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The Nature of Technological Change and Its Main Implications on National and Local Systems of Innovation

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Contents

Abstract

This paper aims at providing a survey (by no means exhaustive) of evolutionary theorising, where by this we mean all the contributions which possess the methodological building blocks of an evolutionary theory, which this approach identifies as the consideration of dynamics, the presence of microfounded theories, the assumption of bounded rationality and of heterogeneity among agents, the recognition of the continuous appearance of novelty, the view of collective interactions as selection mechanisms, and finally the consideration of aggregate phenomena as emergent properties with nonstable nature. Along this path through the linkages from the micro technological studies to a broad aggregate system, we propose a concept and representation of Innovation Systems -national, regional, sectoral and at the micro levels- whereby their main feature will be related to capture empirically some pieces of the evolutionary approach.

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Mario Cimoli and Marina della Giusta

1. Introduction

At the time of writing, some of the main international organisation concerned with development issues (World Bank and OECD) have become increasingly interested in studying the theme of National Innovation Systems (NIS, which the WB addresses as “systems of knowledge”). We believe that this interest needs to be accompanied by a thorough understanding of the microfoundations of a theory that concentrates on such theme, and namely evolutionary theory. This understanding is needed in order to appreciate the consequences that these microfoundations entail with respect to the theorising on the origins and behaviour of organisations and institutions, and the fundamental role of the latter in the processes of development (Cimoli and Dosi, 1994).

This paper aims at providing a survey (by no means exhaustive) of evolutionary theorising, where by this we mean all the contributions which possess the methodological building blocks of an evolutionary theory, which Dosi (1996) identifies as the consideration of dynamics, the presence of microfounded theories, the assumption of bounded rationality and of heterogeneity among agents, the recognition of the continuous appearance of novelty, the view of collective interactions as selection mechanisms, and finally the consideration of aggregate phenomena as emergent properties with nonstable nature.

Along this path through the linkages from the micro technological studies to a broad aggregate system, we shall propose a concept and representation of Innovation Systems -national, regional, sectoral and at the micro levels- whereby their main feature will be related to capture empirically some pieces of the evolutionary approach. Moreover, through the systematisation of this representation, two different attempts will be pursued. On the one hand, the major task of this interpretation will be devoted to the identification of an aggregate structure where the main threads that link technology, institutions, competencies and economic performances may be placed and described. On the other hand, an implication of this view is related to a broader set of approaches that look for a framework where mechanism that support technical change and innovation could be understood, so that governments could form and implement policies in order to influence innovation process.

We begin the survey by explaining what the crucial assumptions of an evolutionary view of the process of technical change are, and we do so by introducing the notions of paradigms and trajectories, intertwining them with a definition of technology and its properties. We then proceed by describing the implications of such definitions in terms of a theory of production. The third section is devoted to a brief introduction to the behavioural assumptions that describe individuals, organisations and institutions. Section four contains some of the main models that describe the evolution of industries. Section five then moves on to describe technological capabilities and production capacity in the process of development, and section six finally boards the theme of National Systems of Innovation, the concept of which is explained by Nelson (1993) as consisting of the set of institutions whose interactions determine the innovative performance of national firms (whereby innovative activity is broadly understood as inclusive of all the processes by which firms master and get into practice product designs and manufacturing processes that are new to them). Section seven concludes the paper.

2. Microfoundations: a definition of technology and its discussion

The model of technical change proposed in early work by Schumpeter (the Theory of Economic Development) was itself linear and has been described as being of a science (and technology)- push type, in that a relationship running from invention through innovation to diffusion was envisaged. There he described inventions as happening discontinuously and exhogenously, with the entrepreneurs exploiting them by turning them into innovations in order to achieve a profit reward. It was only in his later work (1943) that Schumpeter recognised and emphasised the role of corporate R&D, so that a feedback from successful innovation to increased R&D was introduced in his model and, together with it, the fact that the large corporations he was focusing on (which belonged mainly to the pharmaceuticals sector) could influence market demand was also taken into account (Freeman et al., 1982).

The role of demand is seen as that of a crucial stimulus in another linear model of technical change: the so-called demand-pull model derived in Schmookler's analysis (1962). In his empirical analysis of patent data in railroading, petroleum refining and building he found that inventive effort varies directly with output, lagging slightly behind it. He went on to argue that expected profits from invention, the ability to finance it, the number of potential inventors and the dissatisfaction which stimulates them were all positively associated with sales; from all this, variations in inventions were seen as a consequence of economic conditions with which output is also positively correlated, so that a relationship running from economic growth to innovation could be derived.

The demand-pull model stimulated a number of studies, which have been reviewed and criticised by Mowery and Rosenberg (1979): in this famous review these studies were shown to be revealing the importance of demand in successful innovation (in particular the SAPPHO project was found to shed light on a crucial aspect of successful innovations: the attention given to user needs), rather than the causal relationship between the two; moreover, in the authors' assessment, the reviewed studies did not seem to contain evidence that innovation was stimulated by a shift in demand, rather than in technology[1].

Demand-based theories of innovation can be criticised on different grounds. A first level regards their interpretative power with respect to the occurrence of innovation in the form of technological breakthroughs: here the causality running from the -virtually infinite- range of potential demands and the occurrence at a particular time of

[1] For an exhaustive list of studies on this theme, see Rothwell and Walsh (1979) and Saviotti.

an innovation is very difficult to see. Moreover, the process through which a need is recognised and an innovation is produced to respond to it reduces the innovative process to a simple and deterministic phenomenon which has to be strictly connected to market conditions, and finally it enormously understates the complexity in the scientific and technological processes that are necessary for innovation to occur. What the review by Mowery and Rosenberg (1979) demonstrates is that the perception of a potential market is a necessary condition for innovation, but not a sufficient one (Dosi, 1984).

Following this review, and accompanying the diffusion of evolutionary theories, a general critique to linear models of technical change was formulated, based on the fact that they ignored what happens inside firms, which were indeed treated as black boxes (Rosenberg, 1982). The “early Schumpeter” model described a relation running from the science base through firms (in his later version through corporate R&D and then production) to markets; the demand-pull model, on the other hand, essentially run the opposite way. By taking into account the feedback mechanisms proposed in the development of Schumpeter’s work, and the contributions to the understanding of learning in production in Rosenberg’s work, the model of technological change became much more complex: R&D labs were now seen as providers of inputs for learning in production -the locus where technical change primarily happens- and receivers of inputs not only from the science base, but also in the form of problems arising in production and which require solutions. According to the most recent historical analysis by Rosenberg (1982), moreover, it is often science that spills out of technology, as in the cases of radioastronomy and computer science.

In order to begin to understand the complex nature of innovative activity, it is useful to firstly summarise some stylised facts concerning it. Scientific inputs have become increasingly important in the innovative process, and R&D activities more complex, so that it is necessary to adopt a long-run perspective in the planning of such activities within firms. Moreover, there exist a number of studies correlating such R&D efforts with innovative output, for various industrial sectors (whereas market and demand changes do not exhibit significant correlation with it). Another stylised fact that has emerged is the importance of innovation generated by learning-by-doing embodied into people and organisations. As regards the nature of the innovation process, a vision of it as intrinsically uncertain prevails over the assumption of known ex-ante fixed sets of choices, although this does not imply that technical change occurs randomly: its directions are determined by the state-of-the-art technologies and, at the level of firms, of the technology that they possess. Indeed, it is possible to identify patterns of change which are defined in terms of technological and economic characteristics of product and processes (Dosi, 1984).

It is important to bear in mind, however, that it is not possible to formulate a general theory of technical change based exclusively on technology-push or demand-pull models. From this first summary of the main characteristics of innovation it is perhaps already possible to understand how certain components of technology impede the feasibility of the application of definitions that would apply in all sectors, industries and firms. Both the demand-pull and technology-push explanation include elements which make them applicable to describe innovative processes in certain sectors or in certain periods of the historical dynamics of technology, with one model prevailing over the other depending on the circumstances.

The evolutionary nature of the concept of technical change which is being presented can perhaps be better understood now that such vision can be contrasted with the so-called linear models of technical change presented so far and their critique. The core notion, which we now need in order to describe the evolutionary nature of technical change at a macroeconomic level, is that of technological paradigm[2]. By adapting the notion of paradigms formulated by Kuhn in the philosophical sciences, Dosi (1988) defines a <u>technological paradigm</u> as "a pattern of solution of selected technoeconomic problems based on highly selected principles derived from the natural sciences, jointly with specific rules aimed to acquire new knowledge and safeguard it, whenever possible, against rapid diffusion to the competitors".

The notion of technological paradigms is based on a view of technology grounded on the following three fundamental ideas which implies a strong interdependence between economic and technological activities[3].

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[2] A variety of concepts have recently been put forward to define the nature of innovative activities: technological regimes, paradigms, trajectories, salients, guideposts, dominants designs and so on. More crucially, these concepts are highly overlapping in that they try to capture a few common features of the procedures and direction of technical change (for a discussion and references, see Dosi 1988).

[3] The rates and direction of technical change are therefore shaped by the dominant paradigm and their

First, it suggests that any satisfactory description of "what is technology" and how it changes must also embody the representation of the specific forms of knowledge on which a particular activity is based. Putting it more emphatically, technology cannot be reduced to the standard view of a set of well-defined blueprints.

Within the evolutionary perspective there exist several definitions of technology, a possible one, extracted from Cimoli and Dosi (1994) is the following: “technology primarily concerns problem-solving activities involving, to varying degrees, also tacit forms of knowledge embodied in individuals and organisational procedures”. It is very important to analyse the elements that are common to the various evolutionary definitions, on which the understanding of the nature of technology is grounded.

“Problem-solving activity” has been characterised in the work by Nelson and Winter (1982) as a process of irreversible, contingent, dependent and uncertain nature, which generates both technical advance and technological competence of the actors performing it. As regards the feature of uncertainty, Dosi (1988) explains how: “an innovative solution to a certain problem involves discovery and creation since no general algorithm can be derived from the information about the problem that generates its solution automatically”. The dependency and contingency features derive from the fact that “the solution of technological problems involves the use of information drawn from previous experience and formal knowledge; however, it also involves specific and uncodified capabilities on the part of the inventors” (Dosi, 1988), therefore the outcome of the search process will be determined by the history of the inventor, by the available formal knowledge and by the inventor’s capabilities.

The knowledge base that inventors draw on entails two different aspects, which are also often indicated in the literature as the two elements of technology. These are a potentially public and a tacit element: the first consisting of the available formal knowledge (which may be only potentially available due to the different ways of

disruption is correlated with radical changes in paradigms. Freeman and Perez (1988) propose the notion of techno-economic paradigm; changes in the latter are caused by a combination of interrelated product and process, technical, organisational and managerial innovations involving an increase in potential productivity for all or most of the economy. In their view a new paradigm emerges only gradually as a new ideal type of productive organisation; the world is still dominated by an old paradigm and the new paradigm begins to demonstrate its comparative advantage at first only in few sectors. The supply of the key new factors has to satisfy three criteria: being rapidly increasing, having pervasive applications and presenting falling costs. The presently dominating information technology paradigm clearly possesses all these features, as previously did the “electrical equipment and chemical technology-based” paradigm in the interwar period and the “mechanical” paradigm associated with the industrial revolution.

conceptualising and therefore codifying knowledge), the second derived from a concept developed by Polany (1967) and referred to by Dosi as being related to "those elements of knowledge, insight, and so on that individuals have which are ill defined, uncodified, unpublished, which they themselves cannot fully express and which differ from person to person, but which may to some significant degree be shared by collaborators and colleagues who have a common experience" (Dosi, 1988).

Second, paradigms entail specific heuristic and visions on "how to do things" and how to improve them, often shared by the community of practitioners in each particular activity (engineers, firms, technical societies, etc.). ...i.e. collectively shared cognitive frames" (Constant, 1985) and, at the level of individual firms, of routines (Nelson and Winter, 1982) which "incorporate the skilful behaviour required for the generation and application of technology and consist of an interlinked sequence of steps which require knowledge on the part of those who perform them, and which cannot be fully communicated to them unless they join the firm's team and undergo the same learning process" (Cantwell, 1991).

All these concepts will be analysed in grater detail in the second chapter of the present work, but it is necessary to briefly sketch them here, in order to be able to understand that the technological capabilities which define the competence of firms are best understood in terms of the tacit element of technology. In fact, the "strategic assets of firms" (Dierick and Cool, 1989) have been individuated in those assets which posses the characteristics of being nontradeable, nonimitable and nonsubstitutable. Their essential feature is that they must be built over time, and imitability becomes therefore impossible due to time compression diseconomies, to the existence of asset mass efficiencies, to the interconnectedness of asset stocks[4], to the phenomenon of asset erosion which occurs over time, and finally to the presence of causal ambiguity, i.e. the difficulty of identifying, even from within the firm itself, the crucial elements of their technological competence.

All the preceding discussion provides an explanation of this statement by Nelson (1992): "industrial R&D reflects the fact that technology has both a private and a public aspect, and is also a major reason why this is the case". It is now also possible to put

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[4] See also the importance of co-specialised assets described in the work by Teece (1988), and on which we will return in what follows.

forward a distinction between technology and information (Dosi, 1988): the latter spreads across firms, whereas the former includes “tacit and specific knowledge that are not and cannot be written down in a blueprint form and cannot, therefore, be entirely diffused either in the form of public or proprietary information” (further discussion of what is known as the “appropriability issue”, which generated from a paper written by Arrow in 1962, can be found in Dosi 1988 and Freeman 1994). The fact that such tacit knowledge is primarily embodied into individuals is particularly important, and it plays a major role in understanding the nature of the impact of science on technology (an issue which has been dealt with in Pavitt, 1991).

Third, paradigms generally also define basic models of artifacts and systems, which over time are progressively modified and improved. These basic artifacts can also be described in terms of some fundamental technological and economic characteristics. For example, in the case of an airplane, these basic attributes are described not only and obviously in terms of inputs and the production costs, but also on the basis of some salient technological features such as wing-load, take-off weight, speed, distance it can cover, etc. What is interesting is that technical progress seems to display patterns and invariance in terms of these product characteristics. Similar examples of technological invariance can be found e.g. in semiconductors, agricultural equipment, automobiles and a few other micro technological studies.

The concept of technological trajectories is associated to the progressive realization of the innovative opportunities associated with each paradigm, which can in principle be measured in terms of the changes in the fundamental techno-economic characteristics of artifacts and the production process[5]. Nelson and Winter (1977) define as natural trajectories of technical progress those paths which contribute to shape the direction in which problem-solving activities move and which possess a momentum of their own; in this sense, a trajectory represents the normal problem solving activity determined by a paradigm (Dosi, 1988). The core ideas involved in this notion of trajectories are the following. First, each particular body of knowledge (i.e. each paradigm) shapes and constraints the rates and direction of technological change irrespectively of market

[5] The interpretation of technical change and a number of historical examples can be found in pioneering works on economics of technical change such as those by Chris Freeman, Nathan Rosenberg, Richard Nelson, Sidney Winter, Thomas Hughes, Paul David, Joel Mokyr, Paolo Saviotti and others; see for a partial survey Dosi (1988).

inducements. Second, as a consequence, one should be able to observe regularities and invariance in the pattern of technical change, which hold under different market conditions (e.g. under different relative prices) and whose disruption is correlated with radical changes in knowledge bases (in paradigms). Third, technical change is partly driven by repeated attempts to cope with technological imbalances which it itself creates, which are described by Rosenberg (1976) as bottlenecks which act as focusing devices in that the efforts that are concentrated in overcoming them are themselves an important source of technical change. Rosenberg (1982) insists on the importance of the cumulative impact of small increments, and refers to Gilfillian's view, in describing the improvements in shipbuilding, of "the gradual and piecemeal nature of technological change, drawing heavily on small refinements based on experience and gradually incorporating a succession of improved components or materials developed in other industries"(Rosenberg, 1982).

3. The production theory and the main implications of evolutionary view

The elements of the nature of technical change presented so far, and in particular the implications of localised technical change had already been investigated by Robinson and Atkinson and Stiglitz (1969). In particular, by hypothesising that the effect of technical advance would be that of improving one technique of production with little (weak localised) or no (strong localised) spillover effects upon other neighbouring techniques, these authors showed how in terms of the neo-classical production function (in which different points represent different production processes) technical change would imply the outward movement of one point of the function, rather than of the whole function. When, moreover, the effects of learning in production (so that the efficiency of a technique increases with its use) over the costs of switching from one technique to another are considered (so that the existence of productivity losses even when the firm is switching to a more productive technique are to be expected), the authors argued that a picture very different from the one proposed in standard neo-classical theory would emerge.

By explicitly incorporating the framework by Atkinson and Stiglitz in the evolutionary perspective, Verspagen (1990) observes that the concepts of paradigms and trajectories, which stem from the specific and cumulative nature of technology, is akin to the consequences derived from the existence of weak localised technical change[6]. A general property, by now widely acknowledged in the innovation literature, is that learning is local and cumulative. Local means that the exploration and development of new techniques is likely to occur in the neighborhood of the techniques already in use. Cumulative means that current technological development- at least at the level of individual business units- often builds upon past experiences of production and innovation, and it proceeds via sequences of specific problem-solving junctures (Vincenti, 1992). Clearly, this goes very well together with the ideas of paradigmatic knowledge and the ensuing trajectories. A crucial implication, however, is that at any point in time the agents involved in a particular production activity will face little scope for substitution among techniques, if by that we mean the easy availability of blueprints different from those actually in use, which could be put efficiently into operation according to relative input prices.

The notion of paradigms contains elements of both a theory of production and theory of innovation. In short, we shall call it henceforth an evolutionary theory. Loosely speaking, we should consider such a theory at the same level of abstraction as, say, a production function or a production possibility set. That is, all of them are theories of what are deemed to be some stylized but fundamental features of technology and, relatedly, of production process.

In order to summarise what has been presented so far, and have a picture of what the evolutionary approach implies, let us now present a few points which constitute

[6] He stresses that the type of technical progress which is being taken into consideration in his -and in Atkinson's and Stiglitz's- analysis is Hicks neutral technological progress, that is: purely labour-saving or capital-saving technical progress are not considered. Then he investigates the effects of unanticipated price shocks on productivity at the aggregate level, and by applying his analysis to the effects of the oil shocks suggests a possible interpretation of the productivity slowdown in terms of the continuous adaptation to a fast-changing environment which compels firms to produce with techniques they have not yet learnt to exploit efficiently, or old techniques which they master efficiently but are inferior to the new ones.

“predictions” derivable from it (Cimoli and Dosi, 1994):

a) In general, there is at any point in time one or very few best practice techniques which dominate the others irrespectively of relative prices.

b) Different agents are characterised by persistently diverse (better and worse) techniques.

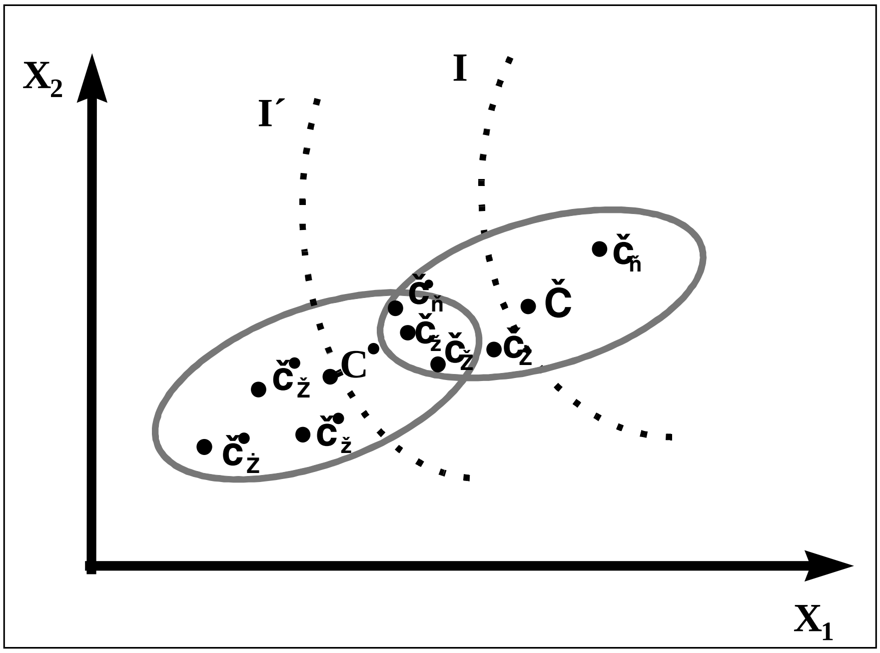
c) Over time the observed aggregate dynamics of technical coefficients in each particular activity is the joint outcome of the process of imitation/diffusion of existing best-practice techniques, of the search for new ones, and of market selection amongst heterogeneous agents.

d) Changes over time of best-practice techniques themselves highlight rather regular paths (i.e. trajectories) both in the space of input coefficients and in the space of the core technical characteristics of outputs.

Prediction a) is related to the existence of phenomena that derive from the processes of diffusion and competition among technologies (described extensively later in the chapter), whereas prediction b) is a consequence of the importance described earlier of the tacit element of technology in determining the level of technological capabilities of firms. The nature of learning processes is responsible for prediction c), whereas the fact that the prevailing paradigm determines the direction that such learning pursues is the reasoning behind prediction d).

In Cimoli’s and Dosi’s words:“ in an extreme synthesis, a paradigm-based production theory suggests as the general case, in the short term, fixed-coefficient (Leontieff-type) techniques, with respect to both individual firms and industries, the latter showing rather inertial averages over heterogeneous firms”. The representation of production and technological activities offered by these authors takes explicitly into account the aforementioned characteristics. A graphical distribution of micro coefficients in the space of unit inputs is presented, under the simplifying assumption of a homogeneous good being produced under constant returns to scale and with two inputs only (see Figure 1).

Figure 1 The distribution of technological coefficients



We are here observing the distribution of coefficients (c_i) at time t, with 1...n being the various firms/techniques in decreasing order of efficiency, i.e. by relative degree of technological dominance. The distribution of coefficients across heterogeneous firms represents the degree of asymmetry of the industry and the reasons for it lie in the discussion presented above: essentially a firm happens to use a technique which is inferior to the best available (best practice technique) because “it does not know” how to adopt the best practice technique.

In Figure 1, the situation at time t+1 is also depicted. The distribution of microcoefficients has changed and the paradigm-based interpretation of such change is that it derives from a set of causes: attempts by below-best practice firms to imitate the technological leader, innovative efforts which may generate new techniques, in some cases superior to the ones available, and finally the changes in market shares or exit of existing firms, together with the entry of new ones. As we shall extensively discuss in what follows, the processes governing the diffusion of innovation are to a large extent responsible for the dynamics by which such changes in the distribution of technical coefficients take place.

In this framework, changes in relative prices, just as in Atkinson and Stiglitz (1969), have an influence on the direction of imitation and innovative search pursued by agents, but these remain constrained by the nature of the underlying knowledge base, the physical and chemical principles it exploits and the technological system in which a particular activity is embodied (i.e. the existing paradigm). Persistent shocks on relative prices have the effect of influencing the diffusion of alternative paradigms, rather than that of inducing static substitution among techniques (as in the analysis of the effects of the oil shocks by Verspagen).

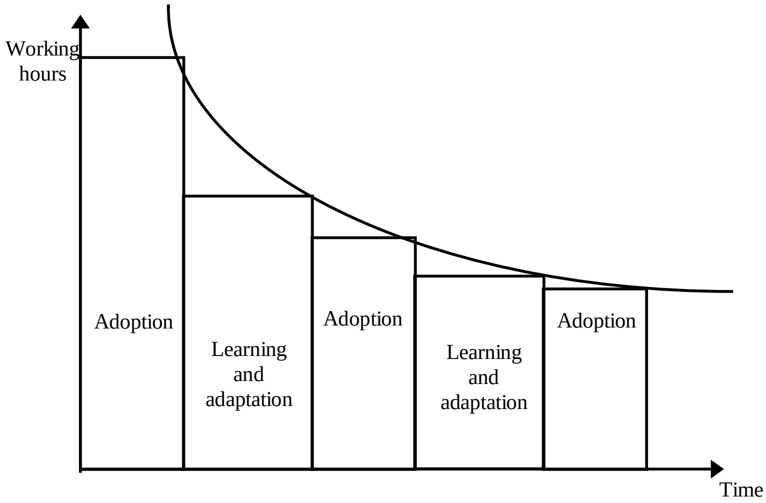
There is a much more general theoretical story regarding the development, diffusion and competition among those (possible alternative) paradigms that are actually explored. It can be told via explicit evolutionary models (as in Nelson and Winter 1982 or in Silverberg, Dosi and Orsenigo 1988), via path-dependent stochastic models (as in Arthur 1989, Arthur, Ermoliev and Kaniovski 1987, Dosi and Kaniovski 1994 and David 1989), and also via sociological models of network development (as in Callon 1991).

Metcalfe (1981 and 1988) provides a useful set of links between micro studies on diffusion of innovation and the wider dynamics of industrial growth, by viewing the latter as the processes by which impulses from innovation are transmitted across the economy via incentives provided by profit rewards. While criticizing the standard diffusion model for concentrating only on the demand for innovation by potential adopters and neglecting the supply side, i.e. the profitability perceived by producers of innovation, he concentrates on the analogies that exist between the problem of the diffusion of innovation and that of the dynamics of industrial growth across countries in the studies by Schumpeter, Kuznets, and Burns. In order to explain retardation in industrial growth, these authors emphasize factors such as inter-commodity competition (i.e. limits on the growth of the market demand for each innovation), inelasticity in supplies of productive inputs (temporary bottlenecks such as those provided by finance and machines, and more permanent ones such as those related to labor and materials) and post-innovation patterns of technical progress (improvements in the technology once adopted, which possess a considerable cumulative impact). The model proposed by Metcalfe, which takes into account the diffusion and the industrial growth perspective, describes the pace of diffusion of an innovation as determined by both supply side constraints and adoption ones, and provides a balanced diffusion path which is determined by an adjustment gap (i.e. the difference between saturation output level and the initial rate of demand) and dynamic elements in demand and capacity growth (summarized in the balanced adoption coefficient, a capital-output ratio). The diffusion process, in this way, becomes the force determining the pace and direction of technical change. Another important result is also the ability to incorporate the transient nature of the profit reward from innovation, a characteristic of Schumpeter's approach. The same line of reasoning lies at the heart of the model by Silverberg et al. (1988), in which innovation diffusion, together with diversity of technological capabilities, business strategies and expectations are formally incorporated into a theory of the evolutionary patterns of industries and countries (this contribution will be presented in the section dedicated to industrial models).

It has to be stressed that all these contributions contain dynamics that are microfounded on the basis of the learning mechanisms within firms. Such learning essentially derives from the modes in which new productive factors (capital goods) are introduced into the system and firms adopt and learn how to use them (in this respect, see the vast literature on learning-by-doing, and in particular Arrow and Rosenberg).

These mechanisms of adoption and learning substantially modify -and add new interpretations to- the cost functions faced by individual firms and their productivity dynamics. An interesting example of the processes which are being described is given by the work by Gurisatti et al (1997), who discuss the patterns of diffusion of microelectronics-based technical change in machine tools employed in metal working firms in one Italian region. By interviewing mechanical engineers within firms, they obtain a description of the process of innovation in which to radical improvements (installation of new machines) there follow long phases of endogenous improvements that substantially improve the process, with gains in productivity that often exceed those coming from the installation of the new machines. Moreover, the authors find that the diffusion process of new machines across firms takes a considerable period of time and that there exist large variations among firms, which depend upon their technological and organizational capabilities. The graphical description of the process proposed by the authors can be integrated in order to show its closeness to that described by Dosi (1984) who explains how unit costs decrease in accordance with a technologically determined learning curve, with competencies clearly possessing a cumulative character. By bearing in mind the situation portrayed in figure 1, it can now be understood how the present discussion serves the purpose of explaining how the points shift in time and how the set of points representing an industry re-composes itself. It is extremely interesting to note, furthermore, how the existence of increasing returns to adoption is equally explained by the micro-level process described here.

Figure 2: A learning curve (adapted from Dosi, 1984, and Gurisatti et al., 1997)



So far, we have discussed paradigms, trajectories or equivalent concepts at a micro-technological level. A paradigm-based theory of innovation and production, we have argued, seems to be highly consistent with the evidence on the patterned and cumulative nature of technical change and also with the evidence on microeconomic heterogeneity and technological gaps. Moreover, it directly links with those theories of production which allow for dynamic increasing returns from Young and Kaldor to the recent and more rigorous formalizations of path-dependent models of innovation diffusion, whereby the interaction between micro decisions and some form of learning or some externalities produces irreversible technological paths and lock-in effects with respect to technologies which may well be inferior, on any welfare measure, to other notional ones, but still happen to be dominant - loosely speaking- because of the weight of their history (cf. the models by B. Arthur and P. David).

However, paradigms are generally embodied in larger technological systems and in even bigger economic-wide systems of production and innovation. These evolutionary characteristics of the process of technical change are seen in a complementary perspective as responsible for the occurrence of what has been called "lock-in by historical events" (Arthur, 1989). This concept suggests a view of the process of selection and adoption of technologies dominated by path-dependency, unpredictability, inflexibility (the more widespread the adoption of a particular technology, the fewer the chances for another of being adopted) and possible selection of inferior technologies (an example of the latter is the adoption of light-water reactors instead of gas-cooled reactors, which are now considered inferior). Several implications are derived from the lock-in approach (especially interesting are those concerning the catching-up by developing countries), among which the fact that the history of a firm (in terms of the techniques it is and was able to master) is very important in determining its current choices of technique and that phenomena of path dependency and lock-in by historical events would emerge (see also the simulation of lock-in contained in Luna, 1997).

It is always possible to interpret the evidence discussed so far in terms of standard production theory; by assuming that the best practice technique C (nearly coinciding with the average) in figure 1 is the equilibrium one. Then, draw some generic and unobservable downward-sloped curve through C and also the observed relative price ratio. Do the same with point C', corresponding to the average values at t', and again with the subsequent average observations. Next assume a particular functional form to the unobserved curve postulated to pass through C, C', etc. and call it the isoquant of a corresponding production function (the same method can be applied over time or cross-sectionally). Then, run some econometric estimates based on such postulated function, using data derived from the time series of relative prices and C, C', etc. Finally, interpret the relationship between the values of the estimated coefficients in terms of elasticities of substitution, and attribute the residual variance to a drift in the technological opportunity set[7]. Even if the evolutionary microdynamics described above were the true ones, one could still successfully undertake the standard statistical exercise of fitting some production function. But the exercise would obscure rather than illuminate the underlying links between technical change and output growth.

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[7] For the purpose of this argument, one can neglect whether such a drift is meant to be an exogenous time-dependent dynamics, as in Solow type growth models, or is in turn the outcome of some higher level production function of blueprints, as in many new growth models.

By referring again to figure 1, it is possible to draw another interpretation of the distributions of technical coefficients pictured there. In particular, it is possible to interpret the two distributions as representative of two countries at the same time, among which there exists a technological gap. The evolutionary explanation for it resides again in the processes of learning of each country; these cause technological gaps between countries that can account for different input efficiencies even in the face of equivalent inputs utilisation and factors intensities. Evolutionary theory, in the line which contrasts the importance of imperfect learning versus optimal allocation of resources as the engine of development (Kaldor, Pasinetti, Schumpeter), predicts persistent asymmetries among countries in their capacity to master production processes and this has two consequences: 1) it is possible to rank different countries by the efficiency of their average techniques of production and the performance characteristics of their outputs, independently of relative prices; 2) these asymmetries will not be in any significant relation with differences in capital/labour ratios (Dosi et al.,1994).

The differences in technological capabilities which account for such asymmetries in production processes also account for the different capabilities of developing new products and the different time lags in producing them once they have been introduced into the world economy. In particular, the specific capabilities of each developing country determine its ability to borrow and adapt the more advanced technologies developed elsewhere which lye at the roots of its industrialisation process.

The next chapter will therefore be devoted to investigating in more detail the reasons and content of the behavioural assumption which lie at the core of this approach and the implications of the behaviour of individuals and organisations in describing the dynamics of firms, industries, and countries. Moreover, when firms are seen as repositories of knowledge which take part in networks of linkages with firms and other institutions, it becomes possible to apply the same line of reasoning to national systems of innovation, so that the existing technological gaps between countries are the outcome of different national technological and institutional capabilities[8].

[8] The differences in such capabilities will in what follows be linked to the concept of NIS in a broader structure aimed at explaining the different performances of countries.

4. From individuals and organisations to institutions: a brief introduction.

By referring once more to figure 1, and interpreting it as the representation of a system of techniques evolving through time, there emerges the question of how they can come into existence independently of the organisations, which also constitute the system. In particular, is it possible to say that to each technique corresponds an organisational structure of the enterprise? And, if organisations differ too, how is it possible to distinguish among them? In order to investigate the behavioural assumptions that are used to describe economic agents in evolutionary models, it will be useful to start from the consequences of approaches that abandon the hypotheses of rationality made in traditional orthodox theory. As Egidi (1996) reports, Hayek in 1936 had already argued that agents would not be capable of fully rational decisions, once the unrealistic assumptions regarding their unlimited capacity of acquiring and processing knowledge were removed, and that therefore knowledge would rather be diffused heterogeneously and asymmetrically amongst agents. According to Egidi, this intuition lies behind the bounded rationality approach formulated by Simon, who provides an explanation for the existence of institutions in the presence of such limits to the possibility for individuals of taking fully rational decisions. Institutions would therefore exist in order to gather knowledge and information, and according to Hayek they would be “the historical and unintended product of the consolidation of inter-individual relationships” (Egidi, 1996). The fundamental notion which Egidi draws our attention to, is that the creation of knowledge was posed by Hayek, as later by Schumpeter, at the core of the process of co-ordination among individuals and consequently of economic change.

The microeconomic foundations to this approach can be found in the work by March and Simon and Cyert, Simon and Trow in the fifties who firstly analysed the role of learning activity in human decision making. Within organisations, individuals learn to solve problems through stable behavioural patterns of action, so that their behaviour becomes routinised. Routines are defined by Egidi as “procedures which solve sets of problems internal to the organisation”, where a procedure is “a set of instructions determining the actions to be taken when dealing with a particular circumstance”. The replication of procedures enables individuals to reduce the complexity of individual decisions, so that routines become automatic, and, as already discussed in the first part of the present work, partly tacit. By using a theoretical framework in which co-ordination among individuals and their activities is the crucial issue, it is possible to classify economic organisations as "devices with which to co-ordinate economic activities" that can vary over a continuum which possesses as its extremes pure markets and pure hierarchies (Egidi, 1995).

In the work by Dosi and Lovallo (1995), the presence and consequences of "decision biases" in organisations are discussed in the context of corporate entry and evolution of industrial structures. Such decision biases (in particular the presence of overconfidence in the future) are a result of the process through which firms build their competence, which is in turn shaped by the characteristics with which technical change takes place, introduced in the first part of the present discussion. Individuals' and organisations' behaviour is again seen as shaped by the features of the knowledge bases they can draw on. With specific reference to the implications of the "bounded rationality" approach, and in particular of analyses of learning processes in circumstances where there exist a "competence gap" (i.e. when not all the skills required in the decisions are available to the agents involved in them), the authors describe the emergence of cognitive frames and decision routines as the result of the presence of "ever-changing and potentially surprising environments", in which three features are present: "...facing an essential ambiguity in the relationship between events actions and outcomes, agents are bound to search for appropriate categories which frame cognition and actions. Action rules often take the form of relatively event-invariant routines which are nonetheless robust, in the sense that they apply to entire classes of seemingly analogous problems. Adaptive learning, involving interrelated units of knowledge (i.e. some sort of cognitive systems), tend to lead to lock-in phenomena" (Dosi and Lovallo, 1995). Again, the characteristics of knowledge shape not only the behaviour of individuals, but that of organisations too.

Organisations (economic, social and political) are seen in the work by North (1990) as the engine of institutional change through their demand of investment in knowledge, the interactions which they determine between economic activity, scientific knowledge and institutional structure, and finally through the gradual change in informal rules which they give birth to in the course of their activities. In his approach, institutions define the set of opportunities of a society, whereas organisations exist in order to exploit such opportunities. In doing so, however, they develop and gradually alter institutions, so that the characteristics of institutional change are depicted as intrinsically evolutionary. Indeed, the institutional dimension has a central importance in evolutionary theories of production and innovation. In his perspective, in fact, he acknowledges a bi-directional relation between market structures and patterns of technological learning. The dependence of firms' performances and therefore of industrial structures from learning characteristics is a direction which has already been illustrated in the first part of the present work; the relationship between institutions and organisations is instead the subject of the present discussion.

According to the interpretation which is being presented, the existence of heterogeneity will manifest itself not only at the level of technical efficiency, but at that of profitability too, as different rates of learning influence the ability of firms to survive and expand, and thus affect industrial structures. There is the idea that firms are a crucial (although not exclusive) repositories of knowledge, to a large extent embodied in their operational routines, and modified through time by their higher level rules of behaviors and strategies (such as their search behaviors and their decisions concerning vertical integration and horizontal diversification, etc.). This idea is central in the characterization of technological capabilities of firms proposed in Nelson and Winter (1982) and Nelson (1992), and in the idea of competence proposed by Dosi, Teece and Winter (1992), whereby "a firm's competence is a set of differentiated technological skills, complementary assets, and organizational routines and capacities that provide the basis for a firm's competitive capacities in a particular business" and "in essence, competence is a measure of a firm's ability to solve both technical and organizational problems".

In part, when the role of firms as actors in the process of technical advance is recognised, it becomes possible to understand how the nature of technological change is fundamentally shaped by the nature of the learning processes of firms. Learning has been so far described as being local and cumulative in nature, where "local means that the exploration and development of new techniques is likely to occur in the neighbourhood of the techniques already in use, and cumulative means that current technological development builds upon past experiences of production and innovation and proceeds via specific problem-solving junctures" (Cimoli and Dosi, 1994).

A locus classicus in the analysis of the profound intertwining between technological learning and organizational change is certainly Alfred Chandler's reconstruction of the origins of the modern multi-divisional (the M-form) corporation and its ensuing effects on the American competitive leadership over several decades (Chandler (1990), (1992a) and (1993)). And, as Chandler himself has recently argued, there are strict links between story and evolutionary theories (Chandler (1992b). While it is not possible to enter into the richness of the Chandlerian analysis here, let us just recall one of the main messages:

[. . .] it was the institutionalizing of the learning involved in product and process development that gave established managerial firms advantages over start-ups in the commercialization of technological innovations. Development remained a simple process involving a wide variety of usually highly product-specific skills, experience and information. It required a close interaction between functional specialists, such as designers, engineers, production managers, marketers and managers [...]. Such individuals had to coordinate their activities, particularly during the scale-up processes and the initial introduction of the new products on the market [. . .]. Existing firms with established core lines had retained earnings as a source of inexpensive capital and often had specialized organizational and technical competence not available to new entrepreneurial firms (Chandler 1993: p. 37).

As thoroughly argued by Chandler himself, this organizational dynamics can be interpreted as an evolutionary story of competence accumulation and development of specific organizational routines (Chandler (1992b)). The model has been further developed by incorporating the importance of the co-specialised assets of firms, analysed by scholars such as Teece, which are complementary to production and lie downstream from product-process development in the value-added chain. These also play an important role in stimulating technical change (a well-known example is that of the role of the distribution network of IBM in supporting the shift from typewriters to computers).

Did seemingly superior organizational forms spread evenly throughout the world? Indeed, the Chandlerian enterprise diffused, albeit rather slowing, in other OECD countries (Chandler 1990, Kogut 1992). However, the development of organizational forms, strategies and control methods have differed from nation to nation, because of the difference between national environments (Chandler 1992a: p. 283). Moreover, the diffusion of the archetypal M-form corporation has been limited to around half a dozen already developed countries (and even in countries like Italy, it involved very few companies, if any). Similar differences can be found in the processes of international diffusion of American principles of work organization- e.g. Taylorism and Fordism- (for an analysis of the Japanese case, see Coriat 1990).

So, for example, a growing literature identifies some of the roots of the specificities of the German, the Japanese or the Italian systems of production into their early corporate histories which carried over their influence up to the contemporary form of organization and learning (see Chandler 1990, Coriat 1990, Kogut 1993, Dursleifer and Kocka 1993, Dosi, Giannetti and Toninelli 1992). It is interesting to observe the "corporate trajectories" that have manifested themselves in some NIEs. To make a long and variegated story very short, in Korea it seems that the major actors in technological learning have been large business groups - the chaebols- which have been able at a very early stage of development to internalize the skills for the selection among technologies acquired from abroad, their efficient use and adaptation, and, not much later, have been able to grow impressive engineering capabilities (as discussed at greater depth in Amsden (1989), Amsden and Hikino (1993 and 1994), Enos and Park (1988), Bell and Pavitt (1993), Lall (1992), Kim, Westphal and Dahlman (1985)). Conversely, the Taiwanese organizational learning has rested much more in large networks of small and medium firms very open to the international markets and often developing production capabilities which complement those of first world companies (Dahlman and Sananikone 1990, Ernest and O'Connor 1989). For the purposes of this work, it is precisely these differences and the diverse learning patterns which they entail that constitute our primary interest.

This impressionistic list of stylized organizational patterns of learning could be of course very lengthy. For our purposes, it should be understood only as an illustration of the multiplicity of evolutionary paths that organizational learning can take. The fundamental point here is that the rates and directions of learning are not at all independent from the ways corporate organizations emerge, change, develop particular problem-solving, capabilities, diversify, etc. It is the core co-evolutionary view emphasized by Nelson (1994). In this view, it is straightforward to acknowledge also a bi-directional relation between market structures (as proxied by measures of the distribution of different characteristics such as firm sizes, innovative competencies, ownership, persistent behavioral traits, etc.) and patterns of technological learning. Different rates of learning influence the ability of firms to survive and expand and thus affect industrial structures. Conversely any particular structure - with its associated distribution of corporate features - influences and constrains what and how fast firms are able and willing to learn. Formal applications of this general idea are in Nelson and Winter (1982), Winter (1984), Dosi, Marsili, Orsenigo and Salvatore (1993).

5. Evolutionary industrial models

The presence of both a continuous turbulence in industry dynamics and a high degree of variety in the patterns they follow is presented in a recent assessment of evolutionary theorising by Dosi and Nelson (1993) as a direct consequence of the hypotheses concerning firms behaviour, which also determine the association of technological and organisational changes.

The literature on the role of innovation in the evolution of an industry, however, has long been based on a different perspective: a well-known dynamic model of such kind is that by Utterbach and Abernathy (1975). The industry life cycle model proposed in their study is developed on the basis of a relationship between both process and product innovation and stages of development of an industry. According to this model, innovations are firstly stimulated by market needs, with product development with the scope of maximising performance and process development still uncoordinated; in the second stage innovations are stimulated by technological opportunity, with product development with the aim of maximising sales and segmental process development; the third and final stage is characterised by innovations stimulated by production factors, with cost minimising product development and systemic process development. In this model, therefore, the locus of innovation, its type and the barriers to it change according to the stage of development of the industry, whereas the type of industry is not influential, so that technical change is implicitly hypothesised to have a uniform effect on all industrial activities.

In the classic evolutionary models by Nelson and Winter (1982) firms are seen as the central actors, and their essential characteristics are given by their capital stocks and prevailing routines. The relative superiority of a technology is determined by its profitability, in so far as it is able to generate profits and lead to capital formation and growth of the firm (Dosi and Nelson, 1993). Moreover, through the imitation by other firms such technology spreads and replaces less profitable ones. More recent models (Dosi et al., 1993) explicitly describe the existing regularities (in terms of size of firms, degrees of asymmetry in performance, rates of entry and exit and variations in market shares) in industrial structures as "emergent properties" deriving from non-equilibrium interactions amongst technologically heterogeneous firms. In particular, the selection criteria among firms are endogenous to the model, which is capable of generating, through simulations in which the system parameters describe learning processes and market selection, the aggregate dynamics empirically observed.

The problem of the processes giving rise to the diffusion of a technology have been investigated in Silverberg et al. (1988), in a paper which is focused on the phase of transition of an industry between two technological trajectories. Again, the diversity in firms' capabilities and expectations is at the centre of the diffusion mechanism; in particular firms make strategic investments which are characterised by the presence of uncertainty stemming from the prevision of what the future course of embodied technical progress will entail. The type of decisions which agents are hypothesised to take are the combined result of three behavioural assumptions with respect to the rules applied in decisions concerning pricing and production policy, replacement policy and expansion of capacity (more on these can be found in Silverberg, 1987). The choice which firms face is between two technologies, one of whom is superior in terms of productivity, but, as already shown in Atkinson and Stiglitz (1969) needs to be developed before being introduced, so that investment decisions, in the words of the authors, become "not merely a question of determining the best practice technology at any time, but one of weighing the prospects for further development either by acquiring experience with it now to gain a jump on competitors or waiting for a more opportune moment and avoiding possible development costs". In the investment choice which corresponds to the adoption decision the diverse firms characteristics and technological expectations are determinant, so that the diffusion of one technology is the outcome of such diversity. On the other hand, obviously, firm's characteristics will be transformed in the process, so that they become themselves endogenous.

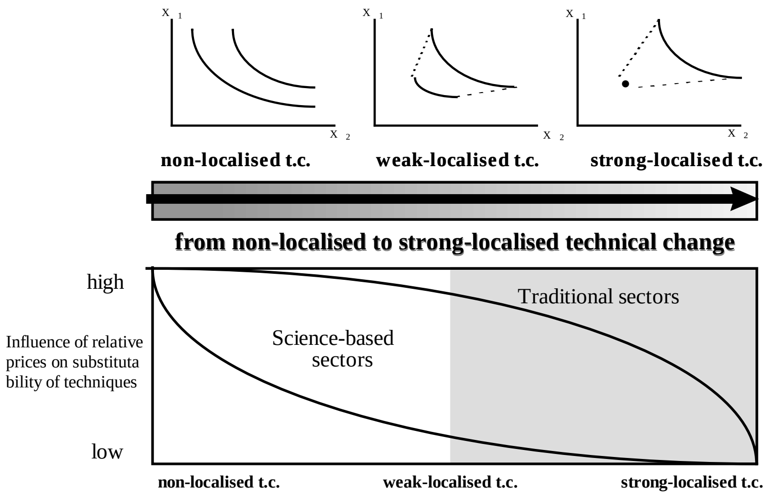
In their early contribution, Nelson and Winter (1982) also proposed a distinction between two different technological regimes following the two phases of Schumpeter's work: the entrepreneurial regime, favourable to innovative entry and the routinised regime, in which established firms perform the bulk of innovative activities (Winter, 1984). The first regime would also be associated with highly innovative industries, in which large firms are dominant, whereas the routinised would be characteristic of capital intensive, advertising intensive, concentrated and highly unionised industries. Audretsch (1996) observes that on the basis of this framework entry rates would be expected to be relatively higher in industries belonging to the entrepreneurial regime, whereas under the routinised regime, where innovations tend to be exploited within the existing firms, entry rates should be lower. Audretsch then makes four predictions concerning firm selection and industry evolution, namely that the likelihood of new-firm survival should be lower in industries exhibiting greater scale economies and under the entrepreneurial technological regime (but in both cases growth rates should be greater), and that such likelihood should be higher for larger firms (but growth rates should be lower) and in high growth industries (where growth also should be greater). In order to describe industry evolution under the two regimes, which according to this model is determined by the underlying technological conditions, the presence of scale economies and demand conditions, Audretsch (1996) uses two metaphors: that of the "conical revolving door", consistent with important scale economies and the routinised regime, and that of "the forest" which is applicable to industries in the entrepreneurial regime.

As we have repeatedly underlined, one of the building blocks of evolutionary thinking is constituted by the recognition of the specificities of technical change; according to Dosi (1988) one model of technical change, suitable to describe the characteristics of all sectors is simply not possible. Indeed, the peculiar characteristics of innovative processes historically observed in empirical studies of different sectors have brought Pavitt (1984) to the formulation of a taxonomy describing industry-specific models of technical change.

Pavitt identifies five sectoral patterns which allow the derivation of industry-specific models of technological change (an earlier version of Pavitt's taxonomy can be found in Pavitt, 1984): the supplier dominated sector (agriculture, services, and traditional manufacture), the scale intensive (consumer durables, automobiles, civil engineering, and bulk materials), the information intensive (finance, retailing, publishing, and travel), the science based (electronics and chemicals), and the specialised suppliers (machinery, instruments, and software). In the supplier dominated and information intensive sectors the main sources of technical knowledge are situated outside the firm. In the science-based sectors, instead, the main sources of technical advance are in-house R&D and basic science; in terms of the discussion presented in the previous chapter, this sector can be characterised as being of the late Schumpeter-type. The scale intensive, characterised by continuous processes, finds its main sources of technology in production engineering, production learning, suppliers and design offices, whereas design and advanced users are the sources for specialised suppliers; both sectors are characterised by conservative and very incremental processes and can be described as being more adjacent to the Schmookler-type (demand driven).

The peculiar features of each sector in terms of its technological characteristics can be combined with the issue of the influence that changes in relative prices possess on innovative activities. As already discussed in the presentation of the localised technical change model, and the view of the behaviour of individuals and organisations which lies at the heart of evolutionary theorising, changes in relative prices do have an influence on the directions of innovative efforts, but these remain constrained by the nature of the knowledge base of the particular activity, the physical and chemical principles it exploits and the technological system in which the activity is embodied. We wish to push the argument further, and suggest that it is in fact possible to express a relationship between the level of localisation of technical progress and the influence of prices on the substitutability among techniques. We therefore draw a representation of such relationship as it can be derived for different sectors, for example in Pavitt's taxonomy, and associate it with a graphic representation (upper part of the figure) of the varying types of technical progress (non-localised, weak localised, and strong localised) that correspond to increasingly localised technical progress in the part below of the figure.

Figure 3 Relative prices and technical change



This further step is based on the theory of production derived in section 2 (refer in particular to the representation of technical coefficients in figure 1 and the discussion presented there), and the problem of the influence of relative prices on substitutability among techniques (Atkinson and Stiglitz, 1969 and Vincenti, 1990), and aims at connecting these microfoundations with the sectoral characteristics of technical change which are now being presented.

Within a purely evolutionary perspective, even if it were possible to think about the start of a particular production activity facing non-localised technical change, given the behavioural assumption based on bounded rationality and the characteristics of the process of technical change, one would eventually observe a situation more akin to the one portrayed in the right half of the figure, where we find ourselves in that part of the continuum of degrees of localisation that varies between weakly and strongly localised t.c. In particular, non-localised technical change would be, in our perspective, the exceptional case, whereas the "real" situation would be represented over the second half of the continuum. If one then relates the influence of relative prices on substitutability among techniques with the situation described above, what emerges is a different behaviour, according to the sector one is looking at. The science-based sector is an example of a situation in which the influence of changes in relative prices over the choice of technique starts to decline in importance very early,. the traditional sectors' curve, instead, depicts a situation in which the influence of prices remains very important for production processes belonging to this group.

Walsh's (1984) analysis of changes in innovation during the stages of development of two subsectors of the chemical industry confirms both the general sectoral characteristics included in Pavitt's taxonomy, and the specificities of the subsectors evolution. Plastics seem to have at first followed an early-Schumpeterian pattern, in that the first plastics were primarily developed through the entrepreneurial activity of the inventors; later on, however, science and anticipated demand in large corporations played a major role, following the late-Schumpeterian model. The analysis of patents in dyestuffs, instead, produces contrasting results if either a solely quantitative, or also a qualitative analysis (i.e. trying to take into account the relative importance of the innovations) are performed: when only the first is carried out, a demand-pull model seems to emerge, when the second is taken into account, again there emerges an early-Schumpeterian pattern.

We have therefore seen how in general to different types of sectors there correspond different and specific modes in innovative processes. The most recent evolutionary studies, moreover, have tried to account for several of the peculiarities that are present in the evolution of industries. In the work by Malerba and Orsenigo (1996), the stylised facts characterising industry dynamics are summarised in: 1) the persistence of diversity among firms in capabilities, organisation, strategies and performance; 2) the presence of a high degree of turbulence, in terms of both entry and exit rates of firms in each sector, and changes in market shares of the existing firms; 3) the persistence of certain sectoral specificities, in particular the historically verified stability of a skewed distribution of both firm and plant size in manufacturing; 4) finally, the presence of regularities in the relationship between sectoral dynamics and rates and modes of technical change. This last observation lies behind the formulation of the taxonomy by Pavitt presented above and Malerba and Orsenigo, moreover, produce a more "restricted" taxonomy, which is based on the two stages in Schumpeter's work which have been briefly introduced earlier and the findings, also by Pavitt, relative to the size and principal activities of innovating firms: a "Schumpeter Mark I" group, characterised by the relative technological ease of entry in an industry, the major role played by new firms in innovative activities and the presence of a continuous erosion in competitive and technological advantages of the established firms in the industry (e.g. mechanical industries); and a "Schumpeter Mark II" group, in which there exist relevant barriers to entry for new innovators, large established firms prevail in innovative activities and a few firms which are continuously innovative dominate the sector, thanks to the accumulation over time of technological capabilities (e.g. chemicals and electronics).

6. Technological capabilities and production capacity in the process of development

During the last three decades, developing countries have shown increased technological dynamics associated with a subsequent development of their industrial structures, thus some significant technological progress did indeed occur in the NlEs. The evolutionary path of technological learning is related to both the capacity to acquire technologies (capital goods, know how etc.) and the capability to absorb these technologies and adapt them to the local conditions. In these respects, one has now a good deal of microeconomic/micro technological evidence highlighting the mechanisms that stimulate and limit endogenous learning in the NIEs. A number of empirical studies describe the increased technological capabilities which have developed in some developing countries over the last three decades, with some of them becoming exporters of technology (see Lall, 1982; Teitel, 1984; and Teubal, 1984).

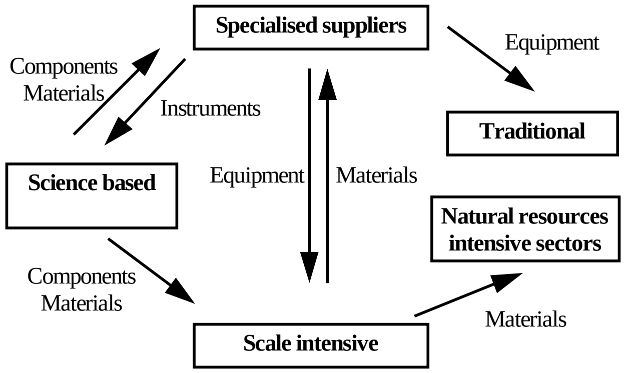
At the country level, however, in order to understand the process by which industrialisation takes place, a distinction is proposed between production capacity - embodied technology, labour skills, product and input specification, organisation- and global technological capabilities -the resources needed for the generation and management of technological change, knowledge, experience and institutional features, which have to do with the national system of innovation.

The analyses of increasing technological capacities which have taken place in the NIEs have revealed the crucial role of certain “core technologies” (in the past, electricity and electrical devices, nowadays also information technologies) which play an essential role as sources of technological skills, problem-solving opportunities and productivity improvements. These core technologies determine the overall absolute advantages or disadvantages of each country, in that they also imply infrastructures and networks common to a wide range of activities (electricity grid, road system, telecommunications and more recently the information network). There seem to be some patterns, albeit rather loose, in the development of a national production capacity. For example, practically every country starts with manufacturing of clothing and textile, possibly natural resource processing, and moves on - if it does - to more complex and knowledge intensive activities.

It is moreover possible to identify a pattern of industrialisation that evolves through the emergence of the sectors classified in Pavitt’s taxonomy. The initial stage in the development of a manufacturing sector is dominated by the supplier dominated and specialised supplier sectors, related to the transfer of foreign technology and in which various forms of incremental learning take place (use of equipment, development of engineering skills in machine and product adaptation and transformation). A second stage related to the emergence of scale intensive industries with new technological efforts focused on creating a technological synergism between production and use of sets of innovations (which gives rise to horizontal and vertical integration), the adoption of technologies associated with the exploitation of static and dynamic economies of scale, and finally the development of formal R&D complementary to informal learning. The final stage is that in which a science-based sector is created, in which the knowledge base is exploited economically through formalised search efforts, and R&D is the typical learning mechanism.

Among these sectors there exist input-output linkages which give rise to a wide set of externalities and interdependencies based upon communality of knowledge bases, complementarities, and technological spillovers. Such untraded technological flows are essential not only for the technological development of the enterprises involved, but for the whole industrial development at large. Figure 3 portrays some sources of technological linkages among the sectors described in the dynamic taxonomy.

Figure 4.Technological lows and sectoral specificiteis



Source: Guerrieri, 1993.

Specialised suppliers produce product innovation and capital inputs for the other sectors, whereas through the production of components and materials the science based generate positive effects which propagate to the whole system. All these linkages are fundamental for industrialisation, in particular those which establish themselves between the most innovative and the traditional and natural resources-based sectors. An application of this type of taxonomic dynamic analysis to the cases of some Latin American and Southeast Asian countries can be found in Cimoli (1990), and Bell and Pavitt (1993).

Sectoral learning patterns, however, are clearly nested into broader ("macro") conditions which exist at the regional and national level, such as those defining the educational system. For example, in "supplier-dominated" and "specialized supplier" sectors, a significant role is played by the levels of literacy and skills of the workforce, and the skills and technical competence of engineers and designers in the mechanical and (increasingly) electronics fields. In scale-intensive sectors, the existence of managers capable of efficiently running complex organizations is also likely to be important. In science-based sectors, the quality of higher education and research capabilities is obviously relevant. In particular the role of technology transfer as a source for the development of local capabilities has been extensively investigated: increasing technology flows towards developing economies have taken place, with a special emphasis towards Asian countries. The development of technological capabilities, which is at the centre of industrialisation processes, is related to both the capacity to acquire technology and the ability of absorbing and adapting it to the local environment. By looking at the nature and direction of learning at the firm level, it is possible to identify a few major activities through which such learning takes place. In particular, the modification of an adopted technology entails learning how to develop an adequate production capacity and how to adapt it to the local specificities; through these processes incremental innovation takes place, and, moreover, a specific pattern of technical change begins to take shape.

A significant body of literature exists explaining the importance of institutions and their role in economic and industrial development. In particular, regarding the Pacific Rim NIEs, the works by Amsden (1989), Wade (1990), Cantwell (1991) and many others help to understand how not only there exist institutional success, but institutional failure too. Bardhan (1996) analyses such issue as one of coordination, which has to be seen in terms of the interaction of distributive conflicts with state capacity and governance structure. The author suggests that the success of institutions in some NIEs (namely South Korea and Taiwan) has to be understood in terms of the capacity of establishing and applying rules of performance criteria, so that, for example, credit allocation by the state was tightly bound with export performance; in this way, international competition was used to foster internal learning. The following chapter will analyze in more detail these types of institutional successes and failures, and what they entail in the technological capabilities' vector framework proposed here.

7. An evolutionary view of national systems of innovation

Government intervention in the Latin American and the Pacific Rim NIEs played an essential role in industrialisation, but with opposite policies with respect to market orientation and specialisation. The Latin American NIEs have been characterised by production for domestic markets, whereas the Southeast Asian ones by export orientation and specialisation in manufactured commodities. In the latter group of economies, a particular emphasis has been put in the promotion of linkages across enterprises, often with the involvement of MNEs subsidiaries, with the scope of promoting a stable access to technology transfer and a fruitful mode of diffusion into the whole economy. Another essential aspect in the development of these countries has been that of human capital formation; the role in industrial development of the scientific and educational system, in particular, has been repeatedly underlined in the literature on the Asian NIEs, where it has been often indicated as a fundamental precondition to their success. On the whole, the general pattern of incentives defined by the existing institutions has accounted for the type of response to internal and external stimuli, which has determined the relative successes, and failures, of the NIEs. This pattern provides an example of the functioning of what is understood as the National System of Innovation (Freeman 1987, Lundvall 1993, Nelson 1993 and Edquist 1997) .

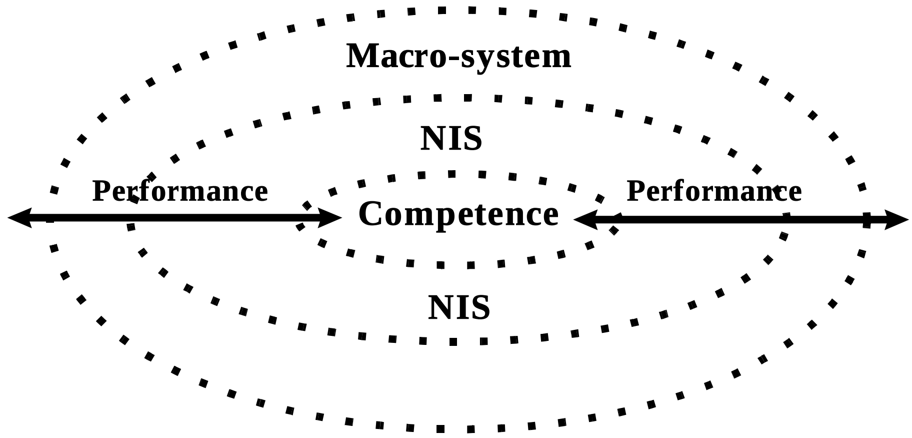
The specificities of national systems of production and innovation are seen as the joint outcome of the three levels of analysis presented in the present work: the firm level -in which firms are seen as repositories of knowledge embodied into their operational routines and modified through time by their higher level rules of behaviours and strategies-, the *meso-economic* level of networks of linkages between firms and other organisations both within and outside their primary sectors of activity -which enhance each firm's opportunities of improving problem-solving capabilities- (and, in as much as it can be interpreted as an externality or an economy-wide mechanism for the generation of knowledge, has been at the centre of new growth theories), and finally at the national level the set of social relationships, rules and political constraints into which microeconomic behaviours are embedded (which has been extensively studied, together with the first level, in evolutionary/institutionalist analyses) (Cimoli and Dosi, 1994).

Metcalfe (1995) provides a policy oriented definition of National Innovation System as a "set of institutions which jointly and individually contribute to the development and diffusion of new technologies and which provides the framework within which governments form and implement policies to influence the innovation process". He argues that the nature of each NIS is fundamentally shaped by both the division of labour and the peculiarities of information, which cause a predominance of co-ordination by non-market means. The institutions that compose them (private firms, universities and other educational institutions, public research labs, private consultancies, professional societies, industrial research associations) "make complementary contributions but they differ significantly with respect to motivation and to a commitment to dissemination of the knowledge they create".

In order to put together the components of the evolutionary account of the economic structure which has been developed so far, and therefore trying to provide a further step in the understanding of the process of technological change at the micro, meso and macro levels, we now propose the idea of a **vector of technological capabilities** (evolving in both time and space), defined by **competence** (that essentially refers to a firm's ability to solve both technical and organisational problems) on the one side and **performance** (as measured by variables such as competitiveness, and contribution to industrial growth) on the other. In between these two entities, and shaping their interaction (and therefore causing the magnitude of the span that exists between the two) lies the **national innovation system**, acting at both the national and regional levels and therefore possessing an inherently **local** nature.

The figure below represents the system defining the vector of technological capabilities at a given point in time and a specific country location, with permeable borders between micro, meso and macro levels, and with performance constituting the link which provides feedback from the other systems. This structure tries to put together the dynamics of each actor in the process and the inherently systemic properties of innovation mechanisms. The "state of a country at a specific point in time" recalls the mathematical notion of state of a dynamic system along one possible trajectory. The peculiarity of the type of systems we are interested in is that of being non-linear, which means that the study of the characteristics of a point along one trajectory will require linearisation of the system in a neighbourhood of such point (which we shall undertake below).

Figure 5: A point in the vector of technological capabilities defining the state of an economic system.



At the national level, the relevant competencies can be identified as those which pertain to the following groups: educational competencies (literacy rate, secondary and tertiary levels enrolment ratios, third level students in maths, science and engineering), R&D capabilities (scientists and engineers in R&D, R&D in GNP, ratio of private vs public R&D), technology transfer-related capabilities (direct FDI stock, imports of capital goods). At the system level, there exist some macro-level indicators of policy that, in our opinion, have to be viewed as both conditioning elements and results of the system's performance. The relevant variables, in this sense are: GDP per capita, population growth, exports as a percentage of GDP, average inflation rate, interest rates, real exchange rates.

In this framework, the possibility of institutional failures becomes incorporated into a broad structure that is able to account for the interactions among the principal agents in the process of development. The essential feature of this system is constituted by the interface between capabilities and performance and the role that the NIS plays in it as the wider representative of institutions (both public and private). Knowledge flows are embodied into individuals and their organisations, as stated above, and therefore it is obvious that the central part in the system be played by a collection of institutions.

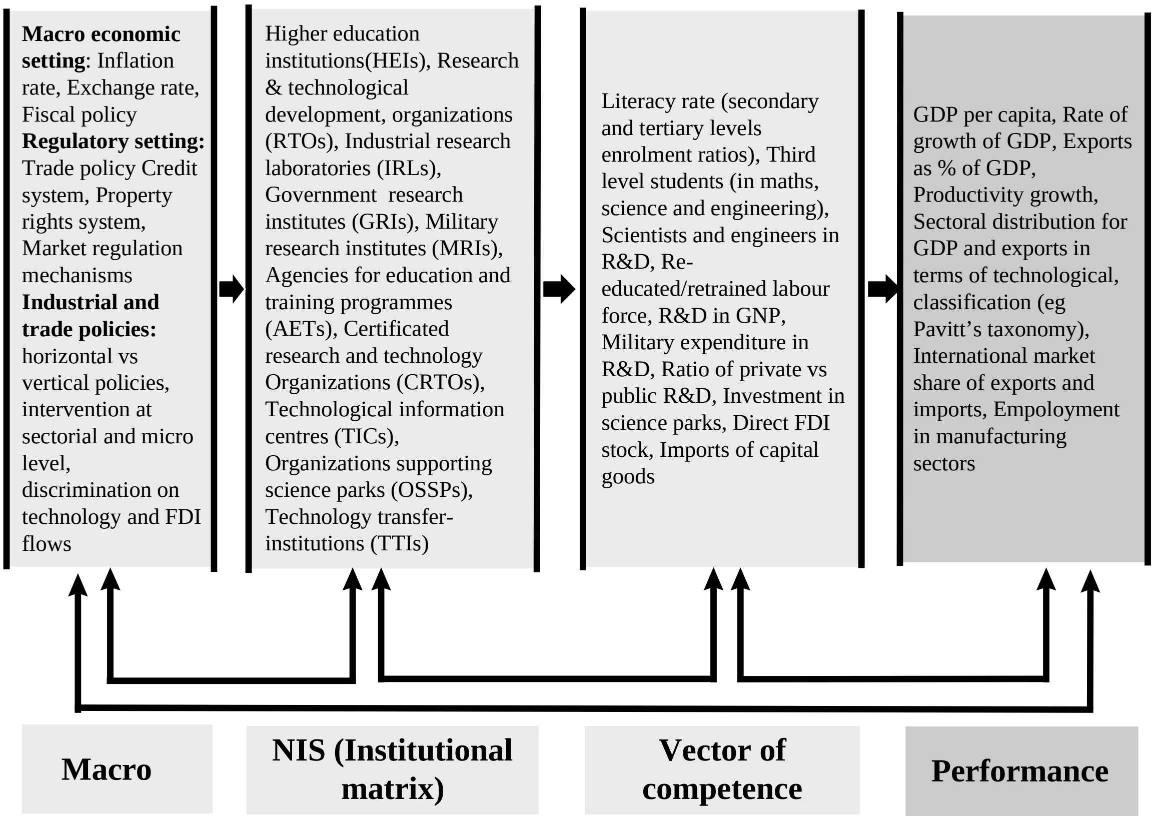
Moreover, by systematising the difference between competence and performance, it could also become possible to elaborate a concept of measurement of the "goodness" or "badness" of the NIS. Through the evolutionary microfoundations introduced above it is possible to explain why technological gaps among countries reproduce themselves over time due to the fact that individual behaviours (in response to the existing patterns of incentives and opportunities) produce suboptimal collective outcomes. In other words, the existence of diverse institutions and organisations and their modes of interaction determine specific national systems of innovation which over time present certain invariant characteristics which account for their phases of relative “technological success and failure” (Cimoli and Dosi, 1994). When organised appropriately, NIS are a powerful engine of progress; poorly organised and connected they may seriously inhibit the process of innovation (Metcalfe, 1995).

There also exist an international dimension given by MNEs strategies that provokes spillover effects of the technology policies of one nation on those of the others. On the other hand, the national unit is too large to understand the effects of the innovative process in a particular area: it becomes therefore important to focus on the appropriate unit of analysis, and therefore on distinct systems geographically and institutionally localised.

Going back to the particular type of mathematical representation we are using, the characteristics of our economy (a point along a trajectory produced by an unknown non-linear dynamic system) can be investigated by analysing the corresponding linearised system (in a neighbourhood of the point). At this stage, it is very important to underline that what we are interested in is the functional relationships among variables, and it is essentially to the estimation of these relationships, rather than to that of the coefficients of the individual variables involved, that the attention should be devoted.

Moreover, the idea is related to the identification of specific linkages that relate macro-setting, institutions, competencies and performances applying a different methodological analysis, which moves from the evidences contained in the historical case studies to the quantitative stimulation exercises introduced in the above sections. It is important to bear in mind that within this context the representation proposed here can be considered as an experimental approach where the relationships of a certain kind between technical change and economic performance are being analysed from a different perspective. Thus, for example, on the one hand, the intuitive hypothesis that improvements in the efficiency of techniques of production or in product performances may be a determinant, or at least a binding precondition, of growth in per capita income and consumption should be more extensively investigated. On the other hand, in a dynamic perspective, we can introduce the debate about the question on whether institutions and competencies supporting technical change are sufficiently adaptive to adjust to whatever underlying economic change emerges from market interactions, or conversely, whether they are inertial enough to shape the rate of direction of innovation and economic performance. In a broad sense, the idea proposed here is aimed at maintaining the concept of NIS anchored at a "macro-technological and institutional" container which enables an evaluation of innovative efforts and economic performance.

Figure 6: A simple representation of the interaction between competence and NIS.



In providing this tentative representation of the processes described above, we are aware of the oversimplification entailed by the implicit assumption that we are making; namely, that the vector of competencies and the matrix of NIS must be of compatible dimensions (i.e. to each component of competence should correspond a component of NIS), and that there still exists the problem of defining and measuring such components. The latter, furthermore, is complicated by the presence of all those informal types of relationships between organisations and institutions (and among both sets of actors) that in the standard literature fall under the heading of “externalities”. Clearly, further investigation will be required in order to provide a more solid base to this representation of our structure, nonetheless, we believe that the structure would provide a help in the understanding of the mechanisms by which NIS determine the success and failure of technological progress, and therefore the positioning of the vector of technological capabilities.

The matrix of the NIS is akin to the concept of “institutional matrix which supports and sustains the activities of innovating firms” proposed by Metcalfe (1995), and although the representation is linear, it must be borne in mind that this is so only for the sake of representation. The evolutionary foundations which account for the characteristics of national systems of production and innovation develop through to the ideas that firms are repositories of knowledge, that they are nested in networks of linkages with other firms and also with other non-profit organisations (networks which enhance the opportunities facing each firm to improve their problem-solving capabilities), and finally that there exists a broader notion (at a wider level of aggregation) of embeddedness of microeconomic behaviours into a set of social relationships, rules and political constraints (Granovetter 1985). Even at a properly micro level, the momentum associated with single technological trajectories is itself a largely social concept: "it points to the organisations and people committed by various interests to the system, to manufacturing corporations, research and development laboratories, investment banking houses, educational institutions and regulatory bodies" (Misa 1991: p. 15). And, in turn, these interests and institutions are sustained by the increasing-return and local nature of most learning activities. Even more so, at a system-level, the evolutionary interpretation presented here is consistent, and indeed complementary, with institutional approaches building on the observation that markets do not exist or operate apart from the rules and institutions that establish them and that "the institutional structure of the economy creates a distinct pattern of constraints and incentives", which defines the interests of the actors as well as shaping and channeling their behaviors (Zysman 1994: pp. 1-2).

Nations are characterised by particular modes of institutional governance which to a certain extent make them diverse auto-reproducing entities. Moreover, there exist an element of nationality which is provided by the shared language and culture, and by the national focus of other policies, laws and regulations which condition the innovative environment (Metcalfe, 1995). Together, they contribute to shape the organisational and technological context within which each economic activity takes place. In a sense, they set the opportunities and constraints facing each individual process of production and innovation - including the availability of complementary skills, information on intermediate inputs and capital goods, and demand stimuli to improve particular products. Institutional and technological diversities are seen in this context as the true determinants of development The processes described here are in fact inherently co-evolutionary (Nelson, 1992) in nature and therefore characterised by constant feedback mechanisms. Such feedbacks take place essentially between performance and competence, but the role of the institutional strategies remains essential in the process.

A few examples of how the system functions are provided by the historical studies contained in Dosi et al. (1990), that describe the mechanisms through which the NIS, by fostering R&D, enhanced the competencies of firms and industries that translated into better performances. The same type of relationship is also confirmed by the case studies recently conducted by OECD, that revealed the extent and types of collaborations between enterprises and the public sector research base (formal collaborations -such as commissioned research, joint R&D projects, co-patenting and co-publications-, informal transaction -informal contacts and use of published scientific knowledge-, spin-offs from universities, and transfer of technology to enterprises - patents and product developments). At a more specific level, and in particular by focusing on the education policy, another example of the relationship running through the NIS to enhanced competence and better performance is provided by the analysis of the Taiwan experience supplied by Nelson (1993) and Della Giusta (1996).

The system introduced applies at different levels of analysis: national, regional and local clusters [9]. The conceptual model introduced above allows us to define each cluster in terms of *"a set of innovative efforts (and technological activities) from which*

[9] According to Carlon and Stankiewicz (1995) and Edquist (1997) the systems of innovation "may be supranational , national or subnational (regional and local) - and at the same time they may be sectoral within any of these geographical demarcations".

it is possible to identify a vector of economic performance and approximate the interplay that exist between such efforts and performance". In a sense, the technological and innovative efforts could be approached by institutions and competencies (public and private) and the channels which allow the distribution of knowledge and, on the other side, the economic performance is identified for each specific cluster. Clearly, this goes very well together with the identification of different level of analysis, whereas we shall consider the anatomy and specificities of the following clusters:

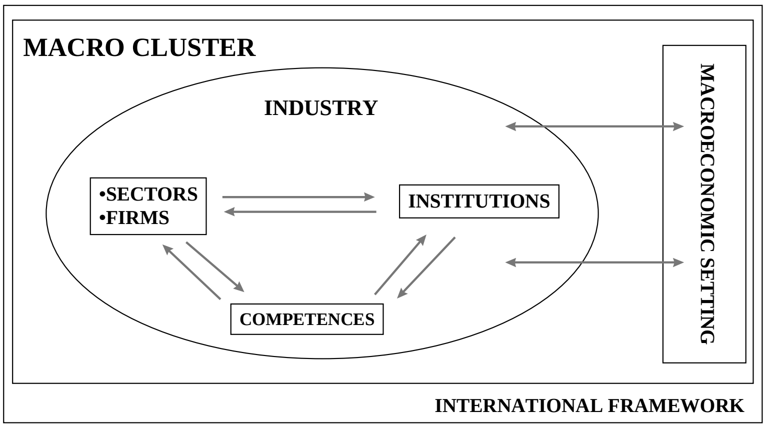
⇒ A macro-cluster containing industry and institutions at the national level where the analysis is mainly based on the industrial technological specificity, institutional matrix, competencies, knowledge diffusion process, macroeconomic setting and their interplay with economic performance at the national and international level. Here, the cluster covers the traditional concept of National Innovation System (Freeman 1987, Nelson 1993) and the main technological features that describe the whole industry within the national boundaries.

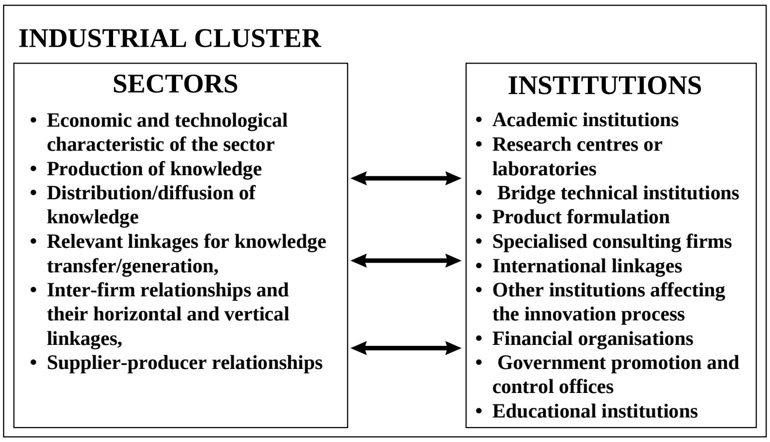
⇒ A meso-cluster with regional and sectoral level. The regional boundaries aim at the identification of an area where the specific institutional matrix, competencies and their interaction with the industry can be related to the generation of local economic performances. In a sense, the main emphasis is placed on a particular institutional matrix and competencies identified in an specific area. The sectoral cluster could be defined as a Sectoral Innovation System (SIS) identified as a "system (group) of firms active in developing and making a sector's products and in generating and utilising a particular sector technologies; such a system of firms is interrelated in two different ways: through processes of interaction and co-operation in artefact-technology development, and through processes of competition and selection in innovative and market activities" Breschi and Malerba (1996). In this cases, performance can be viewed as an effort dominated by local institutions and competencies localised at a regional level or, conversely, by sectors technologies. However, it is more frequent to identify performance as a result of the overlap of both regional and sectoral levels (for example, the auto industry).

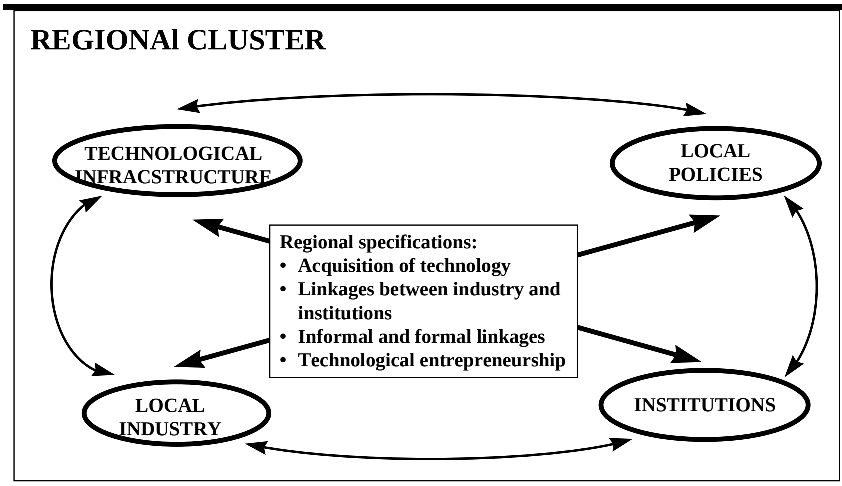
⇒ A micro-cluster with inter-firms and industrial districts levels. An interdependent system could result from the interaction of the regional and sectoral clusters. In this perspective, the empirical and theoretical domain to which this cluster can be applied is related to the interaction, co-operation and competition of firm’s activities developed in a specific region or area. In this context, the cluster is not necessarily related to a specific sector’s product and the system could be characterised by different firms localised at different point in the “value added chain”. In other to understand what this cluster is, think of the cases of the mechanical and textile industries and the interaction between them and the software and modern microelectronics industry in localised districts (for example, this is the typical setting of the Italian district, the Leon case in Mexico, Route 128 in Massachusetts and the phenomenon of the Sillicon Valley etc.).

Cluster Analysis

Level of analysis	Focus of analysis
a) Macro cluster: macro, industrial and institutional level	• Economic performance (International specialisation and competitiveness) • Sectoral specificities in terms of technological patters (Pavitt's taxonomy and others classification for the evaluation of different sectoral technological features) • Linkages between industries and inter industry flows of technology, (joint industry research) • Macroeconomic setting • Foreign technology • SIN-institutional matrix • Vector of competencies • Diffusion of knowledge between different actors (Patterns of patenting and licensing, co-patenting and co-publications across institutions - firms, universities, government research labs etc-, citations of patent and publications, personnel mobility, I-O flows, informal flows, etc.)
b) Meso clusters:	• Sectoral economic performance • Technological characteristic of



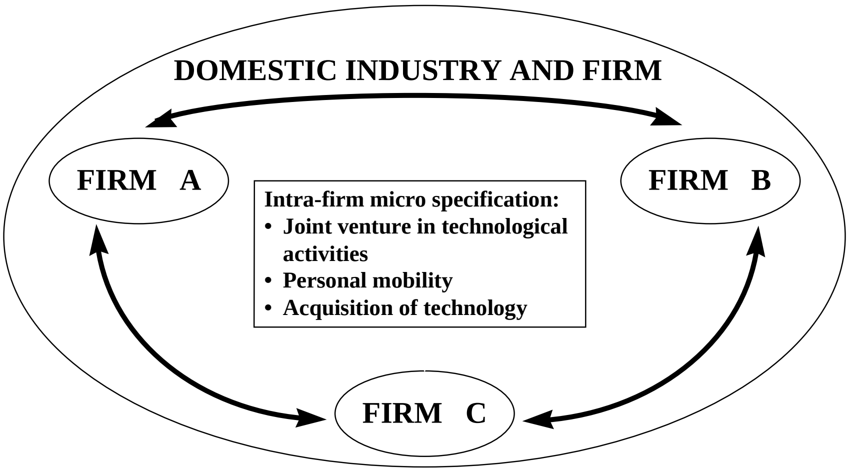
b1) Sectoral clusters 	the sector • Production of knowledge • Distribution / diffusion of Knowledge • Relevant linkages for knowledge transfer / generation, • Inter-firm relationships and their horizontal and vertical linkages, • Supplier-producer relationships • Industry- institutions relationships (Academic-industry relationships, research centres or laboratories, bridge technical institutions , product formulation, specialised consulting firms, international linkages, other institutions affecting the innovation process, financial organisations, government promotion and control offices, educational institutions)
b2) Regional clusters	• Economic performance (regional competitiveness and composition in terms of technological patterns • Linkages between industries • SIN-institutional matrix • Vector of competencies • Acquisition of foreign technology • Linkages between industry and Institutions



- Informal and formal linkages
- Technological entrepreneurship

c) micro clusters:

micro firm linkages



- Identification of the inter-firm micro cluster in the context of the industrial districts analysis
- Production- distribution and diffusion of knowledge (horizontal and vertical)
- Joint ventures in industrial districts
- Personal mobility
- Acquisition of technology

8. Conclusions

The NIS concepts recently introduced could be view as "new full boxes" where the main features that define technology, technical change and their interplay with economic performance seems to disappear in the jungle of thousand ad one elements and interactions adopted to analyse the innovation systems. In the course of the present paper, by building on the microfoundations provided by the evolutionary theory of technical change, we have tried to conduct the reader to the concept of national, local, sectoral and micro system of innovation. In a sense, the subject was related to develop more the roadmap that link the microfoundations of technical change and the system-performance conjectures.

The aim of the paper has been also that of demonstrating a fundamental proposition, and namely that the concept of NIS is based on a consolidated body of theory (Nelson, 1993, among others) and therefore cannot be conceived of as something new, and that this concept is essential in order to understand economic and development performances. Thus, again by explicitly referring to the evolutionary perspective, one observes that the concepts analysed in the previous sections as paradigms and trajectories, which stem from the specific and cumulative nature of technology, have been related to the consequences derived from the existence of localised technical change. A general property, by now widely acknowledged in the innovation literature, is that learning is local and cumulative. Local means that the exploration and development of new techniques is likely to occur in the neighbourhood of the techniques already in use and within a specific institutional framework. Cumulative means that current technological development- at least at the level of individual business units and other institutions- often builds upon past experiences of production and innovation, and it proceeds via sequences of specific problem-solving junctures.

The importance of the institutional dimension for evolutionary theories of production and innovation should come as no surprise, supported by a growing evidence from both micro and macro patterns of technological change. After all, at the micro level, technologies are to a fair extent incorporated in particular institutions, the firms, whose characteristics, decision rules, capabilities, and behaviours are fundamental in shaping the rates and directions of technological advance. In turn, firms are embedded in rich networks of relations with each other and with other institutional actors- ranging from government agencies to universities etc.... Secondly, a major element mentioned earlier linking microeconomic learning with national patterns of development is the embeddedness of the thread of incentives, constraints, and forms of corporate organisation into the broader institutional framework of the political economy of each country.

For our purposes, let us just mention that the micro- and meso-economic theoretical building blocks sketched above and drawn from an evolutionary perspective are in principle consistent with broader institutionalist analyses of national systems of production, innovation and governance of socio-economic relations. Moreover, the emphasis on patterned and local learning, and bounded rationality assumptions, go well together with the view of political economists and sociologists of development according to which a major ingredient of development is the process of change in social norms, expectations and forms of collective organisation.

Moreover, the analysis forced us to concentrate much more on the interplay between innovation system and economic performance. This concept can serve as an instrument for envisaging a set of policies directed at competitiveness and growth, when this is understood as something that does not just have to do only with prices, but is also the product of innovative processes which possess the peculiar characteristics extensively discussed here in terms of macro-setting, institutional matrix and vector of competencies. In providing a tentative representation of these blocks and their linkages, which require further investigation to provide a more solid base, we believe that this approach would provide a help in the understanding of the mechanisms by which NIS determine the success and failure of technological progress.

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