Hence, competition may be conducive to faster rates of innovation.

**New economic geography**

New economic geography is a branch of economics which is mainly concerned with spatial aspects of economics. In particular, it seeks to explain why and how given economic activities concentrate geographically, either within individual countries (agglomerations) or between different countries (industrial clustering). Furthermore, it considers the inter-relationships between geographical concentration of industry, international trade and economic development.

At a broad level, several themes emerge from the literature.

- Geographical concentration of economic activity will occur where transport costs are low enough and the labor force is mobile.

- Key characteristics of a particular industry have also an important role to play. The higher the scope for vertical integration, the higher the share of intermediate goods in output and the lower the labor intensity are, the higher will be the drive for concentration.

Industrial concentration implies the possibility of geographical proximity of firms that lays the foundation for technological cooperation and thus lead to increased innovative activity.

- A high degree of concentration leads to very large markets — and the larger the size of the market, the higher the potential reward of successful innovations.

**The evolutionary economics of innovation**

The evolutionary approach to the study of innovation has been developed on very different methodological basis than those underlying traditional economic models of innovation. In particular, we observe the rejection of the modelling assumptions of rationality and equilibrium that are fundamental to the traditional approach.

Evolutionary economics looks from the outset at dynamic processes. In particular, it is associated with the use of analogies from evolutionary biology to explain economic growth and the process of competition. Thus the cornerstones of an evolutionary analysis of competition and innovation are variety, selection and imitation.

At a basic level, using Darwinian analogies, we can begin to appreciate the role of the market in selecting the more fit firms (efficient and profitable), products and techniques at the expense of less fit firms, products or techniques. In addition to this effect, we would expect to see imitation of winning ideas by those whose survival is otherwise threatened (although this is limited by the tacit nature of knowledge).

Inherent in this model of competition is the association between competition and experimentation and variety. A variety of experiments allows, through the process of selection, for greater economic progress than would be available through uniform optimization.

Thus economic development and innovation can be seen as a combined effect of selection (via competition) from a variety of competing routines and practices as well as the more endogenous process of agents seeking improved routines and practices. While the latter is certainly incorporated, if treated somewhat differently, under the mainstream neoclassical approach, the emphasis on selection from variety seems an important addition to this approach.

This suggests that models found in other branches of economics might miss something important when they analyze dynamics with reference to homogenous profit-maximizing firms: namely the benefits of selection from heterogeneity in capabilities and innovative experimentation.

**Systems of innovation**

At an aggregate level, the evolutionary approach to the study of economic growth draws attention to the importance of institutions in the process of economic growth. The key findings of the literature are as follows:

- Innovation and its diffusion take place within systems of interconnected organizations and institutions. Important constituent elements of such systems are organizations such as firms, governments and universities. Institutions, with which these organizations interact, reflect laws and statutes (e.g. the institution of patent protection) as well as more abstract elements (e.g. cultural aspects of the economy such as the spirit of entrepreneurial activity).

- Innovation within the system will depend not only on single institutions but also on the nature and intensity of interactions between the various elements of the system.

- When considering the interaction between competition and innovation, we must remain aware that the effects of such interaction will depend on the evolving institutional background against which agents in the economy operate.

The overview of the cliometric literature has shown that cliometrics is a methodological framework for the study of economic history. The existing body of cliometrics draws attention to the following factors relevant to "systems of innovation":

- Economic growth is a result of a complex interaction between institutions and markets. Examples of institutions that are frequently important for innovation are the protection of property rights (for example, against piracy) and patent policy.

  Innovation plays a critical role in economic progress and development. This involves not only technological innovations but also changes in institutions. Thus, institutions themselves evolve according to changing circumstances. These two last points complement the concepts of systems of innovation found in the macroeconomic field of the evolutionary approach.

**INTRODUCTION**

**1 ECONOMICS OF INNOVATION**
**1.1 Introduction**
**1.2 Industrial Organization**
**1.3 Endogenous Growth Models**
**1.4 New Economic Geography**

**2 THE EVOLUTIONARY ECONOMICS OF INNOVATION**
**2.1 Introduction**
**2.2 Microeconomics of Innovation**
**2.3 Systems of Innovation and the Role of Institutions**

**3 STRATEGIES OF INNOVATIVE FIRMS**
**3.1 Innovation and Competitive Advantage**
**3.2 Timing of Innovation and Life Cycles**
**3.3 Issues Relating to Network Industries**

**4 BIBLIOGRAPHY**
**4.1 Industrial Organization**
**4.2 Endogenous Growth**
**4.3 New Economic Geography**
**4.4 Evolutionary Economics**
**4.5 Cliometrics**
**4.6 Strategic Management and Networks**

# INTRODUCTION

This is an overview, with references to the seminal literature on the spectrum of dynamic approaches in micro and meso economics covering at least the last two decades – the overview should avoid a pure focus on mainstream approaches and draw benefits from overlaps with neighboring disciplines such as systems theory, cliometrics and institutionalism.

This is a brief overview and classification based on the relevant literature of the most important economic strategies applied by innovative companies to enter new markets or introduce new products.

Section 1 presents the survey of mainstream theories and models of innovation and Section 2 discusses evolutionary economics, systems theory, cliometrics and institutionalism.
Section 3 focuses instead on firms' strategies related to innovative activities.

# 1 ECONOMICS OF INNOVATION

## 1.1 Introduction

*The neo-classical approach to innovation*

In neo-classical theories, production opportunities are described by specifying a production function, which describes the technological relationship between inputs and output. Technological progress is captured by the ability of a firm, or the economy, to produce, for each combination of inputs used, more output. However, such progress was for a long time essentially considered exogenous, as if it were knowledge that falls, like manna, from heaven.

Nevertheless, neo-classical economists were conscious that the consideration of innovation as an economic phenomenon posed some challenges to established theories of perfect competition and that a trade-off may exist between static and dynamic efficiency.

Innovation is essentially the production and commercial application of new knowledge. Neo-classical economists, following the pioneering work of Arrow (1962), have usually treated knowledge as information, that is, as a pure non-rivalrous and non-excludable good. The concepts of non-rivalry and non-excludability are crucial in understanding the neo-classical economic analysis of innovation and can be explained as follows:

(a) Non-rivalry implies that the same piece of knowledge can be consumed by different individuals, the marginal cost involved being essentially zero. Knowledge is considered to be essentially disembodied (as opposed, for instance, to knowledge embodied in organizational routines — a central feature of the evolutionary approach overviewed in section 2) and available in a common stock or pool. In other words knowledge is essentially assimilated to information.

(b) Non-excludability is the inability of the innovator to prevent others from accessing the knowledge produced. Non-excludability arises largely because it may not be feasible, or it is extremely costly, to monitor and charge for the use and enjoyment of a piece of knowledge. In traditional models of innovation, it is often related to the notion of knowledge spillovers, which refers to the positive externality by which the knowledge generated by an agent enhances the technological capabilities of other agents or their ability to discover new knowledge. Non-excludability is not entirely an intrinsic quality of knowledge and depends largely on the legal regime in place and, in particular, on the system of property rights (e.g. patents). Indeed, a patent might allow the innovator to appropriate the value of an (otherwise non-excludable) innovation by granting the exclusive right of its commercial use for a certain period of time.

The neo-classical analysis of the economic forces underlying the production of new technological knowledge follows from the general theoretical framework described above and is developed on the assumption that economic agents are rational and act to maximize their utility or profit.

When non-rivalry is coupled with non-excludability, and both are considered to be essential features of technological knowledge, innovation acquires the characteristics of a pure public good and, accordingly, profit maximizing agents are considered not to have incentives to invest in its production.

In fact, if the process of imitation of an innovation were immediate, a firm would not have the incentive to invest resources in R&D activities since ex-post competition would not allow the innovator to earn profits to pay back its investment. However, although a single firm would not have incentives to discover new knowledge, innovation may well be beneficial for society so that a role for public intervention in the form of direct R&D investment and/or appropriate public policy is usually called for.

These considerations suggest that a trade-off may exist between static and dynamic efficiency and provide the economic rationale for some important public policies such as public funding of research and the definition of a patent system that protects the innovator from imitation. The basic trade-off of a patent system is that between the static costs that derive from the innovator's potential monopoly power and the long-term benefits associated with the discovery of the new knowledge.

*Core models of dynamic competition*

In the last two decades, the analysis of innovation and technological change has attracted much attention within mainstream economics, due to the development of two closely related disciplines — game-theoretical industrial organization and endogenous growth theories. As a consequence, many of the themes that were once a feature of the less conventional theories of technological advance have now found their way into  economics.

Studies of dynamic competition within mainstream economics have developed once inherently static neoclassical economic theories into modern analyses of innovation and dynamic competition. Nonetheless, a strong relationship with neoclassical economics remains in the general methodological approach adopted in these theories, which are characterized by the analysis of equilibrium models where fully rational economic agents make optimizing choices.

Core models of dynamic competition are highly stylized and this is also reflected in the definition of innovation adopted. In these models, innovation is usually defined as the reduction of production costs or as the commercialization of new and/or better products. Apparently this definition identifies innovation with technological change and downsizes the importance of other forms of innovation, such as managerial and organizational changes.

However, notwithstanding the emphasis placed by these models on innovation as the commercial use of new or improved products and processes, this stylized definition of innovation can also be considered to encompass non-technological changes inasmuch these ultimately matter because result in a reduction of production costs or new and better products.

What mainstream models suggest is that the particular form of innovation (e.g. new technological knowledge rather than new organizational knowledge) is not central to the understanding of firms' incentives to exert effort to improve their ability to produce efficiently and to market new and or better products, which is the main question addressed in these theories.

Similar to the definition of innovation , also the treatment of the process by which new knowledge is generated is very stylized in these models. Knowledge is usually considered as deriving from learning-by-doing or from intentional R&D investments, optimally chosen by profit-maximizing agents. The R&D process is captured by the definition of a deterministic or stochastic knowledge production function which related the input used in R&D — notably capital, labor, available knowledge – to the new knowledge produced and/or the timing of innovation.

Game-theoretical models study firms' incentives to invest resources in R&D activities in strategic settings and address issues such as the interplay between innovation and market structure, the dynamics of competition and the nature of the relationship between intensity of competition and innovation.

In general, these models are structured on the fundamental distinction between static and dynamic competition. Static or product-market competition refers to the strategic interaction that arises between firms, taking as given the capabilities of these firms in terms of the variety, quality and production costs of the products in their portfolios. Dynamic competition refers instead to the strategic interaction among rival firms to change these capabilities.

This distinction is usually captured by the structure of game-theoretical models: firms are considered to play a game where they first invest in innovative activities and then compete at the product-market level. The distinction is a fictitious one to a certain extent, since in reality both dimensions of competition are continuously overlapping, but it is a convincing and powerful conceptual categorization since it allows distinguishing activities that occur over different time-horizons, i.e. short-term price competition versus. long-term dynamic competition. When firms compete in the short-term they have to take as given a number of constraints in terms of their and their rivals' "capabilities" that derive from previous innovative activities; when competition is considered over a longer-time horizon, however, these "capabilities" become endogenous to the competitive process as well.

Despite the absence of general results, game-theoretical models are certainly useful to understand what fundamental strategic forces and incentives drive firms' investments in R&D and what factors may lead to different types of dynamic competition (i.e. persistence of monopoly or action-reaction).

Endogenous (or new) growth models, pioneered by Romer, Lucas, Aghion and Howitt have tried to explain the economic forces driving the technological progress underlying economic growth. In these models economic growth, in general, derives from the growth of the stock of knowledge available to society, which in turn is the outcome of economic choices of profit-maximizing agents. Earlier models developed in the 1960s were instead mainly focused on capital accumulation and did not treat technological change as an economic phenomenon amenable to economic analysis.

Although these models are based on the equilibrium methodology typical of the neo-classical approach they are inherently dynamic. The evolution of the stock of knowledge is explained as either being the product of unintentional learning-by-doing activities or the outcome of R&D investments undertaken by profit-maximizing agents and rewarded by the monopolistic rents that the innovator is able to appropriate. Externalities involved in the production of new knowledge usually play an important role in these models, and in particular knowledge spillovers by which the knowledge generated by an agent enhances the technological capabilities of other agents or their ability to discover new knowledge.

This section considers first game-theoretical microeconomic models of innovation developed in the industrial organization literature. It then considers endogenous growth theories and the new economic geography theories.

## 1.2 Industrial Organization

The game-theoretical literature on innovation, which was developed mainly in the 1980s and 1990s, addresses the strategic interaction that characterizes R&D investment decisions in oligopolistic industries. These models provide the fundamental building blocks of more recent endogenous growth models, which cannot be properly assessed without reference to this earlier literature.

More recently, game-theoretical models have focused on the analysis of competition and innovation in markets characterized by network effects, on the analysis of co-operation in research and development activities and on the study of the relationship between intensity of competition and innovation.

The starting point of this section is a categorization of game-theoretical models that should act as a guiding map to this literature. Understanding the nature of the models, and not only their results, is unavoidable to assess the adequacy of a particular model as theoretical reference in a practical case. The results of game theoretical models are generally very sensitive to the specific assumptions adopted and only by having clear the link between the former and the latter can these studies offer useful guidance for practical analyses of competition and market dynamics.

The following sections focus on some of the issues that are addressed in the game-theoretical literature and that are most relevant to the analysis of competition and innovation for antitrust purposes:

- the relationship between market structure and innovation;
- the issue of persistence of monopoly in dynamic markets;
- the relationship between toughness of product market competition and innovation; and
- R&D co-operation.

*An overview of the game-theoretical literature on R&D*

Game-theoretical models of innovation explain the strategic interaction that underlies firms' investments in research and development activities. The focus on strategic behavior distinguishes this literature from earlier decision theoretic models, e.g. Kamien and Schwartz (1980).

Game-theoretical models of innovation can be categorized as belonging to one of three broad paradigms:

- Non-tournament models. These models capture the strategic interaction that can arise in those cases where firms pursue different paths of technological advance so that a discovery made along one path can be used irrespectively on whether a competitor innovates along another technological path. These models have been investigated by Dasgupta and Stiglitz (1980a), Spence (1984) and Judd (1985).

- Deterministic auction models. Auction models of innovation describe R&D competition in terms of rival firms bidding for a given process or product innovation. Important contributions include Gilbert and Newbery (1982), Katz and Shapiro (1987) and Vickers (1986).

- Stochastic tournament models (or "patent races"). These models capture the strategic interaction that arises when firms compete to be the first to introduce an innovation and the issue of timing is crucial to firms' strategic interaction. Papers in this category include Loury (1979), Lee and Wilde (1980), Dasgupta and Stiglitz (1980b), Grossman and Shapiro (1987), Harris and Vickers (1987), Reinganum (1981,1982).

Each of these approaches describes R&D investments in a particular setting, which may be an appropriate depiction of reality in some circumstances and a less appropriate theoretical reference in relation to some other industries or to particular stages of a technology life cycle.

Despite the differences, however, game-theoretical models of innovation illustrate that there are two central economic incentives at the basis of firms' investments in R&D activities, whose relative importance varies according to the specific environment considered: the profit incentive and the competitive threat (or replacement effect).

The profit incentive, or stand-alone incentive, is related to the notion that allocating resources to innovative research and development would, if successful, increase a firm's profits. This incentive can be usually thought of as the incentive to invest in R&D of a firm that takes the innovation decision in isolation. In fact, it is equal to the difference between the profits that the firm would get if it innovates and those that it would get if it does not innovate, all else equal.

The competitive threat, or pre-emption incentive, arises when strategic interaction in innovation activities is considered: a firm not only has to take into account the benefits connected to innovation but also the possible loss of competitiveness where it does not innovate and a competitor does. This incentive reflects the threat posed by the existence of an active rival and can be thought of as the difference between the profits if the firm innovates and the profits if it is left to a rival firm to innovate.

In general settings, both the profit incentive and the competitive threat may play a role in shaping the nature of dynamic competition. This would depend crucially on the specific characteristics of the market environment considered and, in the literature, on the specific assumptions adopted in each model.

*Non-tournament models*

Non-tournament models of innovation investigate R&D investments in a setting where there can be multiple discoverers and firms do not compete to be the first to innovate. In these models symmetric competitors cannot prevent each other from getting equivalent improvements from spending equivalent amounts of resources in R&D.

For this reason, such models may explain R&D investments in those environments where firms pursue different research paths so that an advance made on a single path can be appropriated irrespective of rivals' advances on other research trajectories.

A typical non-tournament model, such as the one by Dasgupta and Stiglitz (1980a), is structured in 3 stages: an entry stage, an R&D stage and a market competition stage. Firms first decide whether or not to enter an industry; active firms would then invest resources in R&D activities to decrease their marginal cost of production or increase the quality of their products and would finally compete in the marketplace.

R&D activities are described in terms of a deterministic production function that specifies the size of innovation according to the amount of cost reduction or quality improvement per unit of R&D investment. Each firm can reduce its costs or improve the qualities of its products independently of parallel innovation by rival firms, although it is usually assumed that a firm can indirectly benefit from a rival's R&D activity for the existence of knowledge spillovers.

Knowledge spillovers capture the notion that innovative knowledge produced by R&D activities may, to some extent, be non-excludable so that firms can, at least partially, appropriate the results of R&D activities of a rival. Cohen and Levinthal (1989) suggest that such learning may not be costless and that firms may have to invest in own R&D programs in order to access external knowledge and benefit from spillovers from innovating rivals.

Non-tournament models have especially been employed to assess the extent of innovation achieved by the operation of market forces and how it compares to the socially optimal one, to discuss technological policy, and to investigate the relationship between market structure (i.e. concentration) and innovation.

However, non-tournament models assume that there are a large number of research paths and the relationship between R&D investments and rewards from innovation is essentially continuous. For this reason they are not well suited to describe market environments where innovation takes the form of a race and competition is for the market rather than in the market.

Although this may be an appropriate description for technological change in some markets, in many others innovation is a more disruptive process that leads to winners and losers in very different competitive positions. In these circumstances, the rewards to R&D investments are discontinuous, performance is rewarded on the basis of the rank within the set of realized performances, and competition takes the form of rival firms racing to be first to innovate (Dasgupta, 1986). An example of this type of race could be that characterizing competition between Intel and AMD to introduce better PC processors.

*Auction models*

Auction models of innovation describe R&D competition in terms of rival firms bidding for a given process or product innovation. The innovation is allocated to the firm which makes the highest bid and the issue is to investigate the identity of the firm which would have the larger willingness to pay for the innovation.

In general, the maximum bid that a firm would make is equal to the difference between the profits it would get if it were successful in the auction and those it would get were it not. For this reason, auction models of innovation emphasize the competitive threat as the incentive underlying competition in innovation.

Auction models have been widely used to investigate dynamic competition and whether market dynamics are characterized by persistent dominance by a technological leader or by “creative destruction” whereby the incumbent is overtaken by some rival whose incumbency is itself short-lived.

In a single auction model, the issue of dynamic competition is investigated by considering a set of firms with different technological levels, i.e. marginal costs in the case of process innovation, and studying their incentives to purchase an innovation. Market persistence is the result of such competition if the winner of the auction is the technological leader, otherwise dynamic competition is characterized by action-reaction.

Assessing market dynamics in a single-innovation auction model, however, may not help to understand dynamic competition because in these models firms do not take into account how the outcome of the current bid may affect the outcome of future auctions. These inter-temporal links, however, may be an important element to explain firms’ incentives to invest in R&D in some contexts where a sequence of innovative opportunities is in prospect. For this reason, the question of dynamic competition may be better posed in the context of sequences of innovation rather than of a single innovation.

Auction models are intrinsically deterministic and this leads to the somewhat disappointing result that losers do not commit resources in R&D and that the process of technological advance is not really explained.

*Stochastic tournament models*

Tournament models of innovation capture the particular interaction that arises in those markets where dynamic competition takes the form of a race to be the first to make a discovery. As opposed to deterministic auction models, tournament models consider the case where there is technological uncertainty. This can be captured, for instance, by considering a stochastic relationship between R&D effort and success.

As such, these models emphasize timing in the context of R&D competition and are well suited to describe those environments where competition is for the market rather than in the market. This nature of market dynamics can arise because technological change proceeds along a small number of research trajectories and there is competition to be the first to innovate because success by a firm would somehow prevent appropriability by subsequent innovators.

The advantage of being the first to innovate is usually explained on the basis of the ability of the winner to appropriate the value of the innovation by means of patent protection. More generally, however, appropriability may depend on factors other than patent protection, such as lead-time, access to complementary resources and secrecy. The relative importance of various appropriability factors is likely to be different across industries. (Levin et al., 1987)

In auction models it is the competitive threat that characterizes firms' incentives to invest in R&D activities. When randomness is introduced, however, both the profit incentive and the competitive threat are relevant in firms' strategic interaction.

In general, these forces need not be symmetric and have to be considered for each firm involved: one firm may face the greater competitive threat and another may have the greater profit incentive. Clearly, if a firm faces both the greater profit incentive and competitive threat it would undertake more R&D and hence be more likely to win the race. However, where there are asymmetric incentives, the nature of the outcome is not as straightforward.

The literature usually focuses on the case where the competitive threat exceeds the profit incentive for all firms involved in the race. However, it could be the case that the profit incentive for both firms exceeds the competitive threat and that competition in R&D takes the form of a waiting game where firms tend to behave as free-riders and invest little resources in R&D. This type of situation has been considered, for instance, by Katz and Shapiro (1987) who explicitly account for the possibility of imitation and licensing of innovation.

An important distinction among tournament models is related to the assumption on the nature of R&D expenditures and whether these are contractual (e.g. Dasgupta and Stiglitz, 1980, Loury, 1979) or non-contractual (e.g. Lee and Wilde, 1980; and Reinganum, 1981,1982). In the first case R&D outlays take the form of a lump-sum cost incurred at the outset; in the second case R&D can be considered as a flow — a cost that it is incurred until the successful innovation is achieved.

Beath, Katsoulacos and Ulph (1994) discuss the implications of these different assumptions. When R&D is of the contractual kind, equilibrium investments can be explained on a relatively simple marginal benefit/marginal cost condition. On the other hand, when R&D is of the non-contractual kind, it is the competitive threat that is the main determinant of a firm's R&D.

As with auction models, tournament models have also been developed to consider a sequence of tournaments in which firms complete a number of R&D stages before competing in the market. Examples of models that fall in this category are Fudenberg et al. (1983), Harris and Vickers (1987) and Grossman and Shapiro (1987).

In these models innovation is obtained only as the result of the completion of a number of stages. A crucial issue that arises in such a setting is the nature of the innovative process and in particular whether each firm has to discover each technological step itself before it can move on to discover the next or whether instead the follower firm can compete directly with the leader for the new state-of-the-art technology.

The latter case may arise if knowledge spillovers are relevant so that a laggard firm has access to (but may not have right to use) the same technological knowledge of the technological leader. On the other hand, knowledge may be excludable to some extent or in-house R&D is very important to assimilate external knowledge so that the technological frontier has to be achieved independently by each firm.

The Grossman and Shapiro, Park and Harris and Vickers step-by-step models assume that each firm has to discover each technological step itself before it can move on to discover the next. Reinganum (1985) and Beath et al. (1987) are examples of leapfrog models where a follower is allowed at any time to compete directly with the leader for the new best-practice technology.

In a step-by-step model firms can compete neck-to-neck or have different technological levels. In a leapfrog model firms are always asymmetric in terms of their technological ability. This distinction turns out to be crucial in the analysis of the relationship between competition and innovation, as recent contributions in the endogenous growth literature surveyed below have shown.

Endogenous growth theories have further developed these non-tournament models by considering sequences of tournaments where firms compete to innovate and compete in the product market before starting the following race to innovate.

*Market structure and innovation*

A long-standing question in the economics of technological change has been the nature of the relationship between market structure and innovation.

The relationship between concentration of an industry and its rate of technological innovation is complex. Market structure may have an impact on the rate of innovation, but innovation is also an important factor that shapes market structure. In fact, it is necessary to recognize that the relationship between concentration and innovation is not a causal one: both are the endogenous outcomes of the operation of market forces and exogenous factors such as the nature of demand, technological opportunity, the conditions governing appropriability, and pure chance.

The classical point of departure in the economic analysis of the relationship between static market structure (i.e. concentration) and innovation is the work by Arrow (1962). Arrow considers the case where a cost-reducing innovation is exogenously available and investigates firms' willingness to pay for the innovation under different market structures. For a drastic innovation, Arrow's analysis shows that a firm that is already a monopolist would have lower incentives to innovate than a firm that is currently in a perfectly competitive environment, essentially because it would have the lower profit incentive.

On the other hand, innovation is certainly an important factor that affects market structure: innovation is a means by which a firm tries to escape the constraints imposed by competition. Studies in the Schumpeterian tradition have emphasized the importance of ex-post market power for firms' incentives to innovate. Some degree of market power is necessary for a firm to cover its R&D outlays: dynamic and static efficiency are somehow conflicting. This is a theme that has been well developed in the recent literature on endogenous growth.

Dasgupta and Stiglitz (1980a) discuss the relationship between concentration and innovation in a non-tournament model. If there are exogenous entry barriers, an increase in the number of firms causes each firm to spend less on R&D in equilibrium, however total R&D expenditure increases with the number of firms. When entry is considered to be endogenous, one would observe more innovation in those industries that are characterized by a higher degree of monopoly power, although no causality should be imputed to this relationship.

Sutton (1998) adopts an innovative approach to the study of technology and market structure and achieves a very general, albeit somehow loose, result on the relationship between concentration and R&D. He is able to characterize, under very general assumptions, a lower bound to market concentration (in large markets) that holds in those industries where the effectiveness of R&D in raising consumers' willingness to pay is high and the product groups within the industry are sufficiently close substitutes. By contrast, in those industries where R&D is not effective or where product groups are not close substitutes, very fragmented market structures can also be equilibrium configurations no matter how large the market size is.

The models discussed above consider the relationship between product market structure (i.e. concentration) and innovation. In the context of models where firms race to innovate another interesting question concerns the relationship between the number of firms that are part of the race and the pace of technological advance.

Loury (1979) considers a tournament model of innovation where R&D expenditures are committed upfront (that is, the probability of success depends on the scale of the R&D lab) and shows that increasing the number of firms reduces the expected date of invention. Lee and Wilde (1980) consider the case where the probability of innovation is related to the research intensity and show that as the number of firms in the industry increases, the equilibrium rate of investment per firm increases and success by any one firm is hastened by an increase in the number of firms. However, the first success date is hastened by an increase in the number of firms in both models.

Reinganum (1982) considers a setting where firms can vary the research intensity as in Lee and Wilde (1980) but does not assume that the rate of expenditure is constant over time. Instead, firms may adjust R&D intensity in response to elapsed time and rival progress. Reinganum shows that, in this setting, when imitation is not possible, an increase in the number of firms increases the equilibrium rate of investment for each firm and decreases the expected time of innovation. When there is no full patent protection, the relationship is ambiguous and depends on the relative payoffs to the innovator and the imitators.

*The persistence of dominance*

In many industries characterized by fundamental long-term market dynamics competition may take the form of competition for the market rather than competition in the market.

In these markets the issue is not whether more or less concentration is associated with faster technological progress but whether market dynamics would be characterised by persistent dominance of the incumbent leader or by action-reaction whereby incumbents are overtaken by some rivals whose incumbency is itself short-lived.

The dynamic evolution of market structure depends on both abilities and incentives of the incumbent and the rivals to innovate. Game theoretical models are well suited to analyse the incentives underlying R&D investments and the resulting evolution of market structure. If we focus on economic incentives, and set aside differences in R&D abilities, persistence of monopoly or action-reaction can be related to the different profit incentive and competitive threat faced by the leader and the follower(s).

Gilbert and Newbery (1982) use the auction model to examine potential competition at the R&D stage and reverse Arrow's (1962) result: potential competition matters and a monopolist may have more incentives to innovate than a potential entrant because the incumbent monopolist may face a larger competitive threat.

The profit of a successful incumbent who innovates is that of a monopolist firm, whereas if it were the entrant to innovate each firm would get the profit of a duopolist. Hence, the competitive threat of the incumbent can be measured as the difference between the profit of a monopolist firm and the profit of a duopolist firm. The incumbent's competitive threat, instead, is simply equal to the profit of a duopolist. This implies that the incumbent would have more incentives to innovate (i.e. the larger competitive threat) if, as it is normally the case, the profit of a monopolist is greater than the combined profits of two duopolists.

Katz and Shapiro (1987) study a general auction model and show that for minor innovations, the industry leader will typically be the innovator, whether or not imitation and licensing are feasible. For markets where patent protection is strong, they predict that the major innovations will be made by industry leaders. But if imitation is easy, industry followers or entrants will make the major discoveries.

Reinganum (1983) in a tournament model shows that when the first innovator captures a sufficiently high share of the post innovation market, then the incumbent firm invests less on a given project that does the potential entrant. This is because the incumbent has less incentive than the challenger to shorten the period of its incumbency.

Beath, Katsoulacos and Ulph (1995) show that in a tournament model under Cournot competition, a large innovation or a large initial gap results in persistent dominance while a small initial gap and a small innovation results in action-reaction. However, if market competition is Bertrand there is persistent dominance irrespective of the size of the innovation or the initial gap. This is a result that points towards the possible trade-off between static and dynamic efficiency suggested also by Vickers (1986).

Market dynamics have also been investigated in models that consider a sequence of innovations.

Reinganum (1985) considers a sequence of drastic innovations and shows that market dynamics are characterised by a process that resembles Schumpeter's process of creative destruction: the incumbent invests less than each challenger in each stage.

Vickers (1986) considers a sequence of non-drastic process innovation in the context of the auction model. He compares market dynamics under Bertrand and Cournot competition and finds that when the product market is very competitive then there is increasing dominance, but when it is not very competitive there is action-reaction. When innovation is drastic, then market dynamics are characterised by increasing dominance.

Reinganum (1989) observes that the differences in the results obtained in different models can be ascribed to the different roles that the profit incentive and the competitive threat play in stochastic tournament and deterministic auction models. In a deterministic model the incentive to pre-empt (larger for the incumbent) dominates the firms' decision. When success is stochastic, however, the threat from the rival innovating is less acute. In the case of drastic innovations, the competitive threat is the same for both firms and it is the profit incentive (which is larger for challengers) that determines R&D investments. The relevance of the profit incentive extends to the case for some non-drastic innovation.

*Competition intensity and innovation*

Market structure is often associated with the concept of competitiveness: usually, a high level of concentration in an industry is interpreted as weak competition. This view is based on a symmetric Cournot model, where price-cost margins are higher as the number of firms increases.

However, it is preferable to disentangle the notions of market structure and toughness of price competition as, among others, Sutton (1998) and Boone (2000, 2001) have done.

In a simple world with homogeneous firms, toughness of price competition can be considered as being related to the level of price-cost margins given any level of concentration. Hence, a differentiated Bertrand market would be considered to be more competitive than a differentiated Cournot market because price-cost margins would be lower in the former, for any level of concentration. As a result, more competitive markets may allow fewer firms to profitably survive.

Recently, Boone (2000,2001) has offered an interesting contribution to the study of the relationship between toughness of competition and innovation. Boone defines intensity of competition on the basis of an axiomatic approach, which allows the result to be general to a large class of specific game-theoretical models. Boone considers four axioms:

- the lower limit of competition is such that firms are not affected by opponents' actions;
- the least efficient firm in the market loses as competition becomes more intense;
- if the leader is far enough ahead, he gains as competition becomes more intense; and
- if all active firms have similar costs, they all lose as competition becomes more intense.

Boone (2001) shows that this definition encompasses, for instance, a switch from Cournot to Bertrand competition and a reduction in travel costs in typical horizontal product differentiation models.

When the notion of intensity of competition is defined in such a way, it is normally inversely related to equilibrium concentration. For instance, in Boone's setting, if intensity of competition is low, then a large number of firms can be active in the market because the less efficient firms can survive as well. On the other hand, fierce competition is associated with high concentration because only the most efficient firms can survive.

On the basis of this definition of product market competition, Boone (2001) investigates the relationship between intensity of competition and firms' incentives to invest in R&D. The central finding of this study is that the relationship between market competition and innovation may not be monotonic; this is so because varying intensity of competition is associated with different identity of the innovator.

Boone (2001) explains this interesting result as follow. When intensity of competition is low it is the follower that would be the next innovator, whereas when intensity of competition is large, it is the current technological leader that is likely to innovate. When it is the follower that innovates, tougher competition implies lower profits and hence lower incentives to innovate. However, when it is the current leader to innovate, an increase of toughness of price competition would further increase the profits related to his technological leadership and hence would increase the value of innovation for the firm. Hence, the relationship between toughness of price competition and innovation would be U-shaped.

Denicolò (2002) observes that Boone's paper generalises the findings of a number of other studies. Delbono and Denicolò (1990) considered a homogeneous product market and found that Bertrand duopolists have greater incentive to innovate than Cournot duopolists. Bester and

Petrakis (1993) and Bonanno and Haworth (1998) showed respectively that horizontal and vertical product differentiation could reverse this result. Qiu (1997) compared the two regimes in a non-tournament model and find that is such a framework the incentive to innovate is greater with Cournot competition even in the case of homogenous products.

Other studies that investigate the relationship between toughness of competition and innovation fall within the endogenous growth literature ,Aghion and Griffith (2005) and are surveyed in the relevant section of this review.

R&D Co-operation

Increasingly, research joint ventures (RJVs) have become a widespread form of industrial co-operation. In parallel, the study of the effects of R&D co-operation has also emerged as an important research topic when considering industry policy.

Co-operative R&D ventures can take many forms, ranging from R&D joint ventures, to cross-licensing agreements and various informal types of technology trading or information-sharing agreements.

Research Joint Ventures themselves can cover a variety of arrangements. One type of RJV is the traditional joint venture, in which two or more parties create a separate entity in which they all have equity interests to conduct well-defined R&D projects for their benefits. Another type is the research consortium. A third form of RJV is the venture capital investment by firms in a stand-alone start-up company.

Economists have investigated the extent to which RJVs might allow firms to internalize spillovers, co-ordinate their research activities and achieve higher R&D efficiency. Co-operative R&D is thought to be socially beneficial for several reasons:

- RJVs can alleviate the under-provision of R&D effort that results from technological spillovers and other sub-optimal R&D decisions.

- Co-operation can lead to greater dissemination of R&D results. It can improve R&D efficiency through good research design and information sharing, avoiding needless duplication of resources.

- Co-operative R&D enables the firms to share risks, to exploit synergies, pool different complementary assets, and exploit increasing returns to scale in R&D. It can enable firms to overcome a cost-of-development barrier impenetrable to any one of them alone.

Adding to these effects, an important issue that is not very developed in the industrial organization literature but is emphasized in the evolutionary economics and the management literature on inter-firm co-operation is that cooperative ventures may be an important means by which firms exchange specialised know-how and tacit knowledge.

Countering these social benefits is the fear that firms participating in co-operative R&D might use the venture to engage in anti-competitive practices or that they might free ride on each other.

*RJVs and R&D investments*

Since the early contributions to the literature on RJVs, the effects of R&D co-operation on the amount of resources invested in innovative activities have been extensively investigated.

This attention is immediately related to the study of the potential of RJVs to correct the sub-optimal R&D decisions that may characterise independent decision-making.

The results of these studies accord support to the presumption that RJVs, by internalising externalities which affect the efficiency of non-cooperative decision-making, can help to correct the non-optimality of independent investments in R&D. In explaining what impact RJVs may have on R&D investments, knowledge spillovers are widely acknowledged as a crucial factor, and their consideration plays an important role in most economic models of RJVs.

In their seminal paper, d'Aspremont and Jacquemin (1988) pioneered an influential approach to study the effects of co-operation on R&D investments. They consider a two-stage model in which duopolists first conduct partially inappropriable research leading to a reduction in unit cost, and then compete à la Cournot in the product market. The focus of their analysis is on the comparison of the magnitude of cost-reducing technical advance achieved when firms conduct R&D competitively versus co-operatively, in the presence of spillover effects.

The difference between the independent decision-making equilibrium and the co-operative one results from the balance of the spillover internalisation effect and the reduced strategic incentive effect. Joint decision on the levels of R&D expenditures internalises two externalities disregarded under independent decision-making:

- Research knowledge is partially inappropriable, and it can benefit other firms without the innovator being able to fully appropriate the value of the knowledge created. This externality causes sub-optimality of independent R&D investments. Its internalisation under joint-decision making (spillover internalisation effect) will tend to increase co-operative R&D investment relative to the non-cooperative level.

- The innovative activity of a firm comprises also a negative pecuniary externality on the profits of the rival through a clear strategic market interaction. Joint decision-making internalises this externality (reduced strategic incentive effect) and tends to decrease the co-operative level of R&D investment relative to the non-cooperative equilibrium.

The balance of these opposite forces is crucial to understand the effects of co-operation on the level of resources invested in research and, in turn, on the appropriateness of co-operation to reduce the gap between the private and social incentives for doing R&D.

In case of “high” spillover rates, the spillover internalization effect would dominate the reduced strategic incentive effect, the net effect being an increase in the R&D expenditures. By contrast, if spillovers are “low”, R&D co-operation would cause R&D investments to decrease relative to the non-cooperative equilibrium.

The contributions of Kamien, Muller and Zang (1992), Suzumura (1992) Simpson and Vonortas (1994), have proposed extensions of the basic modelling framework to cover an arbitrary number of firm, general demand and cost assumptions.

*RJVs and R&D efficiency*

As we have discussed, considerable attention has been devoted to the study of the effects of RJVs on the amount of resources allocated to R&D, and of the advantages of technological co-operation in terms of correcting inefficient R&D efforts that independent decision-making involves.

Another commonly acknowledged advantage of R&D co-operation is identified in the increased efficiency of R&D activities: RJVs not only can affect the absolute levels of R&D spending, but also the amount of R&D spending per unit of cost reduction/quality improvement achieved.

Indeed, to the extent that co-operative R&D is more widely disseminated than individually conducted R&D, ex ante co-operation increases the efficiency of R&D efforts because a single investment benefits a greater number of firms.

The efficiency gain can have three types of positive effects. First, sharing lowers the cost of investment for each firm, which may induce them to conduct more R&D. Second, for a given level of R&D investment it might increase the effective amount of R&D. Third, co-operative R&D can eliminate the wasteful duplication that would occur if several firms separately undertook the same projects. Even if several firms continue to conduct separate R&D under an ex ante agreement, they still can improve the efficiency of their efforts by co-ordinating them.

Some studies have formalized these intuitions, by investigating the effects of co-operation on the level of information-sharing and the co-ordination of research activities.

Katz (1986) presented an early, albeit isolated, study in which firms choose the level of spillovers in the RJV, by determining the amount of information-sharing achieved. However, the endogeneity of spillovers is restricted to the co-operative equilibrium only, and this limits the significance of the comparison of the (exogenous) non-cooperative and (endogenous) co-operative information-sharing levels.

To fully exploit the endogenization of knowledge spillovers, and explain the differences of information-sharing levels in the co-operative and non-cooperative equilibrium it is necessary to model both as the result of firms' choices. Katsoulacos and Ulph (1998) have presented a stochastic model of innovation with this feature.

The authors adopt a structured approach to model knowledge spillovers by distinguishing two relevant dimensions: the adaptability of the research to the other firm and the amount of information-sharing that actually takes place.

They show that the non-cooperative equilibrium generally produces minimal spillovers; in this case, RJVs might lead to a higher information-sharing. However, if firms operate in different but complementary industries, it is possible to achieve maximum information-sharing also in the non-cooperative equilibrium.

Poyago-Theotoky (1999) analyses endogenous spillovers in the context of a simple non-tournament model of R&D where firms are engaged in cost-reducing innovation. It is shown that when spillovers of information are treated as endogenous firms never disclose any of their information when choosing their R&D non-cooperatively. Under co-operative R&D, firms will always choose to fully share their information, i.e. a research joint venture will operate with a maximum spillover value.

The relationship between the research paths followed by firms can be manifold, spanning a continuum from perfect complementarity to perfect substitutability. Co-operation in R&D can take advantage of joint research design, by choosing the number of labs to operate for optimally exploiting such substitutability or complementarity.

The issue of organisation design in an RJV has been further considered by Katsoulacos and Ulph (1998) who relate this choice to the nature of research paths followed and the endogenous level of information-sharing chosen by firms. An important result of this study is that cost considerations, dominant when research outputs are close substitutes and firms are willing to share a lot of information, are only one of the factors behind the RJVs decision as to whether to operate one or two labs.

Indeed, the RJV may close a lab for anti-competitive reasons, to prevent having to face a very competitive situation when both firms discover. Or, when there are very strong complementarities between the research outputs of the two firms, the RJV might prefer to keep both labs open in order to exploit such complementarities.

### 1.3 Endogenous Growth Models

Technological change is a fundamental driver of economic growth. However, only recently have the economic forces that underlie technological progress in a dynamic economy been investigated. Advances in this field have been associated with the development of endogenous growth theories, one of the most fertile grounds for economic research in the last 15 years. The relevant research agenda has been set on the study of economic growth as the result of knowledge production — we shall focus on technological knowledge in this survey — which is explained as the outcome of economic decisions.

Before the development of endogenous growth theories economic models of growth were essentially models of capital accumulation developed on the basis of Solow's (1956) seminal contribution. These models suggested that the simple accumulation of physical capital cannot sustain long-run economic growth as long as its marginal productivity is decreasing and not bounded from zero. Long run economic growth had to be attributed to the effect of some other factor, exogenous to the economic choices analyzed in these models, such as technological change.

In fact, even in older exogenous growth theories that studied capital accumulation, technological change was acknowledged as one of the major factors that explain the ability of an economy to grow in the long run. Certainly, advances in technology are a desirable element in any explanation of growth: "a story of growth that neglects technological progress is both ahistorical and implausible"(Grossman and Helpman,1994,p.26). Cliometric studies have also examined the relationship between knowledge
and economic growth as shown in the historical background below.
Nevertheless, for a long time the forces underlying advances were not explained on the basis of economic incentives but were essentially related to the exogenous evolution of scientific knowledge and its technological applications.

Endogenous growth theories or new growth theory have certainly contributed to fill this gap. These theories are based on product differentiation and imperfect competition, economies of scale and increasing returns instead of perfect competition and diminishing returns put forward by neo-classical theory. Freeman (1994) argues that these theories have been considerably influenced by the neo-Schumpeterian school of innovation.

New growth theory not only emphasizes knowledge accumulation and diffusion, in the form mainly of human capital (Lucas, 1988, Rebelo, 1991) or technological innovation (Romer, 1990; Aghion and Howitt 1992), as fundamental drivers of economic growth but also the economic decisions that underlie both.

The model developed by Rebelo (1991) represents the first generation of endogenous growth models that underscore the importance of human capital accumulation. In this model, there is no exogenous productivity growth given that the entirety of output growth is explained by human capital and capital stock accumulation.

As such, this review focuses on the second generation of endogenous growth models that consider technological innovation as well as human capital accumulation. In general, these models relate economic growth to innovations that improve firms' productive efficiency and/or lead to the production of new or better intermediate and consumer goods.

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Innovations result from new knowledge produced as the outcome of firms' learning-by-doing and/or intentional R&D activities. In general, R&D models of endogenous growth have drawn heavily from the earlier game theoretical literature on innovation and extended those analyses to more dynamic settings.As such, they have developed the analysis of long-standing questions investigating, for instance, the relationship between the intensity of competition and innovation and the nature of market dynamics.

Recent economic analysis in this field has offered interesting new insights on the relationship between competition and innovation. Despite some suggestive conclusions, however, endogenous growth models suffer from the same limitations as their constituent micro foundations: results often depend crucially from the assumptions adopted and the specific structure of the model studied. Unfortunately, in many cases some of these important assumptions relate to features of market environments that are hard to observe and evaluate.

Economic theory provides no general results that can be considered to hold in any market situation, but rather specific considerations that suggest which features of a market environment are worth considering to assess the nature of competition, market dynamics ,their relationship and growth. (Aghion and Griffith, 2005).

Learning-by-doing

Knowledge generated by learning-by-doing can be a significant engine of economic growth and models of endogenous growth with technological progress driven by learning-by-doing have been studied by Romer (1986), Young (1991,1993), Stokey (1988) and Aghion and Howitt (1998).

Learning-by-doing, since the seminal work of Arrow (1962), Solow (1997) has been considered an important source of technological knowledge. Firms can produce new knowledge without investing in institutionalized research and development activities but rather, as a by-product of their usual production activity. Indeed, experience has been shown to be an important source of technological improvements in many industries such as artificial fibres, semiconductors and memory chips.

Generally, in these models learning-by-doing is the unintentional by-product of production or investment activities and it is usually considered to result in technological knowledge that is only partially appropriable. The existence of knowledge spillovers is in fact generally acknowledged: a firm can, in part at least, benefit of the knowledge generated by the learning-by-doing of other firms.

Young (1991, 1993) studies a setting where new technologies are discovered through R&D activities but are initially inferior to the older technologies they seek to replace. Experience, however, generates incremental improvements over time, which allow the new technology to supplant older technologies. These incremental improvements are only achievable to some extent, in the sense that there is a bound to the technological advance that can be generated by learning-by-doing. This hybrid model emphasises that inventive activity and production experience are complementary forces in driving technological change.

*R&D models*

Endogenous growth models have also investigated economic growth as driven by the accumulation and diffusion of knowledge generated by Research and Development activities, undertaken by profit-maximising firms.

These models investigate the process of discovery of new or better products. Accordingly, a distinction can be drawn between those models that treat innovation in terms of the development of new varieties of products and those that consider sequential improvements of the quality of existing products.

The major difference between these two types of models is that the latter capture an important characteristic of the innovative process, namely that new inventions entail an element of destruction because they make old technologies or products obsolete. For this reason, early endogenous growth models with sequential improvements in the quality of products are called Schumpeterian.

Despite these differences however, the two types of models share the same fundamental structure. In both models, firms invest resources to acquire the exclusive right to manufacture a new product and it is usually assumed that R&D activities generate knowledge spillovers that benefit other research firms. The production of new knowledge and its diffusion drive economic growth in the long run.

Variety of products

Romer (1990) provides the seminal model where technological progress is captured in terms of an increasing variety of products. The increase of the variety of intermediate or final goods is reflected in higher productivity or utility and hence economic growth.

New varieties of products are discovered as outcomes of R&D investments and remunerated by the rents that accrue to the successful innovator who can benefit from patent protection (or, more generally, of other appropriability factors such as lead time, secrecy, access to complementary resources).

In these models, it is generally assumed that R&D activities lead both to new knowledge that can be appropriated by the innovator and new general knowledge that cannot be appropriated but instead contributes to a stock of publicly available knowledge that facilitates further discoveries. Not only is the production of new knowledge necessary for economic growth, but also its diffusion.

A distinguishing feature of Romer's (1990) growth model is that it studies horizontal product innovations that involve no obsolescence: new goods are never close substitutes for existing goods (i.e. each new product finds its own horizontal niche).

Although this feature of the model may detract from its realism is some cases, it is not necessarily so. There are some industries where innovation is fundamentally directed at the introduction of new varieties of products rather than at improving products' qualities. An example discussed in the literature is the flowmeter industry where technological advance takes the form of the development of new types of flowmeters. In this industry there is no escalation of R&D on a single technological trajectory and related product group but proliferation of product groups.

Quality of products

Aghion and Howitt (1992) examine growth as driven by industrial innovations that improve the quality of products.

Vertical innovation models of this kind introduce, relative to models with expanding varieties of products, the consideration of the process of creative destruction: a new innovation makes, to some extent, old products obsolete and negatively affects the economic rents of previous innovators. For this reason, models with qualitative improvements are also called Schumpeterian because they embody Schumpeter's idea of creative destruction by emphasizing the process by which new products (and innovators) displace old products (and innovators).

Endogenous growth models with vertical innovations have very elaborated micro-foundations describing the nature of market dynamics, which are similar to and develop further earlier game-theoretical models of innovation. As such these models have developed the study of dynamic competition.

Aghion and Howitt (1992) study a model of economic growth based on creative destruction. Innovation consists of a higher quality intermediate good that can be used to produce output more efficiently than before. Research firms invest resources in R&D activities that stochastically determine the time of the new innovation; the arrival rate of new innovations depends only upon the current flow of input to research. Firms' R&D investments are motivated by the prospect of monopoly rents that can be captured when a successful innovation is patented. However, unlike the horizontal innovations considered in Romer (1990), these rents would last only until the next innovation occurs, when the current innovation would become obsolete.

Aghion and Howitt consider the cases of both drastic and non-drastic innovation. In the first case the new innovator is unconstrained by potential competition from the previous patent; in the latter case, such a constraint is binding.

In the case of drastic innovations market dynamics take the form of a continuous process of action and reaction whereby at each point in time the market is dominated by a monopolist whose incumbency is short lived. In theory, a new innovation could be introduced by either the current monopolist or an outside research firm. The value of innovation is the expected incremental present value of the flow of monopoly profits generated by the innovation over an interval whose length depends on the occurrence of the next innovation. Because this incremental profit is lower for an incumbent monopolist, only outside research firms would innovate and the monopolist chooses to do no research.

The reason for this result lies in the fact that, given the assumption and the structure of the model, firms' incentives are driven only by the profit incentive, which in the specific case is always larger for an external firm. This is the replacement effect emphasized by Arrow (1962) whereby a monopolist would have lower incremental profits from innovation than a perfectly competitive firm. In the case of drastic innovation the competitive threat does not play a role because the flow of profit is independent of the identity of the innovator.

Innovations are non-drastic if the previous incumbent could make a positive profit when the current one is charging the unconstrained optimal monopolistic price. In the case of non-drastic innovation the competitive threat may potentially play a role in shaping equilibrium investments in R&D activities. However, Aghion and Howitt assume that the monopolist chooses to do no research also in the case of non-drastic innovations, i.e. assume that the efficiency effect is smaller than the replacement effect. As a result market dynamics take the form of continuous action/reaction.

Finally, Aghion and Howitt consider the case in which firms can affect not only the frequency but also the size of innovations. Their finding is that innovations would be too small if they were drastic; in the non-drastic case, the tendency to make innovations too small is in part mitigated by the incentive for innovators to move away from their competitive fringe.

Grossman and Helpman (1991) have built on the model by Aghion and Howitt to consider an economy where a continuum of, and not only one, intermediate goods. Each product has its own quality ladder and entrepreneurs target individual products and race to bring about the next generation. In each industry, success occurs with a probability per unit of time that is proportional to the total R&D resources invested to improving that product. The authors allow free entry in the race for the next generation of products and assume that potential entrants can learn enough about the state of knowledge to compete to produce the new state-of-the-art quality. These assumptions imply that, without a cost advantage, industry leaders do not invest resources to improve the quality of their own state-of-the-art products. This is because of the replacement effect whereby the leader would obtain an incremental flow of profits that is less than that of an external firm.

Aghion and Howitt (1998) introduce an element of heterogeneity in innovative activity that captures the distinction between fundamental and secondary research. They first investigate this heterogeneity by considering fundamental research as deriving from R&D activities and secondary innovation from learning-by-doing. Each innovation resulting from research consists of a potential new product, and learning-by-doing leads to improvements of the quality of goods that have been invented. They also consider the possibility that learning-by-doing contributed to a general stock of knowledge that creates new opportunities for research as well. Moreover, Aghion and Howitt (1998) consider both the case where learning is not appropriated by the firm but is shared by all firms and where the quality enhancement of learning is fully internalized. Finally, they consider the case where the distinction between fundamental and secondary innovations is captured in terms of research versus development.

A feature of Aghion and Howitt's (1992) influential model, shared by most early models of endogenous growth with quality ladders and leapfrogging, is that more competition (i.e. higher elasticity of demand for each firm) is associated with less innovation and growth, a very Schumpeterian result. The reason for this conclusion is that these models capture only an increase of ex post product market competition and not of ex ante competition as well. Some recent studies modify this feature of earlier models and reach a different conclusion on the relationship between competition and innovation: tougher competition may increase the incentives of firms to innovate in order to escape from a more competitive market state.

In the model developed by Aghion, Harris and Vickers (1997) and subsequently analysed by Aghion et al. (2001) and Aghion et al. (2002), the study of the relationship between product market competition and innovation is carried out in the context of a model of endogenous growth with vertical differentiation in a duopolistic industry where the incumbent firm can innovate.

The model considers a sequence of tournaments with step-by-step innovations: the technological follower has first to catch up with the leading-edge technology before being able to become the new technological leader. This assumption can be justified on the grounds that innovative knowledge is to some extent tacit so that a rival has to invest in its own R&D to catch up and cannot simply rely on knowledge spillovers.

Aghion, Harris and Vickers (1997) focus on the comparison between Cournot and Bertrand competition to capture different levels of market competition. Aghion et al. (2001) and Aghion et al. (2002) use the same model to investigate the relationship between innovation and competition where the latter is captured in terms of a substitutability parameter at the product market competition level.

The substantial difference of these models compared to earlier Schumpeterian models lies in the fact that, by considering the possibility that the incumbent innovates, it is the incremental profits of each firm that drive R&D investments and the impact of product market competition has to be evaluated both ex ante and ex post. Tougher product market competition might reduce a firm's pre-innovation rents by more than it reduces post-innovation rents, hence it may increase R&D firms' investments.

In these models, technological progress does not involve leapfrogging. Hence, a typical industry can be in either of two states: it can be a leveled industry where firms compete neck-to-neck or an unleveled industry where one firm is technologically ahead of the follower.

The effect of an increase in product market competition would have to be evaluated considering the impact in both leveled and unleveled industries. The impact is actually twofold: on the one hand the degree of product market competition affects equilibrium R&D investments in each of the possible state of the industry (leveled and unleveled); additionally, product market competition has an impact on how often the industry will be in one of either states.

In a leveled industry increased competition would spur innovation because it would increase the incentives of firms' to get ahead of the rival (the new "escape competition effect"); in an unleveled industry, increased competition would reduce the incentives to innovate for the classic Schumpeterian effect.

The reasoning in Aghion et al. (2002), which leads to the conclusion that the relationship between intensity of competition and innovation has an inverted-U shape, is discussed below.

Consider the case of very large innovations, in which case the leader never innovates and the largest gap between the leader and the laggard is one technological step.

When there is not much product market competition, there is hardly any incentive for firms to innovate when they compete neck-to-neck, and the overall innovation rate will be highest when the industry is in an asymmetric state. Thus the industry will spend relatively more time in the levelled state where the escape-competition effect dominates. An increase in product market competition would then result in larger incentives for the firms to innovate. Hence, if the degree of competition is initially low, an increase will result in a faster innovation rate.

When initial product market competition is high, there is relatively little incentive for the laggard firm in an unleveled state to innovate and a relatively large incentive for a neck-to-neck firm to leave the leveled state. The consequence is that the industry will spend most of the time in the unleveled state where it is the Schumpeterian effect that dominates. Tougher product market competition reduces the Schumpeterian effect so that when the degree of competition is initially high, an increase may result in a slower average innovation rate.

These results extend to the general model with no upper bound to the technological gap.

Aghion et al. (2002) also provide empirical evidence that support their claim of an inverted-U relationship between intensity of competition and innovation.

Aghion et al. (2001) use the same framework to investigate the relationship between imitation and innovation and conclude that this is also characterized by an inverted-U shape. Again this may be the case because easier imitation may decrease a firm's pre-innovation rents by more than it reduces post-innovation rent.

Denicolò and Zanchettin (2002) consider the relationship between competition and growth in the case of non-drastic innovations by comparing innovation and growth under Bertrand and Cournot competition in a standard leapfrogging model. The main finding of this study is that:

"[…] when the size of innovations is sufficiently large, the equilibrium rate of growth is unambiguously greater with Bertrand than with Cournot competition. For smaller innovation, Cournot competition may (but need not) create greater incentive to innovate.

The intuition is that more competition entails lower prices but at the same time leads to greater productive efficiency (hence greater rates of growth) in that it lowers the market shares of less productive firms (Aghion and Shankerman, 2000). When firms are symmetric only the first effect is at work. When technical progress creates asymmetries between firms the productive efficiency effect becomes important and the effect of more competition on innovators' profits is generally ambiguous. However, the productive efficiency effect must dominate if innovations are close to being drastic.

D'Aspremont et al. (2002) investigate the relationship between competition and innovation in a tournament model under uncertainty where, unlike Aghion et al. (2001), the number of firms in each industry is endogenously determined and the race entails the possibility of several simultaneous winners and spillover effects. The main conclusion of the paper is that the relationship between toughness of market competition and the incentives to innovate is non-monotone. The key for this result lies in the possible multiplicity of successful innovators in the same period.

Introduction of Agency Considerations

The adoption of a step-by-step technological assumption is not the only means by which the relationship between competition and growth takes a different nature that in the traditional Schumpeterian model. Aghion and Howitt (1998) consider also an alternative approach, based on a study published later by Aghion, Dewatripont and Rey (1999) that leads to conclusions on the relationship between competition and growth that are different from those of the classic Schumpeterian model.

This approach is based on relaxing the traditional behavioural assumption that firms are profit maximizing. Non-profit maximizing behavior is a common assumption in the literature that emphasises the existence of agency problems between producers and their financiers. Aghion et al (1997) consider a principal-agent model of the firms where managers are interested in maximizing some private benefits of control while minimizing private costs that innovation would entail such as the costs of reorganizing the firm or training costs.

Within this new setting, the impact of intensity of competition on growth can be positive because tougher competition may lead to managers to speed up the adoption of new technologies to avoid bankruptcy and the loss of control rights and hence to faster economic growth.

The literature on the importance of competition for incentives is extensive and it suggests that there are other important mechanisms though which competition may have a positive impact on incentives is through the improvement of the ability of assessing managers' efforts and hence of monitoring them. At the same time, similarly to other areas of research, theoretical predictions of these studies are not as immediate as these simple considerations may suggest.

Nickell (1996) provides empirical evidence on the relationship between intensity of competition and innovation by studying the impact of competition on both the level and the growth of total factor productivity of a large number of UK manufacturing companies. The main findings of this paper are that

- market power, which is captured in terms of market share, generates lower levels of productivity; and that

- competition, which is captured by the number of competitors or by lower levels or rents, leads to faster total factor productivity growth.

Blundell, Griffith and van Reenen (1999) also study the relationship between competition and innovation. Their study provides evidence that

> "[…] within industries in was the high market share firms who tended to commercializemore innovation although increased product market competition in the industry tended to
> stimulate innovative activity" (p. 550)

For a very comprehensive survey of empirical studies on competition and innovation see the recent OECD study by Ahn (2002).

### 1.4 New Economic Geography

New economic geography was effectively initiated by Krugman (1991). The main goal of this strand of research is to provide a theoretical explanation of why economic activity and population tend to concentrate, that is to say, why cities and industrial belts come into existence and keep on expanding at the expense of the periphery. This approach is similar to new growth theory in that the models assume imperfect competition and product differentiation, economies of scale and increasing returns.

The underlying story is that manufactured goods will be produced in regions where nearby demand is higher, as this allows firms to minimize transport costs. Demand will come either from agriculture or from the manufacturing sector itself (manufacturing workers). Because of a possible positive feedback between production of and demand for manufactured goods, manufacturing production will tend to relocate into these regions.

This phenomenon is formalized by the canonical modelling of core and periphery (Krugman (1991)) that assumes that the economy is split into two sectors - namely manufacturing and agriculture – and into two regions (the core and periphery). In manufacturing, monopolistic competition à la Dixit-Stiglitz (1977) prevails: manufacturing produces differentiated products in the presence of increasing returns. In addition, labor, specific to manufacturing, is mobile between the two regions. Wages, both in nominal and real terms, can differ between the two regions. The driving force behind labor mobility is indeed differences in real wages.

Transportation costs when shipping from one region to the other occur in the form of Samuelson's iceberg cost (Samuelson (1954)). This means that transport costs are not explicitly considered but rather it is assumed that only a fraction of goods arrives, with the difference "smelting down" during transportation.

By contrast, agriculture is characterized by perfect competition with homogenous goods and constant returns to scale. Wages equal prices and labor, specific to agriculture, is immobile between the two regions. Furthermore, no transportation costs are assumed to occur when goods are moved from one region to the other. Assuming constant returns to scale and the absence of transport costs secures wage equalization in agriculture. It should be also noted that agriculture is evenly divided between the two regions.

For concentration in manufacturing to take place in one of the regions, several conditions have to be fulfilled. First, a large share of population should be allocated to the manufacturing sector so as it generates large demand (that triggers the virtuous circle). Second, economies of scale should be high enough and transportation costs low.

Three cases can be considered.

1 First, in the event that transport costs are large, there is an equal division of manufacturing between the two regions.

2 If transportation costs are low, manufacturing still can remain equally divided between regions. However, this situation is not a stable one (unstable equilibrium) for the following reason. If manufacturing were only slightly more important in one of the regions, this would lead to an increasing share of manufacturing in this sector accompanied by a dwindling of manufacturing in the other region. At the end of this process, manufacturing ends up being concentrated in one of the regions, and this can be referred to as the core-periphery pattern.

3 The third case, characterized by intermediate transportation costs, can lead to either complete specialization or equal division between regions.

### Extensions

#### The three-region model

A possible extension of the basic model is to simultaneously consider three regions. Keeping the assumptions of the two-region model would yield basically the same results: No concentration of manufacturing activity in the presence of high transport costs, extreme concentration in one of the three regions if transport costs are low, and the combination of the two previous situations in the case of intermediate transport costs.

#### Transport costs in agriculture

The second extension of the basic two-region model consists in releasing the assumption related to the absence of transport costs in agriculture. Empirical evidence clearly indicates that transport costs exist not only for differentiated goods produced in the manufacturing sector, but also in the other sectors, and that these costs are likely to be at least as high as the cost for manufacturing products. For this reason, iceberg-type transport costs are allowed for in agriculture. As a corollary, wages and consequently prices of agricultural products do not equalise between the two sectors.

The introduction of transportation costs for agricultural products when shipped from one region to the other results in higher agricultural prices in the destination region (with highly concentrated manufacturing at the expenses of the other region). Hence, higher prices for agricultural products, translated into higher costs of living would actually discourage labour mobility between the two regions, and thus hinder the concentration of manufacturing activity.

It seems very unrealistic to assume that the same homogenous agricultural good is produced in the two regions. The next step is therefore to consider differentiated agricultural products. The results are similar to the previous ones. In general, it is possible to reach the conclusion that while high transport costs in agriculture tend to prohibit concentration in manufacturing, a decrease in costs leads to concentration.

#### Urban agglomerations

A second strand of the new economic geography is concerned with urban agglomerations and attempts to answer questions as follows:

- How do cities come into existence and why do they exist in the longer run?
- How do new cities form and which are the mechanisms underlying the growth of cities?
- What is the reason that cities turn out to be linked one to another through a hierarchy?
- What is the role of natural advantages, such as harbors, in the development of cities?

International trade

New trade theory, as developed by Krugman (1980), has much in common with new economic geography. The former aims at investigating international specialization phenomena in the case of two or more countries, which can be viewed as the equivalent of agglomeration and concentration within an individual country. It should be noted that the logic and the mechanisms at work are very similar and what makes the difference are different restrictions to the basic model as discussed below.

Fujita et al. (2001) develops a model with intermediate goods. In this two-country framework, each individual country is composed of two sectors, namely manufacturing and agriculture with labor being assumed to be perfectly mobile between agriculture and the manufacturing sector. By contrast, labor is assumed to be immobile between the two countries. It is worth drawing attention to the fact that this model corresponds exactly to the canonical model with the difference that two countries instead of two regions are considered. There is no labor mobility between the two countries (regions) and intermediate goods are added to the model.

The introduction of intermediary goods is normally associated with input-output matrices. Put differently, firms are assumed to be linked with each other through input and output linkages. The model avoids the inclusion of new sectors by assuming that the range of goods produced in manufacturing serves not only for final consumption but also as input for manufacturing itself.

As a result, manufacturing uses labor and intermediary goods as inputs. In accordance with the model, the greater the gamut of intermediary goods, the lower the costs of production. In addition to that, if those goods are available locally, prices do not include transport costs. As far as sales are concerned, what firms produce is sold either to consumer as final goods or to manufacturing firms as intermediate goods.

On the one hand, high trade costs leave manufacturing equally divided between the two countries because firms have to supply consumers. On the other hand, low trade costs translate into the full concentration of manufacturing activity in one of the countries on the grounds of backward and forward linkages. In the presence of intermediate trade costs, concentration is possible but not inevitable

This model also manages to give an explanation for differing nominal and real wage levels in different countries. According to the model, the real wage in the country where manufacturing concentrates rises relative to those in the other country. One reason for this is that demand for labor increases and so does the wage level as a consequence of concentration in the first country. Another reason is that the country without manufacturing production has to pay the bill of transport costs of the imported manufactured goods, which in turn decreases the real wage.

Economic development: a sequential process

In this stage of the analysis, an exogenous growth process is added to the model and it is assumed that demand for manufactured goods rises faster than potential supply. A model consisting of two countries is considered. The model seeks to explain under which conditions industrial concentration starts spilling out from one country to the other.

The point of departure is to consider one country with highly concentrated manufacturing. It is shown that concentration will continue until the gains of backward and forward linkages in the industry exceed the potential loss that could be associated with the fact that wages are considerable higher in the industrialized country. If the losses are higher than the gains (that is the wage gap exceeds a given threshold) firms start moving into the other country. These firms then create their inter-firm linkages in the other country, which, through a positive feedback process will attract other firms and thus accelerate the concentration process.

However, there are some interesting questions to answer. For instance, which industry is the first to move, and how does the industrial structure of countries at different stages of industrialization change? This is studied using a five-country model in which each country is composed of seven different industries. According to the model, the most labor intensive industry will be the first to move into the other country, followed progressively by less-labor intensive industries. However, the latter will move faster.

The authors suggest that the inter-industry structure of the economies changes depending on several factors, including:

- the higher the share of final consumption goods in sales, the higher the probability that firms move (forward linkage); and

- the lower the intermediate input requirement, the quicker firm moves (backward linkage).

Industrial clustering

Fujita et al. (2001) construct a two-country, two-industry model with a single factor of production. Agriculture is dropped in the analysis and two manufacturing industries are used instead, both monopolistically competitive. The question is: under which circumstances do concentration or dispersion occur?

The model provides us with two conclusions. First, in the event that one industry is strongly connected to the other industry through input-output linkages, concentration will not happen. In contrast, in the case of strong intra-industry links, the model predicts a high concentration, that is, each country specializes in one of the industrial activities. When considering trade costs, the results are similar to the previous ones: the two industries remain present in both countries if trade costs are high, but a dwindling in trade costs allows for and subsequently leads to specialization of the countries.

The authors suggest that with deeper economic integration bringing about lower trade costs, European economies are expected to undergo a concentration process and will converge towards the economic structure of the US.

The two-country, two-industry framework is then replaced by a model including more than two industrial sectors. Although the model cannot predict why one industry concentrates in one country and not another, it can provide a theoretical underpinning in favor of the argument that in case one country loses a particular industry as a result of some sort of exogenous shock, there exists no mechanism that could ensure that, after the shock, the industry in question regains ground in the country under consideration.

Empirical works related to industrial clustering show that the US experienced a high concentration of economic activities and a high degree of industrial clustering chiefly during the period prior to WW-I. (see e.g. Kim (1995)). Patterns of concentration and industrial clustering remained relatively unchanged afterwards. Studies focusing on Europe indicate a strong concentration and clustering which has occurred during the last 20 years or so. Even so, the level of concentration and sectoral clustering in Europe is not as high as in the US (e.g. Midelfart-Knarvik et al. (2000)).

In a recent study with a strong cliometric influence (see section 2), Davis and Weinstein (2002) set out to investigate agglomeration patterns in Japan based on a unique data set stretching over 8000 years. Data drawn from archaeological findings and population census indicate that dispersion in population has been historically high in Japan. However, variation in population density considerably widened from the outset of the industrial revolution. The authors argue that although increasing returns can hardly explain the origins of geographical agglomeration, they play a prominent role in explaining temporal dynamics, i.e. the acceleration of geographical concentration throughout the last 200 years. New light is also shed on the temporary nature of even very large shocks. For instance, the massive bombardment of Japanese cities at the end of WW-II does not appear to have permanently altered the spatial structure of the Japanese industrial structure.

## 2 THE EVOLUTIONARY ECONOMICS OF INNOVATION

This section discusses the main findings from the evolutionary approach to the study of innovation and technical change. It then discusses the relationship between innovation and institutions (known as "systems of innovation").

### 2.1 Introduction

The evolutionary approach to the study of innovation and technological change arose largely because the mainstream theory was considered inadequate to tackle the inherent disequilibrium dynamics that characterise technological innovation. Nelson and Winter (1984) point out that both the economy as a whole and the economic actors taken individually can be considered to evolve continuously, similar to the evolutionary process described in biology. Hence the name of evolutionary economics.

Dissatisfaction with the traditional approach is almost pervasive and embraces the definition of innovation and knowledge, the description of the R&D process and more generally of the innovation process, the modelling approach based on the notion of full rationality and equilibrium, and the lack of consideration of institutional factors.

Though these themes trace back to earlier researchers — in particular, the Schumpeterian perspective, which places emphasis on dynamics and competition through innovation — dynamic theorizing in evolutionary economics is often seen to start with the models of Nelson and Winter (1982).

Although evolutionary economics is perhaps not a coherent theory with a common methodology, it may be categorised as a group of various approaches that share the same criticisms of the neo-classical approach. For example:

- First, evolutionary economics does not treat economic agents as rational, in the sense they are in neo-classical economics. They do not maximize returns through calculating the optimal strategy from a range of probabilistic outcomes.

- Second, evolutionary economics does not seek to analyse economic phenomena from equilibrium outcomes. In particular, dynamic change within the economy is considered best analyzed in terms of the processes that govern it, which are inherently disequilibrium dynamics.

Evolutionary models draw their theoretical foundations on different sources and particularly on biological models, evolutionary game theory and institutionalism in order to capture essentially dynamic and irreversible processes.

The literature tends to place emphasis on innovation and selection from variety as the force of economic development. Of particular importance is the need to see innovation as more than simple technological development (and much more than the production of knowledge as a public good) and to analyze economic development through technological and organizational improvements (which lead to the introduction of new products, inputs and techniques).

In evolutionary theories innovation is in fact defined more broadly than in mainstream models and as a multidimensional phenomenon. Innovation is not only a reduction in production costs or the commercialization of new products but also a more efficient reorganization of a firm's activities, the adoption of more sophisticated managerial techniques, access to new markets, etc.

This richer definition emphasizes that innovation extends outside the realm of technology in two ways: many innovations are not technological but involve other aspects of a firm's activities such as its organizational structure; moreover, even technological innovations often affect non-technological activities of a firm: technological and organizational changes are often importantly intertwined.

Another important difference with mainstream models of innovation is that evolutionary models emphasize the tacit and specific nature of knowledge, as opposed to the idea of knowledge as information that somehow underlies mainstream models of innovation.

In terms of the process that leads to the discovery of new products, evolutionary models describe the importance of learning, and of organizational learning often embodied in organizational routines as a source of knowledge. The process through which innovations emerge is by no means linear, but it is characterized by complex feedback mechanisms and interactive relations involving science, technology, learning, production, institutions, organization, policy makers and demand (Edquist 1999).

Evolutionary economics can be looked at both from a microeconomic and macroeconomic perspective. The microeconomic aspects of evolutionary economics are mainly concerned with how innovation arises at the firm and market level. In contrast, the macroeconomic strand of evolutionary economics places innovation into the social and economic context and examines the dynamic process through which the innovation systems generate innovations through a complex and reciprocal relationship network connecting different components of the system.

## 2.2 Microeconomics of Innovation

### *Knowledge and rationality*

At the heart of evolutionary economics is a definition of knowledge and of its characteristics that is substantially different for the neo-classical assimilation of innovation to information. In each technology there are elements of tacit and specific knowledge that cannot be formalised and cannot, therefore, be diffused in the form of information. These firm-specific, local and cumulative features of knowledge are, to various extents, essential characteristics of innovation.

The term tacit knowledge is used to encapsulate the idea of knowledge that is found to be useful (e.g. in an organizational routine or a skill) without being directly accessible to consciousness (Pavitt, 2002) or articulable (Winter, 1987). Thus individuals can be considered not to understand all that they know — tacit knowledge cannot be fully explained, written down or otherwise diffused; yet it remains valuable. By contrast the term information can be taken to mean 'explicit' knowledge, which can be codified and transmitted.

Information, as explicit knowledge, can be diffused around the economy (and fits most closely with the neo-classical concept of knowledge as a public good). Tacit knowledge cannot be passed from agent to agent in this way, but it is transferred and transmitted implicitly. Firms, and other economic organizations, can be seen as vehicles through which tacit knowledge is replicated through routines and techniques (Foster, 2001).

Furthermore, as mentioned in section 1.2.5, drawing mutual benefits from tacit knowledge that cannot be explicitly transferred between firms may bring benefits to inter-firm co-operation in innovative activity that complement those benefits identified in the industrial organization literature.

Support is found for this concept of tacit knowledge from psychological experiments. Nelson and Winter (2002) cite studies that examine the difference between processes acquired through rationality (understanding the underlying nature of the problem and calculating strategies for success) and learning-by-doing (learning successful strategies through trial and error without a complete theory on why such strategies are successful). They note that “a close logical connection between a learned task and a newly presented task does not necessarily indicate a potential for easy transfer”. Thus there is an important difference between knowledge from understanding and knowledge from practice (tacit knowledge).

Such results indicate that the more knowledge that is embedded in firms, through working practices, research programs and ongoing developments, is tacit, the less transferable this knowledge is to outsiders. To some extent, if a firm cannot rationalize why a particular routine has proved beneficial, but continues with it on the basis of past performance, then it will be less able to adapt to a slight change in conditions and less able to apply successful strategies to slightly different problems. Thus, it is perhaps unrealistic to expect firms to re-optimize their strategies immediately when circumstances change — by its very nature a process of trial and error (or imitation) takes time.

In a similar manner, the idea of tacit knowledge helps explain the large international differences in living standards and economic development that seem inconsistent with knowledge being a public good transferred and adopted at minimal cost. At a more micro level, it may be expected that different organizations may obtain different levels of output from ostensibly the same inputs.

Evolutionary economists not only disagree with the neoclassical tradition on the definition of technological knowledge but also on fundamental assumptions on the behavior of economic agents.

Evolutionary economics does not treat economic agents as rational, in the sense they are in neo-classical economics. This is not solely because economic agents do not have full information, but more importantly because they have limited cognitive powers; they do not profit-maximize (given their information set) but rather aim at sufficiently high levels of success to enable survival in a dynamic environment.

Related to this, Dosi (1988) emphasizes that innovative search is characterized by strong uncertainty whereby the list of possible events is unknown and one does not know either the consequence of particular actions for any given event.

Instead of being rational and thriving for maximizing profit, economic actors are assumed to develop routine behaviors, which they follow as long as they turn out to work well. In case the routine behaviour fails to function, they will be revised and changed so that new routines may be developed. As a result of the evolutionary process, viable routines prevail whereas the less successful ones are eliminated. It must be mentioned, however, that these changes are not taking place continuously but are rather unevenly distributed over time and tend to occur sporadically.

*Innovation and competition*

Variety is an important part of evolutionary theories of innovation and competition and can be traced back to the assumptions on limits to economic agents' rationality.

A classic issue raised by the concept of Schumpeterian competition as a process of creative destruction is that this, on its own, would imply that economic growth leads to suppression of variety and ultimately to monopoly (Nelson and Winter, 2002, p 35). Thus, to counter this prediction, there is need to consider how new variety originates.

Metcalfe (1998, p98) draws the link between the rejection of the neo-classical assumption of rational maximizing agents, and the generation (and re-generation) of variety:

> "…the positive side of bounded rationality is that it frees the imagination from the limits of calculation. When problems become too complex to be well-defined, let alone solved analytically, one is inevitably dependent and judgment, conjecture and the guiding hand of experience."

The point here is that while rational agents, profit-maximizing under identical resource and information constraints should, by definition, reach the same strategy, more realistic agents, guided by judgment and experience, will reach a range of preferred strategies. This process can be expected to lead to significant variety in innovative solutions, within which there are elements of path dependence as agents bring past experience to bear on current problems.

From these factors leading to the generation of heterogeneity, competition proceeds to bring economic development. As discussed below, this is because competition leads to improvement through selection, adaptation and imitation.

Foster (2001) emphasizes how the traditional (mainstream) discussion of competition in economics has much to do with static outcomes and little to do with dynamics. By modelling competition in terms of equilibrium, competition is seen as timeless, rather than a process of development. A key feature of evolutionary economics is its emphasis on competition as a process rather than an outcome.

Adopting a more dynamic approach, evolutionary economics is in part associated with the use of analogies to evolutionary biology to explain economic growth and the process of competition. At a very basic level, the notion of competition through natural selection associated with Darwin seems similar to the process by which economic competition selects more fit (efficient and profitable) firms at the expense of less fit firms.

In this context, Mokyr (1999a) defines the Darwinian model "as a system of self-reproducing units (techniques) that changes over time." Such a system appears to be best characterized by the following three properties:

- The relationship through which the underlying structure determines the manifested entities. From an economic viewpoint, an underlying structure is the "useful knowledge" that provides the framework for the "feasible" techniques (manifested entity) i.e. what society potentially is able to do.

- A Darwinian system is likely to undergo dramatic changes over time. Techniques reproduce themselves between two time periods through either repetition or learning and imitation. This process then entails constant changes part of which cannot be foreseen and which can turn out to destabilize the current system. An important question that this raises is the pace of innovation. Is the innovation process a gradual one or does it occur in a stepwise manner? This is indeed a crucial issue (for example, in cliometrics as discussed below, the debate on whether the first industrial revolution as it occurred in Britain created discontinuity or whether it can be regarded as a smooth transition).

- Excessive variety in a Darwinian system implies that the actual number of techniques exceeds the number sustainable in the system. This results in a selection process. Mokyr (1999a) argues that selection can operate through three channels. The first one is the standard neo-classical mechanism where techniques are chosen in the event they maximize an objective function incorporating supply and demand side consideration as well as externalities. Second, there is inertia in the system that eliminates useless techniques. Finally, and more importantly, selection not only happens in the market but also at the social level.

Inherent in this model of competition is the association between competition and experimentation. A variety of experiments allows for economic progress beyond the scope that would be considered achievable through comprehensive calculation and strategy (i.e. if each agent had to specify all permutations of outcomes, the likelihood of each, and the interrelationships involved).

Nelson and Winter (2002, p 28) identify that the economic development 'puzzle' is how the vast technological progress and efficient forms of organization seen in the modern age could have arisen given the cognitive limits of humans and organizations. To this end, they propose that competition is the means through which the deficiency of human rationality and ability are mitigated to achieve favorable economic outcomes:

> "Neo-classical economics discovers social value in human selfishness, but not virtue that
> is robust against the human limitation of incompetence — and the possible role of the market process in achieving that robustness is not featured."

Adopting this position, limited rationality, rather than being an impediment to well-functioning markets, is actually seen as part of the process of competition, and through it, innovation. If agents possessed far greater cognitive powers and rationality, the importance of competition in delivering economic development would be reduced.

Arguably there is an interesting correspondence between this concept of competition and the role of competitive markets in conveying information, most famously associated with Hayek (1945):

> "The marvel is that in a case like that of a scarcity of one raw material, without an order being issued, without more than perhaps a handful of people knowing the cause, tens of thousands of people whose identity could not be ascertained by months of investigation, are made to use the material or its products more sparingly; that is, they move in the right direction."

In this example, the focus is on competition as a force for distilling information in an efficient manner.

Thus the process of competition can be seen to bring benefits exactly because agents in the economy do not have full information — for example, through "price signals" competition tackles the deficiencies and asymmetries of information across the economy. Similarly, as discussed above, the process of competition can be seen to bring benefits exactly because agents in the economy are not fully rational — for example, selection from experimentation tackles the inability of economic agents to make optimal use of all the resources and information they have at their disposal at a point in time.

Yet the Darwinian reference to competitive selection does not quite mean the same in evolutionary economics as in biology. Foster (2001, p120) argues that competition in economics should allow for "inheritance of behavioral characteristics acquired from experience in particular environments." In other words, competition is not just about selection between firms (raising industry standards through elimination of weaker firms) but also the benefits of learning through creative endeavors, experience and also imitation that allows individual firms to make progress. (In fact Foster sees this process as more reflective of the evolutionary theories of Lamarck than Darwin — a significant difference being that Lamarck considered that organisms evolve because they are willing or need to evolve, rather than on the chance-orientated basis of Darwin).

In particular, any competitive advantage one firm has over another depends on the extent to which the factors underlying that advantage are imitable. While species may not be able to imitate other species (imitation is fundamentally different from the process through species may adapt in a similar way to similar circumstances), firms are often able to imitate their competitors at low cost. Therefore an evolutionary approach to economic should not be so Darwinian as to miss the importance of imitation in economic development. Furthermore, the role of imitation in economic development will be governed by the ability of firms to maintain their competitive advantage through patents, and secrets, as well as relative speeds of innovation where timing matters to success. (How firms seek competitive advantage is discussed further in section 3 within the context of the management and strategy literature.)

Thus economic development and innovation can be seen as a combined effect of selection (via competition) from a variety of competing routines and practices as well as the more endogenous process of agents seeking improved routines and practices. The role of 'dynamic' competition in this regard is quite different from its "static" force in constraining prices.

This emphasis on competition as a selection process is supported by a quite separate strand of empirical literature that seeks to decompose industry-level productivity growth to examine the 'microstructure' of this growth. Such studies use panel data of firms (or plants within multi-plant firms) to examine the extent to which economic development at the industry level is driven by productivity improvements within firms ('internal restructuring') versus expansion (and entry) of high-productivity firms and contraction (and exit) of low-productivity firms ('external restructuring').
For example, Disney et al. (2000) analyze a dataset which covers the period from 1980 to 1992 and contains data for 140,000 UK manufacturing establishments a year. They examine the relationship between industry-level and firm-level dynamics. Of particular significance they find that external restructuring explains approximately 50 per cent of changes in labor productivity, and 90 per cent of changes in total factor productivity, over the period. These results indicate that in the industries studied, competition in terms of selection from variety was a very important driver of productivity growth.

Note that such studies focus more on technological and organization improvements than drastic innovations (major new lines of products) that would not be fully captured in the productivity studies. But it is clear to see how evidence of internal versus external restructuring, in the context of industry-level economic development fits in with the evolutionary concepts of competition as a selection process.

*Industry structure and innovation*

Schumpeter is often associated with the hypothesis that large firms with market power are more innovative than small ones, although Fagerberg (2002) argues that Schumpeter was more interested in the difference between new firms and old firms. Evolutionary economics offers an interesting perspective on the relationship between firm size and innovation.

Fagerberg (2002) cites models by Nelson and Winter from the early 1980s that seek to explain why larger firms may be more innovative than smaller firms. On the one hand, if firms use retained profits to finance R&D, large successful firms will have advantages over smaller firms. On the other hand, a large firm is able to derive greater benefit from finding a better "routine" because it can put it to use across a larger number of units of production. Such analysis would suggest that large firms are at a competitive advantage, although Nelson and Winter are reported to see this effect counteracted by large firms (with more market power) having a higher profit target (price/cost ration) and this may provide some restraint in these dominating smaller firms.

These models also suggest that if large firms are aggressive in pursuing their advantage over small firms, and there is in turn a tendency towards concentration, large "imitating" firms may do well at the expense of smaller innovators. Thus where technological progress is endogenous, productivity may be hindered compared to a situation of a more varied industry structure.

An alternative way of considering whether large firms are more innovative than small firms is to focus more on heterogeneity in ability. To the extent that competition leads to the growth of innovative firms, we might simply expect causality to run the other way: it is not that large firms are inherently better innovators than smaller firms, just that the better innovators will be successful and hence grow in size. Theories based along these lines would therefore be treating innovation as exogenous to firm size, with causality running from the former to the latter.

This exposition between exogenous and endogenous innovation is valid more generally than firm size. Nelson and Winter (2002) draw a distinction between industries that are characterized by "science-based" innovation and industries that are characterized by "cumulative" innovation.

Science-based industries are considered to be those where the thrust of innovation comes from R&D activities outside that industry. For example, firms in such an industry might benefit principally from external scientific developments and innovative activities by their suppliers. By contrast, in cumulative industries, innovation stems from R&D activity within each of the firms in that industry.

An important difference may be expected between science-based industries and cumulative industries. In the former, where firms reap the benefits of innovative activities from outside their own industry, new entrants and previous laggards may be expected to have similar scope for development than industry leaders. Just because a firm has performed poorly in the past, or is a newcomer to an industry, should not totally undermine its ability to take advantage of external innovations if these are exogenous.

However, if the innovative activity within an industry comes predominantly from the efforts of firms within that industry, we may expect a significant degree of path dependency. Successful innovators in one period will gain advantage over other firms that allows them greater potential for innovation the next period. The cumulative effect of this is that less innovative firms fall further and further behind, and incumbents have some degree of advantage over new entrants.

*High-level policy implications*

In discussing policy implications, Fagerberg (2002) draws distinction between evolutionary approaches and neo-classical approaches. Neo-classical economics places emphasis on the failure of markets to deliver "public goods", and makes the case for government support to provide the public good of knowledge. By contrast, evolutionary economics does not treat knowledge as a public good in this sense; for example tacit knowledge exists in routines and practices rather than the consciousness and cannot be transferred from one party to another in the way that a formula or design can. Adopting a perspective more in line with the evolutionary approach would therefore provide les support for government funding of knowledge as a public good.

Furthermore, evolutionary economics argues that variety is an important part of the scope for innovation and development, while the role of heterogeneity per se is underplayed in neo-classical economics. Policy proposals stem from this stance. For example:

″Rather than subsidizing R&D in well-established firms in traditional sectors, one might put the resources into new types of activities or actors, not necessarily with the expectation that these would do extremely well, but because the entire system (including thetraditional sectors) might benefit from such increased diversity” (Fagerberg, p 41).

### 2.3 Systems of Innovation and the Role of Institutions

The emphasis on the notion of “systems” of innovation suggests that innovation is not a phenomenon which results from the activities of isolated innovative firms, but the result of complex important interactions between firms and other organizations and institutions. Each innovative activity by a certain organization involves an element of reliance on external sources and innovation in the economy results from the complementary contributions of different organizations in a particular institutional environment.

This strand of the literature draws together many common themes between two related approaches — evolutionary economics and cliometrics. What is cliometrics?

Cliometrics was initiated by Alfred Conrad and John Meyer (Conrad and Meyer 1957,1958) and has been popularized by Robert Fogel and Douglass North. Cliometrics is also often labelled as new economic history or quantitative economic history. It attempts to provide new insights into economic history, mainly by considering issues related to economic development and growth.

A more precise definition for cliometrics is given by McCloskey (1978): “a cliometrician is an economist applying economic theory (usually simple) to historical facts (not always quantitative) in the interest of history (not economics)”. Despite substantial initial criticism, cliometrics has become a well-established branch of economics and in 1993, the NobelPrize in Economics was awarded to Robert Fogel and Douglass North.

According to Claude Diebolt , cliometrics can be broken down into three major categories. First, descriptive cliometrics, which seeks to disentangle the economic and social influence that might have exerted an influence on historical events and processes.
Second, positive cliometrics, which is concerned with organizing data based on which then different theoretical conjectures can be tested. Third, normative cliometrics, which cannot be tested empirically and which deal with ethical questions such as efficiency,distributive and social justice and with how to ameliorate social welfare.

Cliometrics is largely based on reconstructed long (secular) time series or large panel data related to historic events. The theoretical background underlying cliometrics was initially neo-classical theory, but it has been evolving continuously with developments in general economics over the past 40 years or so. Recent works in this field are essentially related to evolutionary economics as a theoretical background.

*Defining 'Innovation Systems'*

Different definitions of the concept of innovation systems have been offered in the literature, and, despite the inevitable differences, all point towards the importance of the notion that invention, innovation and its diffusion result from interactions between different complementary organisations and institutions.

Freeman (1987) defines a system of innovation as:

> "[…] a network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technology".

Lundvall (1992) defines a system of innovation as a system that includes all parts and aspects of the economic structure and the institutional set-up affecting learning as well searching and exploring. Alternatively, Gregerson and Johnson (1998, pp. 5) provides the following description for system of innovation:

> "…overall innovation performance of an economy depends not only on how specific organizations like firms and research institutes perform, but also on how they interact with each other and with the government sector in knowledge production and distribution. Innovating firms operate within a common institutional set-up and they jointly depend on, contribute to and utilize a common knowledge infrastructure. It can be thought of as a system which creates and distributes knowledge, utilizes this knowledge by introducing itinto the economy in the form of innovations, diffuses it and transforms it into something valuable, for example, international competitiveness and economic growth."

In general a system of innovation is defined in terms of its components and the relations through which the components are linked with other another.

The elements of the system of innovation are organizations and institutions. Institutions exert a considerable influence on organizations, and simultaneously, organizations also impact on the institutional environment. Institutions may give rise to new organizations as well as being the origin of new institutions.
Edquist (2001) argues that organizations are formal structures that are created with a well defined goal in mind on the one hand, and institutions such common habits, routines, established practices, rules or laws on the other. Organizations within the system can be broken down into two categories - primary and secondary. The activities listed above are associated with primary organizations whereas secondary organizations impact on how primary organizations behave when performing fundamental activities.

Schoser (1999) argues that the institutional setting can be broken down into formal and informal institutions and that the factors identified by Gregerson and Johnson (1998) – institutional set-up, knowledge infrastructure, specialization patterns, public and private demand structure and government policy – may impact on innovation either directly or indirectly.

Typical organizations in an innovation system are private firms, universities, government laboratories and industrial research associations, among which a division of labor is realized, mainly coordinated by non-market means. These various organizations undertake different activities within the system, depending on their particular objectives, research mechanisms and incentive structures.

The division of labor within a system of innovation explains why the systemic view holds that not only the components of a system of innovation are important but crucially also their links and interactions. Metcalfe (1995) observes that connectivity within a system is achieved by a variety of mechanisms as for instance:

- mobility of employers in the labor market;
- grants and contracts for research; and
- informal networks, e.g. the links between user firms and their suppliers

How 'Innovation Systems' Work

There are various activities undertaken within a system. Liu and White (2001), identify five activities: research; implementation, i.e. manufacturing; end-use; education and linkage. Bergek and Jacobsson (2002) put forward the following functions of a system of innovation: creation of new knowledge; guidance of the research process; supply of resources; creation of positive externalities and creation of markets.

Pearce (2002) offer a different approach to defining the activities of a system of innovation. Pearce identifies basic research as the first element on which applied research is based. Product development including market research is then built on both basic and applied research. The final stage of the system of innovation is adaptation and marketing of the products. The first two stages depend heavily on research institutions, government support as well as firms. By contrast, the last two stages mainly concern private firms.

Nonetheless, Nelson (1996) notes that the notion of systems of innovation does not imply that the system was consciously designed or that interactions between the components of the system work are smoothly and that the system is coherent as a whole.

Systems of innovation are often considered to be national, although it is debated whether national boundaries can be deemed relevant.

On the one hand it is argued that the element of nationality may derive from different factors such as the national focus of technological and other policies, laws and regulations that have an impact on the innovative environment (Metcalfe, 1995). Nelson (1996) argues that because the education and research system, public infrastructure, laws and financial institutions keep some of their national characteristics, differences across different nation innovation systems are likely to persist even in the longer run.

On the other hand, the boundaries of systems of innovation in different countries are getting blurred with the rise of international firms present in several countries and increasingly intensifying cross-country inter-firm connections to share knowledge and innovate.

It may also be argued that systems of innovation may be local and regional rather than national and that one may think of different systems of innovations at various levels of aggregation.

It is widely recognized in the literature that there is a dilemma in national systems of innovation. This dilemma is whether to create incentives for innovation or whether to foster diffusion of innovation. At the heart of this problem is the patent system that encourages innovation by allowing for reaping the benefits and which at the same time hinders diffusion.

The role patents play in innovation is controversial. For instance, Levin et al (1987) report a fairly limited role of patents when it comes to protecting new technology. A brief discussion of some of the findings of the literature review regarding patents is presented in the box below.

Mokyr (1992, 1999a) also suggests that some institutional arrangements may hinder innovation. He points out that self-organizing systems become the cornerstone of evolutionary economics and notes that:

> "…the most interesting property of these systems is that they resist change. Resistance to change is essential for any system if it is to function and not degenerate into chaos."

However, he also emphases that resistance in society might have not only a stabilizing effect but can also act as a break on innovation. Indeed, high resistance can slow down or even eliminate the introduction of innovations or even deter innovation activity.

Opposition against new innovations might come from both owners and employees. Mokyr (1999a) enumerates the following sources of resistance:

- economically motivated resistance;
- ideologically motivated resistance;
- systemic resistance; and
- frequency resistance.

However, the success of an innovation hinges on two factors. On the one hand, the greater the value of the equipment and the more specific the skill that are threatened by a new innovation, the higher the incentive to resist. On the other hand, in the event that the innovation generates high social gains, the incentive to establish the innovation will be equally high.

Second, the introduction of the new technology requires time for people to become familiar with it and to make best use of it. Atkenson and Kehoe (2002) build a quantitative model of technology diffusion in order to simulate this slow transition from a low towards a high-productivity regime. The model seems to fit actual data rather well for the late-19th century US manufacturing sector.

One important feature of the model is that the new technology can be adopted only by building new plants. This assumption is consistent with empirical literature on the microstructure of productivity growth that finds that multi-plant firms often achieve productivity gains by closing down inefficient plants rather than improving efficiency within those plants (e.g. Disney et al, 2000).

For the model to produce the slow transition, another assumptions are needed. Manufacturers using the old technology dispose of a slowly accumulated stock of knowledge. At the outset of the transition (from old to new technology), they are hesitant to relinquish this stock of knowledge in favour of the new technology. The higher the stock of knowledge compared to the one related to the new technology, the slower they are to go for the new technology.

## The role of patents

A number of papers attempt to analyze the history of patents and the patent system in theUS. For instance, Sokoloff (1988) examines 4,500 patents accepted in the US during the period 1790-1846 and sheds light on the fact that the number of patents changed at an uneven pace over time. Apart from an important rise of roughly 300 per cent in patents that can be observed during 1805-10 and 1820-36, the number of patents recorded stayed fairly constant during the rest of the period.

Using a different set of US patents, Phillips (1992) is concerned with the period spanning from 1831 to 1879 and confirms the finding of Sokoloff (1988). Accepted patents rose sharply over the periods 1950-60 and 1962-68, but remained relatively stable in other years. If the number of patents is viewed as a good proxy for innovative activity, it could be argued that innovation follows a stochastic path. Sokoloff (1988) suggested that the surge in the number of patents occurred between 1820 and 1936 was due to major changes in the patent system that enforced incentives for innovative activities. In fact, patent theory tells us that the higher the expected return to an innovation, the higher the incentive to innovate.

Khan (1995) puts forward that the US patent system, which was introduced in 1790 ,and especially the pro-innovation attitude of judges when accepting patent demands fostered substantially innovative activity in 19 century US.

Phillips (1992) emphasizes the demand-driven nature of patent activity. He argues that not only accumulation of human capital, but also the increasing demand for patentable ideas and new technology in the context of increasing industrialization, which lead to an increase in accepted patents.

However, some others have argued that patents do not truly reflect innovations. MacLeod (1986) points out that patentees are likely to react sensitively to the economic and financial conjuncture. She sets out to show that the increase in registered patents between 1691-1693 was influenced by the increased availability of risk capital. It remains an unanswered question, however, whether innovations were also that dependent on the economic environment. MacLeod also notes that the ongoing war gave a significant impetus to military innovation. Another important question here is the degree of development of the patent system. It is argued that weaknesses in the system probably exerted a deterrent or at least not conductive for patenting new innovation.

MacLeod (1992) investigates the 19 century British mechanical engineering industry and argues that the existence of a patent system was one key to innovation. The system provided certainty for innovators so that they could reap the benefits of their innovation. Therefore, the uncertainty prevailing before 1830 due to the unreformed and inappropriate patent system encouraged secrecy, which in turn worked against the diffusion of new technology.

Do Different "Systems" Matter?

There are differences of opinion as to whether differences between "Innovation Systems " matter in terms of promoting innovation and technical change.

One factor that can promote technology diffusion is the presence of multinational companies worldwide. However, Saviotti (2000) documents substantial differences that persist between national systems of innovation of different countries. He observes that different institutional and organisational configurations result in different specialization patterns across countries (see also section 1.4 on new economic geography.)

Nelson (1996) also sets out to analyze the cause of differences in different national systems of innovation. Innovation systems are analyzed in three groups of countries, namely large high-income countries such as the US, Germany, Japan, small high-income countries such as Sweden and developing, low-income countries, e.g. South Korea and Argentina.

Based on this categorization of countries, it is argued that the size and the affluence of a particular country mainly determine its capability to innovate. In addition, economic and political circumstances and priorities also have a significant role to play in shaping the innovation system.

Further to this, Nelson (1996) emphasis the importance of competition. Strong competition is believed to promote innovations. However, he argues that domestic markets especially in small countries fail to play this role and therefore international competition encountered in world markets, that is on export and import markets, is crucial in fostering innovative activity.

A strong and competitive export sector is thought to be the engine of economic growth in many economies. However, for the export sector to withhold international competition, the national system of innovation should be shaped to increase innovation and thus support exports.

Nonetheless, competitiveness can be viewed and defined differently in high-income and low-income countries. High wage level in developed countries implies that only new, improved products and the constant amelioration of the underlying technological process offer possibilities to boost competitiveness. By contrast, in less developed countries with lower wage levels, competitiveness is to be improved by diffusing and learning foreign technology.

Security policy considerations also seem to forge the shape of the innovation system. Nelson (1996) argues that the bulk of government backed research and development is concentrating on the defense industry in the US and Britain. Military inventions are then applied to civil problems giving birth to new products.

Furthermore, the current German and Japanese systems of innovation deeply root in the past when the system was designed to back the production of better weaponry. However, after World War II, those innovative capacities were turned toward civilian production, and this led to flourishing exports.

This is a clear sign for the strong continuity in national innovation systems over time. Nelson (1996) points out that the German and French innovation systems in 1990 were very similar to those in 1890. This phenomenon seems to hold true for the majority of developed countries except for the US where a major change occurred after 1945.

Grupp et al. (2001) set out to investigate the system of innovation in Germany throughout the past 150 years and come to the conclusion that the innovation system has been very stable over the period under investigation. According to the authors the industrial research system can be associated with an increase in innovative activity. When analyzing how R&D expenditures and innovation activity have changed from 1850 to 1999, they found that the German industrial research system has been very stable. In particular, they provide some more in depth econometric analysis, which reveals that during 1850-1913, patent activity can be predicted by growth in human capital. Furthermore, there is causal link from patent activity to standard of livings whereas standard of living influenced human capital.

These results clearly indicate the presence of a virtuous circle that results in substantial economic growth. Results for the second period (1951-99) are less straightforward: the standard of living variable appears exogenous and turns out to explain patent activity as well as on public and private expenditures in R&D.

The education system and especially universities have a significant role to play in the formation and the successful functioning of the innovation system. One important question to be addressed is how and to what extent the research and teaching orientation of universities satisfies the need for technological innovation.

In fact, the design of a good interface between public research organizations and private firms has been central to innovation policy in most advanced Countries. This interface is considered important both because it may allow research conducted in public organizations to be more easily translated into economic growth and competitiveness and because it may result in fertile combination of complementary knowledge-basis and skills. Countering these benefits, the concern that closer linkages between public and private research organizations, and an increased privatization of university research, may diminish the variety of reward systems in the economy and in the long-term the potential of public research organizations to contribute to the innovation system.

Evidence from Studies using Cliometric techniques

Cliometrics also offers some observations on the role of the relationship between innovation and institutions.

Neo-classical theory posits that economic agents maximise aggregate income in the absence of transaction costs. However, since Coase (1960), it is clear that transaction costs do matter. For instance, Wallis and North (1986) show that in 1970, 45 per cent of US GNP was linked to the transaction sector. As a corollary, the institution setting, which, to a large extent, determines the magnitude of transaction costs, has a considerable impact on the final outcome.

What matters in the long- run is the continuous interaction between institutions and organizations that exerts an influence on developments in the institutional environment. Organizations are born and are operating within the given framework of the institutions and their activities reflect the opportunities provided by institutions. If, for example, security is lax, piracy will come into existence, whereas if, say, property rights are properly enforced, actors may engage in more innovative activities. (This approach is indeed very close to the systems of innovation)

Olson (1996) puts forward that institutions are essential for efficiently functioning markets. Nonetheless, it does not necessarily hold true that institutions provide per se the conditions required for efficiency in markets and therefore they are subject to changes. If the rules of the game are perceived by the organizations as too restrictive, they may attempt to modify the institutional setting. The driving force behind changes is, according to North, learning by individuals. And it is argued that competition contributes significantly to the learning process given that learning is indispensable for survival. That is, the greater the degree of competition, the bigger the incentive for learning.

In a series of seminal studies, Douglass North (1990,1991) underscores the importance of social and economic institutions, which are likely to affect innovation and hence long-term economic development. According to North, institutions form the incentive structure of a society, and as a consequence, the political and economic institutions are the underlying determinants of economic performance.

The institutional environment provides a general framework for social and economic interactions. Institutions fall into two categories. The first category can be referred to as formal constraints and is composed of rules, laws, constitutions, property rights, whereas the second one is labeled as informal constraints and is made up of customs, traditions, behavior, conventions, codes of conducts etc.

In North (1994), the evolution of institutions is analyzed in a historical perspective. It is argued that there are some primitive institutional settings that are most unlikely to experience changes triggered by pressures coming from the inside. In three types of exchanges under consideration, namely tribal society, regional economy and long-distance caravan trade, learning, and hence the accumulation of knowledge and skill will not lead to changes, simply because innovation is perceived as something endangering the system's survival. This is also borne out by Posner (1980).

North (1968) also explores the impacts that changes in the institutional environment have on technological progress. He analyses the case of ocean transportation and finds that from 1600 to 1860, the costs of ocean shipping dropped by 50 per cent due to huge increases in total factor productivity. The question is whether productivity gains are driven by technological advances or by other factors.

North argues that in the period 1600-1784 productivity advances were slow, and virtually all the productivity growth came from decreased crew size and the better use of shipping time, that is the reduction of time spent in harbors. This productivity advance may be understood within the evolutionary economics framework as an improvement in organizational routines and working practices.

Between 1814 and 1860, North finds that total factor productivity experienced a considerable acceleration compared with the previous period, and grew roughly 10 times faster than before. North argues that the bulk of these productivity gains can be attributed to larger ships and to an increased load factor.

Essentially, an increase in the size of the market and a sharp reduction in piracy explain these changes in the characteristics of ships. On one hand, shipping capacity was significantly better used because of immigrants pouring in America: Ships that used to return to America without carrying anything but the ballast were transporting men. On the other hand, security became better because of the elimination of piracy. This led to a reduction in the need for military personal and equipment on board. All in all, North emphasizes that productivity gains were not due to technological progress but rather the consequence of organizational innovations and changes in the institutional environment.

With regards to the first industrial revolution in 18th and 19th century Britain, Landes (1994) argues that it was not pure accident that the first industrial revolution occurred in Britain and not elsewhere, e.g. in France. This is because of the structure of the industry and the institutional setting, which made it more likely that major inventions would be produced in Britain. However, Crafts (1995a,b) disagrees with this view and suggests that major inventions follow a stochastic process and thus those inventions could have occurred with roughly the same probability in France than in Britain given that the things in common between the two countries outweighs the differences between them.

According to Mokyr (1993), two types of inventions can be distinguished. The first is "macro invention" and describes inventions of paramount importance for the economy as a whole. The second is "micro invention" and consists of small steps by which already extant techniques are ameliorated. Mokyr (1993) points out that macro inventions "… do not seem to obey obvious laws, do not necessarily respond to incentives, and defy most attempts to relate them to exogenous economic variables. Many of them resulted from strokes of genius, luck or serendipity." Mokyr notes that Britain was by no means in a better position in the realm of macro inventions compared with France but the institutional and economic environment were more conducive as regards micro inventions.

# 3 STRATEGIES OF INNOVATIVE FIRMS

This section sets out some of the strategies applied by companies to enter new markets and introduce new products. This is addressed by looking at the strategies employed to gain and protect such an advantage.

The section then looks how the optimal timing of innovation can be used as a strategy and includes a discussion of life cycles more generally. Finally, the section considers competition in network industries.

## Innovation and Competitive Advantage

In considering the strategies employed by innovative firms, it is useful to draw a distinction between two broad categories:

- how a firm gains a competitive advantage over rivals; and
- how a firm can protect and maintain that competitive advantage.

In the following sections, we discuss further these strategies and their relationship with innovation,although it is necessary to be aware that the distinction between these components is not clear-cut.

### *Value creation: how firms gain a competitive advantage*

The first strategy focuses on how firms can create more value, which can be achieved in principle through:

- cost reduction underpinned by efficiency improvements;
- increasing quality and value of existing products and services via differentiation relative to competitors; and
- developing new products and services.

At the centre of value creation is the notion of competitive advantage popularized by Porter (1985). Porter's view is this:

> "Competitive advantage is at the heart of the firm's performance in competitive markets.After several decades of vigorous expansion and prosperity, however, many firms lost sight of competitive advantage in their scramble for growth and pursuit of diversification. Today the importance of competitive advantage could hardly be greater. Firms throughout the world face slower growth as well as domestic and global competitors that are no longer acting as if the expanding pie were big enough for all."

In accordance with Porter (1985), competition is a continuous quest for competitive advantage.

External and internal sources of competitive advantage can be identified. External sources such as changing consumer patterns or changes in technology are exogenous to firms. Since firms are heterogeneous in their resources and capabilities, they are not equally able to adapt to such changes, and thus some firms are able to realize competitive advantage through more timely and efficient responses to exogenous factors.

The internal source of competitive advantage is essentially the capability to innovate, by which we mean inventive effort, rather than adaptive or imitative behavior.

Cost leadership

As highlighted above, value to customers can be created by means of decreasing costs, through which a firm is able to reduce prices relative to competitors.

At the extreme, focus on this strategy can be described as thriving for cost leadership, which refers to the situation when a firm has the capability to produce similar products at significantly lower cost than its competitors. There are several routes through which a firm can achieve cost advantage, for example:

- Economies of scale and scope yield benefits to the extent that an increase in production volume will entail a reduction in unit cost.

- Economies of learning describe experience-based learning. The more complex the process technology or the product, especially in terms of tacit knowledge (i.e. that which cannot be codified and transferred) the larger the scope for benefits from learning-by-doing. This provides means for established companies to experience cost advantage over new firms.

- Enhancing process technology and process design allows for greater productive efficiency and lower production costs for the same output.

- Similarly, enhancing the organizational efficiency and routines (for a given technology) will increase productive efficiency.

- Reducing input costs allows for lower unit costs for the same level of productivity. Because of the use of different suppliers, geographical differences in input prices and different bargaining power, different firms may pay a different price for the same set of inputs.

- Augmenting capacity utilization: In the presence of high fixed costs, unit costs are to be decreased by increasing capacity utilization. On the other hand, overcapacity resulting in overtime pay, premiums for night shifts and rising maintenance costs also increase unit costs.

## Product quality and differentiation

Changes to product quality (in particular quality-price trade-offs) and product differentiation compared to rival products represent the second facet of value creation.

A firm can set out to differentiate its product according to the tangible and intangible aspects of the products it manufactures. The former concerns physical characteristics and performance of the product, while the latter relates to perceived, mainly social and psychological faculties.

The nature of competition in a market will be associated with whether firms strive to gain competitive advantage through innovation in physical attributes of the products they supply, or the intangible characteristics. For example, where an industry is mature and there appears little scope for changes in product innovation and cost leadership, competitive advantage may be achieved through a successful branding exercise that provides differentiation relative to rivals.

## Product innovation

While changes to the quality of a product represent some degree of product innovation, innovative behavior is likely to be greater with regard to the introduction of new products and services that have features to mark them as distinct from current products.

A strategy of product innovation may have the effect of creating new markets (in competition policy terms, the introduction or products for which there are no good substitutes on the demand-side) but may also, though not necessarily, destroy old markets (as consumers cease consumption of previous generation of products in favor of the new products).

When it comes to assessing how to exploit an innovation to the maximum, that is to maximize profits related to the innovation, firms can choose from several options depending on

- How much risk can or are they willing to take, and thus how high a return do they expect;
- How many resources can or are they willing to put at disposal when exploiting the innovation.

Risks are high in emerging, innovative industries. First, firms have to face technological uncertainties (such as the direction technology develops in and which technical standards are established in the industry). Second, there are substantial market uncertainties. In other words, it is difficult to predict the potential size and expansion of the market. Nonetheless, these risks are manageable to some extent via:

- Co-operation with lead users
- Limiting financial risks related to financing innovation
- Maintaining a high degree of flexibility and reactivity.

Grant (2002) enumerates five different strategies through which innovative firms can reap the benefits of their innovations. These strategies, shown in Table 3.2, can be associated with differing involvement of he firms, different risk-taking, resource requirements and firm size.

Strategies in Innovative Markets

| Strategy | Risk | Necessary firm size | Resource requirement |
|---|---|---|---|
| Internal commercialization | High risk, high returns and complete control | Medium-large | High |
| Joint venture | Sharing investment and risk but also risk of conflict with the partner company | Medium-large | Resource and capability synergies among several firms |
| Strategic alliance | | Medium | |
| Outsourcing | Limits risk but increases dependence on the outside world | Small | Access to outside resources |
| Licensing | Small risk and small returns | Small | Low |

Source: Adapted from Grant (2002 p342).

Each of these strategies is described below:

- The strategy of internal commercialization means that the firm commercializes the new product — that is, the output of the innovation — without any external productive help. This is the highest level of involvement that goes hand in hand with the heaviest investments and therefore the highest risk. Nevertheless, the firms can have the whole process under its control. In doing so, the resource requirements are substantial, which implies that the firm is expected to be fairly large to be able to bear the burdens.

- The decision to start a joint venture still implies a great deal of involvement. By contrast, it also helps to share the cost and the risk of the investment. In addition to that, the participating firms can pool their resources together and thus benefit from synergies. On the other hand, however, they run the risk of potential disagreement and possible differences in corporate culture.

- Strategic alliance represents a middle way between total and very small involvement. Risk and resources can be shared.

- Outsourcing is suited to both large and small companies so as to enable access to outside resources without too much commitment.

- Licensing is typically — but not exclusively — employed by small firms, which do not possess the necessary resources to exploit the innovation on their own.

*Protecting competitive advantage*

The second strategy can be understood as efforts to protect and maintain a competitive advantage that has been achieved through value creation. In particular, it concerns efforts firms may take to prevent imitation by rivals, since in competitive environments, imitation is a crucial force that undermines the competitive advantage of a firm over time. Such behavior may be both legal (e.g. patenting) and illegal (e.g. certain types of anticompetitive behavior that inhibit rivals access to a market).

Once a firm has been able to gain competitive advantage in some respect, it will have incentives to protect and maintain this. In particular, where a firm has benefited relative to competitors from an important innovation it will be keen that rival firms do not undermine this advantage through imitation.

One way in which firms achieve such protection is through various legal institutions put in place for this purpose (e.g. patent policy). These are highlighted below before we turn to other ways in which a source of competitive advantage can be maintained.

The use of legal institutions against imitation

Intellectual property rights are legal institutions that may protect the competitive advantage a firm has realized through innovation by restricting the degree of imitation of the innovation that can take place.

Patent policy provides a firm with protection against direct imitation of certain types of inventive innovation, for a period of time, subject to disclosure of information relating to the innovation. Similarly, copyright protection prevents the direct copying of new content. In both cases the aim of the legal protection is to provide incentives for the innovation to take place, exactly because in the absence of this protection such incentives for such innovation would be mitigated by the threat of direct imitation and risk of immediate erosion of any competitive advantage accruing to the innovation.

Nonetheless, there are ways in which patent policy may be used by firms against the interests of consumers. Pre-emptive patenting describes the case where firms gather a series of patent around an initial innovation, not for the purposes of using those patents in the introduction of new products, but rather to stop other firms form inventing around the original innovation. Thus the new patented products or technologies are neither used by the patentee nor licensed to other firms, but their value derives from the fact that rivals cannot use them rather than the use the holder makes of them.

Alternatively, where a particular product or service protected by patent represents a bottleneck to a range of related markets, the patent holder may be able to use its protection in the supply of the patented product to enjoy competitive advantage in the supply of products in these related markets.

In some sense, there is overlap between creation of competitive advantage through product differentiation and maintenance of this advantage through branding. Where firms can link an innovative product to a successful brand image, and protect that brand from imitation (e.g. via trademark law), the advantage from the initial innovation can be maintained in the face of imitation as to the products physical characteristics. For example, in the pharmaceutical industry, successful creation of goodwill, reputation and brand recognition allow firms to enjoy some (albeit less) competitive advantage over a drug that they have created once the patent has expired.

Other protection against innovation

Besides the use of intellectual property rights, the competitive advantage associated with an innovation can be obtained through other mechanisms.

The first strategy is secrecy. Where an innovation is hard to observe or hard to codify, the innovative firm may able to maintain competitive advantage simply by not facilitating the flow of information about the innovation to competitors.

A second strategy to protect competitive advantage is to merge with rivals. This could provide protection where a particular rival is capable of reducing the competitive advantage a firm has gained through innovation. Of course, the merger could bring other benefits that are associated with creation rather than maintenance of competitive advantage. For example, the combination of tacit knowledge in the merged parties may bring greater capability to innovate.

Finally, a firm may be able to with sufficient market power may be able to protect its competitive advantage by using this power to restrict rivals' ability to compete with it. Besides predation, a firm may be able to use competitive advantage with regard to one good or service, and spread this advantage to related services, for example:

- denying the rival access to some important input service, ranging from necessary raw materials and components to services that allow supply of a service to particular customers, or even IP rights; or

- bundling or tying products such that rivals are forced to compete against the bundle of services offered by a firm and the competitive advantage the firm holds is transferred across the range of products supplied together.

Not only could such a strategy help maintain the competitive advantage from the original line of innovation, but it may also serve to expand the economic area of which returns from the competitive advantage can be enjoyed. However, it is essential to recognize that such strategies may also be conducive to value generation. For instance, with respect to bundling, this pricing option may be the only way in which sufficient revenue could be generated to cover the initial outlay required for an innovation.

### 3.2 Timing of Innovation and Life Cycles

Having set out firm strategies according to two broad categories, we discuss below issues of timing. The first sub-section considers how the success of innovation, and thus the optimal innovation strategy, may be dependant on timing. The second sub-section considers product 'life-cycles' more generally.

First-mover advantage

An essential question in innovative markets is to choose a strategy whether to enter early in the market and invest heavily in research and development in the hope of future profits and market leadership or to adopt a wait-and-see policy and to follow the technology leader by copying the innovation. The benefits of a first-mover strategy relies on three conditions:

- Length of the lead time (i.e. the time over which the innovation is protected from imitators and followers) either through IP rights or less formally.

- The extent to which complementary resources are required while exploiting the innovation. If the need for complementary resources is relatively low, the initial investment and therefore the risk is lower. This may stimulate firms to try to be the first-mover.

- The possibility to set a standard is also likely to give an impetus for first-movers.

The reason why standards are set is closely connected with positive network externalities (discussed further below in the context of the economics of networks). The higher the number of users of the standardized product, the more valuable the product to individual user. Positive network externalities have three major sources:

- users of the product are connected with each other through networks (such as transportation and the internet);

- the ease with which complementary products are available (for example, software applications for Windows); and

- switching cost between different networks: the larger the network the customer uses, the lower the costs to switch to another network (for example, mobile telephony networks).

Generally, technological standards tend to result in ever increasing positive network externalities. If a technological standard appears to be dominant in the industry, more and more users are likely to choose this one that may easily lead to winner-takes-all situation. This is one reason why innovative firms try hard to establish their technology as the industry standard.

Shapiro and Varian (1999) identify three possible and highly complementary strategies how firms could establish their own technology as the standard. The first strategy builds on obtaining the support of other, rival companies and firms producing complementary products, possibly through tacit agreements. The second approach consists of market pre-emption. Finally, and importantly, the firm aiming at winning the standard war has to make the impression from the very outset that its standard will be accepted at the end of the standard war. Put it another way, marketing and other communication techniques can be employed so as to create self-fulfilling expectations among customers and rivals.

However, different firms may have different strategic windows. These are defined as the time period during which they are able to seize market opportunities in line with their resources and capabilities. Smaller firms tend to have shorter strategic windows because they cannot wait for a long time to introduce new innovations and procure competitive advantage as opposed to large corporation that do not tend to rush in introducing new technologies and take unnecessary risks given their solid financial background.

*The role of the life-cycle of an industry*

The position in the life cycle of a particular product, market or industry is likely to have a role to play as regards the strategy adopted by any firm towards the creation and protection of competitive advantage. Life cycle theory sets out a useful analytical framework for analyzing this.

In this context, there is some ambiguity in the relevant literature regarding terminology between product life cycles and industry life cycles. In principle these are different concepts since industry usually refers to a wider set of entities that a product, but these terms refer broadly to the same approach and are sometimes used interchangeably. In some sense the concepts of an industry life cycle is associated with the industrial organization literature (Bonaccorsi and Giuri (2000), Horvath et al. (2000) and Klepper and Kenneth (2001)), while marketing literature may be more likely to use term product life-cycle. In this overview we refer to product life cycles.

Based on a series of case studies and empirical papers, Klepper (1996, pp. 564-565) comes up with five major regularities that best characterize the product life cycle:

- The number of new entrants rises very rapidly at the beginning and then starts declining and eventually stabilizes at a very low level.
- The number of incumbents increases in the initial phase and then starts falling accompanied by a steady increase in output.
- Initially, market shares change quickly, i.e. some firms grow fast and others loose ground. However, after a while, market shares stabilize.
- Simultaneously, there is an increase in the diversity of products competing in the market because of a rise in product innovation.
- However, as the market gets more mature and with the consolidation of the firms, incumbents spill more energy on process innovation.

Werker (2003) provides two more stylized facts associated with the product life cycle complement the analysis above. First that prices fall sharply at the outset of the life cycle with standardization and a growing number of customers. However, later on, prices decrease at a lower pace and the decrease finally comes to a halt. Second, that the beginning of the life cycle favors entry whereas established firms are favored to new entrants at later stages of the life cycle.

More generally, the life cycle of a product may typically have four phases: (i) introduction; (ii) shakeout; (iii) maturity; and (iv) decline.

During the first phase, i.e. the introduction, a few companies produce a wide range of goods with substantial differences in product features partly on the grounds of differences in the underlying technology. The competition among technologies yields rapid product innovation. Werker (2003) notes that at this stage of the product cycle, consumers' preferences are not well established. Therefore, firms exert effort to discover the unclear preferences through high rates of innovation.

The second stage of the life cycle usually witnesses a shakeout and the emergence of a dominant technology, accompanied by standardization of around this technology. This lays the ground for further rapid innovation. The competitive environment forces unsuccessful firms to exit the market and leads to mergers and acquisitions. Product differentiation in this phase can be achieved mainly through new product design and by continually improving quality.

For instance, Klepper and Simons (2001) provide empirical evidence for dramatic shakeouts that occurred at some point in the automobiles, tires, televisions and penicillin industries in the US. They suggest that earlier entrants are more likely to survive shakeouts. Shakeouts do not seem to be triggered by drastic events but rather the consolidation in these industries was a result of the process of competition during which early entrants gain high market shares through innovation. A similar conclusion is drawn by Horvath et al. (2000), who find that the shakeout in the US beer brewing industry occurred from 1880 to 1890 was a consequence of earlier mass entry and the subsequent competition.

When an industry reaches maturity, products tend to become increasingly homogeneous and could be viewed as commodities. In this context, and to counter this tendency, branding and the introduction of complementary services represent an effective way to differentiate products. Price competition also tends to become more intense in this phase of the life cycle. Hence, cost advantage is a crucial aspect of competitive advantage. Simultaneously, the technology developed in earlier stages becomes diffused and firms seek to improve this technology incrementally.

The final phase can be referred to as the decline of the industry. During this phase fierce and possibly destructive price wars become the norm given that product differentiation is extremely difficult. The lack or at least the very low pace of product and process innovation is one reason for this. As a result, some firms decide to exit from the market and this further contributes to the decline.

Different industries may be very different as regards the intensity of competition and the pace of innovation in the same stage of the life cycle. Accordingly, three types of industries can be identified:

- In local monopoly markets, products are very specialized and target narrow market segments. Products are of high quality with high unit values, which implies that volume of production is low. Because of substantial differentiation, competition is very limited. Examples for this kind of market are found amongst the following areas: highway and residential construction, surgical appliances, defense industry.

- Traditional industrial markets are characterized by homogenous products where competitive advantage can be usually achieved via cost leadership, branding or product variety. Passenger cars and household equipment are examples of products belonging to this category

- Schumpeterian markets are dominated by product innovation, where incumbents can be completely displaced by entrants. These markets might be seen within the computer software industry and within consumer electronics.

### 3.3 Issues Relating to Network Industries

Network industries give rise to a number of issues that are likely to affect — or at least influence — the strategies used by firms to innovate. The characteristic features of these industries originate from network externalities. A positive network externality arises when "a good is more valuable to a user the more users adopt the same good or compatible ones". A common distinction is that between direct and indirect network externalities.

Direct externalities typically occur in a two-way (physical) network. This externality reflects the fact, for instance, that a telephone user benefits from others being connected to the same network: an additional telephone increases the number of potential communication within the system, and thus the value of membership.

Indirect externalities arise from the fact that a network of users increases the incentives to produce compatible products that are complementary with the network good. These externalities arise in systems, which can be defined as "[…] collections of two or more components together with an interface that allows the components to work together" (Katz and Shapiro, 1994, p93). The typical system comprises of a "platform" (or hardware) and of "applications" (or software) that can only be used with a platform. Compatibility refers to the possibility that software can be used with a particular platform. The network externality arises when users make their purchase over time, because in the presence of economies of scale a greater number of complementary products can be supplied at a lower price when the network grows.

The existence of network externalities has a substantial impact on the way technologies are chosen and promoted. In this section we follow closely Katz and Shapiro (1994) overview of systems competitions and their identification of three main issues that have been addressed in the literature:

- technology adoption decisions;
- product selection decisions; and

- compatibility decisions.

Technology adoption decisions

A number of issues that arise in markets characterized by network externalities can be addressed by considering a system only, setting aside competition between different systems.

The existence of direct network externalities drives a wedge between private and social incentives to join the network. A single user does not consider the benefits that would accrue to others by his joining the network and as a result the market may lead to network of inefficient small size. In fact, the benefits that an individual would take into consideration when choosing whether to join a network depends not only on the current size of the network, but also on its expected future size.

Consumers' expectations play a central role in driving market outcomes where there are technology decisions in markets with important network effects. An important consequence is that multiple equilibria can easily arise. For instance, if all consumers expect no one else to join the network, then its size would be zero, even if the network may be valuable for consumers; if all expect everyone to join, the network may achieve a large size.

Indirect externalities may have a different impact on the size of the network. In a system market, one consumer's adoption decision would does not affect other consumers, given the prices and varieties of products available. The externalities arise indirectly through the impact of one consumers' adoption decision of the future variety or prices of applications. Katz and Shapiro (1994) note that in such an environment, if cost conditions are consistent with the existence of a competitive equilibrium, a perfectly competitive equilibrium arises in system markets. When, at the other extreme, a monopolist is the sole supplier of the components of a system, there are issues regarding multi-product pricing and inter-temporal pricing.

We follow Katz and Shapiro (1994) closely to discuss these issues. Consider the case where the monopolist can commit to the prices of both components of the system:

- with fixed proportions technology, the monopolist simply sets the price that maximizes profits in the usual way.

- with a variable proportions technology, issues of bundling and price discrimination arise but again the inefficiencies are attributable to monopoly power rather than externalities.

If the supplier cannot commit to prices in advance, buyer expectations are again crucial: a monopolist would like to convince consumers applications will be available at low price in the future. After consumers are locked in, however, the monopolist may raise price to the monopoly level.

In the literature, it is usually assumed that consumers' expectations on the future prices of applications are affected by the quantity of hardware currently sold which may act as a signal: a larger base may lead to cheaper and/or more varied applications. Hence, the monopolist may want to lower the price of hardware to create a larger network and software aftermarket.

*Product selection decisions*

Competition in network industries may take the form of competition between incompatible systems.

Network externalities may lead to a de facto standardization whereby everyone uses the same system. Due to positive feedback elements, a system may become dominant once it has gained an initial edge, a phenomenon which is usually referred to as “tipping”.

Two main factors, however, may limit tipping and sustain multiple networks:

- network externalities being exhausted at a smaller network size;
- consumers’ heterogeneity and product differentiation.

In the latter case multiple networks would reflect consumers’ love for variety and there is a typical trade-off between variety and standardization.

Competition between systems may be very intense, at least before a dominant system, if any, would emerge as dominant. For instance, firms may be engaged in very intense price competition at an early stage for seeking to establish an installed base and achieve leadership. This competition can be interpreted as firms bidding for future monopoly profits.

Competition may also be played in trying to affect consumers’ expectations about the dominant system that would emerge.

An important implication of the network externalities literature is that the market may settle in an equilibrium where the dominant system is that with a lower social evaluation. Markets can exhibit “excess inertia” and remain locked into an obsolete standard, even though a better one is available.

However, markets can also exhibit “excess momentum” whereby the market tips inefficiently to new technologies. This could, for instance, arise when competition is between an older technology which is competitively supplied and a new technology which is sponsored. The new technology that is sponsored may have an advantage over an older technology that is more competitively supplied because the sponsor of the technology may engage in pricing below costs or other types of investments (with the hope of recouping these later once the technology is established). Nonetheless, this perceived risk is not straightforward — pricing very low from the outset may be the only way of introducing an efficient new technology, and tipping may be inevitable.

*Compatibility choices*

Compatibility between different networks/systems is often a choice variable of firms. Two types of compatibility can be considered:

- horizontal compatibility: between two comparable rival systems; and

- vertical compatibility: between successive generations of a technology.

Compatibility entails both social benefits and costs:

- compatibility expands the size of both networks thereby avoiding the cost of participating to two different networks (e.g. duplicate equipment);
- compatibility in systems may lead to lower production costs for economics of scale, learning effects, etc;
- compatibility enhances variety by allowing consumers to combine components from various systems;
- the risks of adopting a particular technology are lower; and
- costs derive from the mechanism by which compatibility is achieved. Standardization may lead to a loss of variety and may prevent the development of new incompatible systems; adapters that allow interfacing have a cost themselves and may work imperfectly.

The nature of competition in the market is affected by compatibility decisions. For systems that are compatible, competition is essentially at the level of each component. For incompatible systems, competition is at the network or system level.

Katz and Shapiro (1986) consider the impact of compatibility on pricing competition over time. Price competition is relaxed at earlier stages of the product life cycle because the market loses its winner-take-all feature. For the same reason, however, competition may be intensified in later stages of the product life cycle.

Compatibility decisions may be affected by a number of factors:

- asymmetries in the probability of being the winner, e.g. reputation;
- product differentiation; and
- installed base

Side payments may help firms to reach an agreement on compatibility. When they are not feasible, it is useful to distinguish markets where a firm can unilaterally impose compatibility and those where a firm can unilaterally impose incompatibility.

In general, there may be different mechanisms and institutions that govern compatibility choices: standards committees, unilateral action and hybrid mechanisms. (Farrell and Saloner, 1988)

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