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1. Introduction[1]

The growth of modern economies has been characterized by the emergence, development and decline of different industries. Moreover, industrial evolution is characterized by intense change, at any time scale which might be considered. New firms enter the industry, some exit; some firms grow, other decline. In addition, economic entities expand or contract their boundaries and undergo organizational change

These remarks have been advanced by several economists in the past. Both Alfred Marshall and Joseph Schumpeter, although in different ways, focused their attention on the internal dynamism that occurs within any one industry. Moreover, in the Principles of Economics (1890) and the Economics of Industry (1879) Marshall noticed that an economy is characterized by quite different sectors, some of which are fast growing while others are declining and that their specific relevance for the overall economy may change over time. This point was greatly emphasized also by Schumpeter in "Business Cycles" which contains a lenghty and articulated discussion of the emergence and decline of leading industries in the development of the industrial economies of the past centuries. Simon Kuznets noticed also in "Secular Movements in Prices and Production" (1930) that economic growth is characterized by shifts in the relative importance of leading industries which show life cycles in terms of sales and innovations. Colin Clark reaffirmed this point at a more aggregated level in "Conditions of Economic Progress"(1940) by linking the stages of economic growth to the rise and decline of major sectors such as agriculture, manufacturing and services, while Hollis Chenery in his "Patterns of development:1950-70" analyzed the structural characteristics of the economy by grouping industries in early, middle and late ones. Finally W.W.Rostow in "The Process of Economic Growth" (1952) and "Stages of Economic Growth" (1960) pointed to the fact that there are regularities in the dynamics of industries, which usually starts with a take off and then moves to technological maturity, usually associated with high mass consumption.

Most of these authors had in mind a broad dynamic qualitative analysis of the emergence, development and decline of industries, jointly with the consideration of the turmoil generated by competition in the shorter run. They never entered into the details of how industries change over time in terms of their structural features and forms of organization, but they certainly set up the stage for possible subsequent studies of the factors affecting the structural evolution of industries: think, for instance, to Schumpeter's "Capitalism, Socialism and Democracy" (1942).

These studies did not take off and the insights of Marshall, Schumpeter and Kutznets about industrial dynamics were not developed. During the 1950s, 1960s and 1970s industrial economists concentrated their efforts on the static analysis of the structure of industries: in those years industrial economics became concerned with the explanation of the determinants of features of industrial structure and performance, such as concentration, firms size and profitability. The pioneering contributions of leading industrial economists such as Mason and Bain and the so called "Harvard Tradition" in industrial organization during the 1960s and 1970s emphasized the importance of some relatively invariant features of production technologies as ultimate determinants of observed structures and performances under the implicit assumption that microeconomic behaviours would be shaped - at least in a first

[1] The ideas presented in this paper owe a great deal to the conversations and discussions we have been having at different times and in different places mainly with Giovanni Dosi, David Lane, Richard Nelson and Sidney Winter. Indeed, in various cases, they have actually suggested them. Whilst we fully acknowledge their fundamental contributions, we strongly emphasize that the usual disclaimers and caveats have to be taken very seriously in the present case.

approximation - by these deeper technological constraints. A most notable exception in this respect has been Stigler's analysis of the determinants of vertical integration during the growth of an industry.

During the 1980s the interpretative focus of the "New Industrial Organization" shifted to the motives and the rational decision procedures of individual agents. Symmetrically, structural constraints on microbehaviours have been treated in rather casual manners.

Despite these profound differences, however, these two opposite archetypes, the structuralist approach of the 1960s and 1970s and the contemporary game theoretic models of industrial economics, have both a static and equilibrium flavour. In the former, the burden of the interpretation of empirical regularities is pushed upon unexplained features of sectoral production functions. In the latter, the core of the exercise is an ex-post generalization showing that whatever is observed can also be interpreted as the equilibrium outcome of some (rather sophisticated) strategic interactions.

Most of the hints and suggestions of Marshall, Schumpeter and Kutnetz implicitly pointing to a better understanding of the dynamics and evolution of industries have been left undeveloped in current theoretical models. Recently however, empirical research has uncovered a large number of stylized facts about industrial dynamics and evolution which fit uneasily with the structuralist or the game theoretic explanations. In recent years the development of detailed histories of specific industries in terms of technological innovation and structural change and the growing availability of large longitudinal micro data-bases have significantly improved economists' data and knowledge, at the same generating new questions and puzzles.

Some of these questions about industry dynamics have also started to be addressed by theoretical models. Still, these models address only specific aspects of industry evolution. More substantially, we still do not know much about the dynamics and evolution of industries as a whole. The debate on "long waves" is possibly the only recent example of studies concerning the long-run properties of the evolution of industries. But still, our knowledge is extremely limited, particularly as it concerns the patterns of change of economic organizations and structures, not only as in terms of entry and exit of firms and firms' growth but also in terms of vertical integration, diversification, creation and closures of relationships and networks among firms and changing role of institutions.

In this paper we aim to shed light on what we know about this issue. We will discuss the scattered empirical evidence, the major stylized facts, the current explanations and the relevant unanswered questions concerning the dynamics and evolution of industrial structure. We will also point to possible directions of future research.

We shall distinguish between three levels of analysis which can be found in the theoretical and empirical literature:

a. specific structural dimensions of industrial dynamics;
b. structural dynamics according to the life cycle model;
c. industrial structural evolution.

The first level refers to specific features of industrial structures such as industrial demography, firms' growth and size distributions, persistence in asymmetric performances at the firm level. The second refers to the dynamics over time of several structural variables examined jointly: entry, exit, firm size and concentration as well as product and process innovation. The third refers to a broader view of industrial structure and its evolution over time. In addition to the dimensions examined in the life cycle model of industry dynamics (entry, firm size and industrial concentration), industrial structural evolution includes and focusses on the emergence and transformation of technologies and products within an industry, on the changing boundaries of established firms, on firms' growth, vertical integration and diversification, on the relationships among firms. and on the role of institutions others than firms within an industry (government, scientific and financial institutions, suppliers and users).

In the paper we will argue that whilst a large part of the scattered empirical evidence on the evolution of industries refers to structural evolution, we have almost no empirical generalizations, taxonomies or theories on how industries evolve over time. In the last section we will therefore discuss some conceptual and methodological problems that arise from the attempt to analyze structural evolution. We advance the view that the explanation of this phenomenon requires major empirical advances in our knowledge of industry dynamics and evolution.

2. Specific structural dimensions of industry dynamics[2]

Empirical research has uncovered over the years a large number of stylized facts.

a) persistent significant diversity within and across industrial sectors in firm behaviour, organization and performance;

b) significant degrees of turbulence in industrial dynamics;

b) sectoral specificities in industrial dynamics;

c) regularities in some aggregate statistics describing industrial structures, despite such variability at the microlevel.

Let us briefly illustrate some of the major and best known examples of this kind of evidence.

2.1 *Persistence of diversity among firms*

One may start from the naive observation of high degrees of heterogeneity in firms capabilities, organization, strategies and performance. These differences concern significant differentials in costs and productivity (Nelson and Winter 1982, Baily 1987, Contini and Revelli 1990); profitability (Mueller 1990, Geroski and Jacquemin 1988); output and innovative activities (Freeman 1982, Jaffe 1986, Griliches 1986, Patel and Pavitt 1991, Malerba, Orsenigo and Peretto,1994).

What is particularly puzzling, however, is not the existence of such diversity, but its persistence over time. For example, as far as innovation is concerned, firms which have innovated at time t have - ceteris paribus - a higher probability of innovating at time t+1 (what is known in the literature as

[2] This section draws heavily from Dosi, Marsili, Orsenigo and Salvatore (1993) and from Dosi, Malerba and Orsenigo (1993).

cumulativeness). The same applies to profits: firms enjoying higher (lower) profits are expected to earn higher (lower) profits also in the future. That is to say, profits don not seem to converge to a common rate of return.

Persistence in innovative and profitability differentials may reflect either (or both) the persistence of differential technological capabilities and productive efficiencies which are not eroded away by the competitive process or the sluggishness of imitation and competitive processes. The evidence available does not provide a definite answer to this question. Persistence seems to characterize firms' innovative activities in several technologies (Malerba, Orsenigo and Peretto,1994). As far as profits are concerned, it tends to suggest that the adjustment of profits to their firm-specific "permanent" values is rather quick, although a significant variability is observed across different countries.

2.2 *Turbulence*

Several studies have now shown that all industries are characterized by high degrees of turbulence, due to entry, exit and changes in market shares (Beesley and Hamilton 1984, Acs and Audretsch, 1989, 1990, 1991).

In particular, gross entry is a pervasive phenomena. Birth rates are quite high, even in industries characterized by high barriers to entry (for example, high capital intensity). Most entrants are new small firms, far below any measure of efficient minimum scale. However other entrants are firms operating in other industries or countries which engaged into a process of diversification. In this case, entry often occurs through the acquisition of existing plants. The role of this second type of entry is limited in terms of number of firms. but much more important in terms of share of output or employment.

Mortality however is high too, so that turbulence (entry and mortality) is significant but the rates of net entry are much smaller than gross entry. In general, a large percentage of the entrants exits the industry within few years after entry and the probability of survival appears to increase with age. Finally, it must be noted that surviving firms have either a higher initial size or higher growth rates. Bigger initial size implies lower growth, but higher survival. (Dunne, Roberts and Samuelson 1988, Baldwin and Gorecki 1991, Cable and Scwalbach 1991, Acs and Audretsch 1991 and 1992, Phillips and Kirchoff 1989, Audretsch and Mahmood 1992, Geroski and Schwalbach 1991).

An interpretation of this evidence is that turbulence is primarily a characteristic of the fringe of each industry. This seems corroborated by the observation that substitution of "old" firms with "new" firms occurs to a much larger extent among small, young firms which are relatively similar to each other. In other words, entrants in the fringe are usually not more efficient than the incumbents. Turbulence appears to be much lower in the core of the industry and among large firms: large firms appear to be relatively sheltered from selective pressures (Levinthal 1991). This is confirmed for the innovative activities of the core and the fringe of firms within industries (Malerba-Orsenigo,1994).

2.3 *Firms growth and stable skewed distributions of firm size*

The observation of the stability of a skewed distributions of both firm and plant sizes in manufacturing - approximately a Pareto distribution - over all the history for which data can be estimated is certainly one of the best known "stylized facts" in industrial economics. This phenomenon has been usually accounted for by some version of Gibrat's Law of proportionate growth. In its simplest formulation, this "Law" states that firms growth rates are i.i.d. random variables independent from size. The Law generates log-normal (or under suitable modifications, Yule or Pareto distributions) of firm size (Ijiri and Simon 1977, Simon and Bonini 1958).

However, the evidence about the Gibrat process is mixed. It mostly tends to reject it or to restrict its applicability to particular size classes. In particular, recent studies show that both firms' growth rates and their variance tend to fall with size and age (Hall 1987, Evans 1987a and 1987b), whilst Acs and Audretsch (1991) find some corroboration for the Gibrat's Law by including in the sample also firms exiting the industry. In any case, Gibrat's Law seems to be better suited to describe the growth process of relatively big firms (Geroski and Machin 1992).

2.4 *Sectoral differences in the specific structural dimensions of industry dynamics*

Whilst the above mentioned phenomena constitute rather general characteristics of industrial structures, at a finer level of disaggregation one finds significant differences across sectors; Indeed it is worth stressing that intersectoral differences are bigger the more disaggregate the observations on industrial structures are. At the static level, sectoral differences in some dimensions of industrial structure are the very essence of industrial economics. And nobody would seem to be unduly surprised by the consideration that industries differ a lot also in terms of advertising intensity, capital intensity and so on. Sectoral specifities, however concern also the persistence of diversity across firms, turbulence and firms' growth.

Persistence of profits appears to depend on industry- specific characteristics as well as on firm-specific characteristics. In particular, industry-specific features as the intensity of advertising and R-D appear to be robust explanatory variables of the persistence of profits above the norm. Empirical evidence is rather fuzzy as it concerns the effects of industry- and firm-specific variables of the speed of adjustment. Important differences among countries and industries emerge in both the extent to which profit differentials permanently persist and in the speed of adjustment to "equilibrium". In general, however, firm-specific variables are more important in explaining the long-run "equilibrium" levels of company profits, whilst industry-specific variables are more important in the explanation of the adjustment process to those long-run equilibrium values. In the U.S.A., excess returns appear to erode more slowly in highly concentrated industries, experiencing rapid demand growth, and characterized by significant economies of scale, large absolute capital requirements, large sunk outlays and high advertising expenditures (Kessides 1990). (Other studies, however challenge these results, cf. Odagiri and Yamawaki 1990).

Turbulence differs drastically across sectors, too. The econometric literature investigating the determinants of birth rates is now burgeoning. It is now possible to draw some consistent results.

Turbulence tends to be comparatively lower in industries characterized by high rates of innovation and advertising, high capital intensity, low concentration, low growth (Acs and Audretsch 1991).

However, one has to distinguish between the determinants of gross entry, exit and net entry, and between large and small firms. In particular, advertising appears to constitute a greater barrier than capital intensity to both gross and net entry, irrespectively of firm size. Concentration seems to inhibit entry of small firms but not of large companies. Similarly, high rates of innovation do not necessarily deter small firms from entry. In certain industries, in which small firms account for a significant share of total innovative activities, birth rates are rather high.

Evidence is less clear about the role played by variables like industry growth and profitability. The latter variable does not seem to have any significant effect in attracting entry, whilst mixed results are obtained for industry growth. Similarly, the growth of GNP (but also unemployment) appear to trigger new firms formation. In any case, there appears to be no robust evidence about the cyclical behaviour of birth and death rates. Some studies report strong correlation between indicators of favourable macroeconomic conditions, birth rates (positive) and death rates (negative). Other studies however find absence of correlation or even inverse correlation (as in the models of self-employment).

The probability of survival of new, small firms appear to be lower in capital-intensive industries, and in sectors characterized by high rates of innovation and high economies of scale. However, further distinctions need to be made. Concentration, scale economies and capital intensity actually seem to facilitate survival in the short run, but not in the long run. Indicators of innovativeness do not affect survival in the short run, but only in the long run. Moreover, survival is also easier in those industries in which small firms are important sources of innovation.

New surviving firms tend to grow faster in innovative industries. Scale economies and capital intensity have a positive effect on growth in the short run: surviving firms tend to grow faster in the early periods, but afterwards those disadvantages do not matter.

In sum, capital-intensity does not affect entry but survival and thus turbulence. Surviving firms appear to grow faster as a function of the gap between minimum efficient scale (MES) of output and firm size. At the same time, however, the likelihood of survival decreases as a function of that gap. The same happens in terms of innovation rates. Thus, factors promoting growth reduce survival and vice-versa. An exception is the industry growth rate, which has a positive effect on both growth and survival.

Finally, sectoral specificities appear to affect the processes of firms' growth too. For example, in one of the few recent studies which lend some support to Gibrat's law, Acs and Audretsch (1990)- find that growth rates are significantly different across firms-size classes in about 40% of the industries considered in their sample.

2.5 *Regularities and taxonomies of technological change and industry dynamics*

One of the major results of the empirical studies on industry dynamics has been the discovery of a relationship between the dynamics of an industry to the rate of technological change (Nelson and Winter,1982; Rosenberg,1982; Levin, Cohen and Mowery, 1985).

In this respect, the empirical evidence has also shown that technological change proceeds differently in terms of rate, type, direction and effects across technologies, industries and over time. Such diversity concerns the sources of innovation, the organization of innovative activities and the set of competences involved in the innovation process.

For instance, a first attempt to put some order in such diversity is Pavitt's taxonomy (Pavitt 1984) of the patterns of organization of innovative activities and features of technological change. Pavitt distinguishes between:

-science based industries, in which R&D and learning by searching are key elements in firms innovative activities. The structure of the industry is characterized by large oligopolistic firms with advanced and often diversified competences (the core of the industries) and in several cases also by small new (the fringe). Major as well as incremental innovations are frequent. Technological trajectories may involve the increase in the performance and the physical properties of products, as well as the improvements in process yields.

-scale intensive industries, in which scale economies and productive features play a relevant role in competition among firms and in shaping the structure of the industry. Learning by doing and by using, as well as R&D, play a major role in the innovative activities of firms. The structure of the industry is characterized by large firms, usually upstream vertically integrated, with long term relationships with equipment suppliers. High barriers to entry are present. Production and engineering competences play a major role in affecting competition among firms. Both process and products innovations are important. At the process level, technological trajectories are focussed on the improvements of process yields, increases in the scale of production processes and automation.

-specialized supplier industries, in which firm competences in development, engineering and design, and the ability of adapting and tailoring products to user needs, are highly idiosyncratic and mostly tacit. They generate products aimed at specific applications, market segments or single users. Interactions with users are relevant in the innovative process, and give a relatively high appropriability of product innovations. The structure of the industry is often made of small and medium size firms, highly specialized (or at the most diversified in correlated applications or market segments). Product innovations, mostly of the incremental type, are common. Technological trajectories relate to improvements in the performance and reliability of products.

-supplier dominated industries, in which innovative activity is rather limited (mainly of a learning-by-using and -doing type), centered on incremental improvements and adaptation of new capital equipment, which have been developed and produced by upstream suppliers. The rapidity in adopting new technologies rather than the generation of new processes and products, becomes a key element in the competitive process. This implies that the speed of diffusion rather than technological innovation itself becomes crucial in industrial dynamics. Firms in the industry are of small and medium size. Technological trajectories are aimed at improvements in process yields.

At a different level of analysis, another taxonomy concerns the patterns of innovative activity according to some typical learning patterns of firms over time. Malerba and Orsenigo (1994a and b) find it convenient to classify them on the grounds of the two Schumpeterian models of innovation: Schumpeter Mark I (Schumpeter 1912) (characterized by technological ease of entry in an industry, by a major role played by new firms in innovative activities and by the continuous erosion of the competitive and technological advantages of the established firms in the industry) and Schumpeter Mark II (Schumpeter 1942) (characterized by relevant barriers to entry for new innovators, by the prevalence of large established firms in innovative activities and by the dominance of few firms which are continuously innovative through the accumulation over time of technological capabilities). Their empirical analysis of the patterns of innovation in Europe, Japan and the United States shows that a significant similarity is observed in the sectoral patterns of technological change across countries and that indeed one can classify most technological classes in this way. For instance, empirical investigation suggests that systematic differences in the patterns of innovative activities can be found in the three main technological families: chemicals, electronics and mechanics. Chemicals and electronics seem to have the characteristics of the "Schumpeter 2" model, whilst mechanical industries seem to show a "Schumpeter 1" model.

Empirical research provides some further indications towards a preliminary interpretation of these phenomena. In particular, the economics of innovation suggests a few useful concepts in this respect.

First, innovation studies have started to disentangle the plausible idea that innovative activities are to be analyzed as a complex learning process. activities in an industry are heavily affected by the nature of what has been termed technological regimes. The notion of technological regime dates back to Nelson and Winter (1982) and provides a description of the technological environment in which firms operate. More generally, Malerba and Orsenigo (1990 and 1993) have proposed that a technological regime is a particular combination of opportunity and appropriability conditions, degrees of cumulativeness of technological knowledge and characteristics of the relevant knowledge base. Opportunity conditions reflect the easiness of innovating for any given amount of money invested in search. High opportunities represent a powerful incentive to the undertaking of innovative activities. Appropriability condititions summarise the possibilities of protecting innovations from imitation and of extracting profits from innovative activities. Cumulativeness captures the properties that today innovations and innovative activities form the starting point for tomorrow innovations and that today innovative firms are more likely to innovate in the future in specific technologies and along specific trajectories than non-innovative firms. Technologies differ also in terms of the characteristics of their knowledge base. The knowledge base can be primarily tacit, local and firm-specific or rather codified and "universal" and thus relatively more easy to get access to. Similarly, the relevant knowledge base may show varying degrees of complexity because innovations may require the integration of different scientific disciplines and technologies, and because innovative activities may be fed by the contribution of a variety of competences concerning the production process, the nature of markets, the features of demand and so on. Some of these competences may be external to the firms in the industry and may derive from e.g. suppliers of materials, equipment producers, users, universities and government laboratories and so on.

The notion of technological regime has indeed proved to be useful in providing a framework for interpreting a substantial body of empirical evidence on firms organization and strategies (Malerba and Orsenigo 1993) and on the sectoral patterns of technical change and industrial structure. The introduction even of rough proxies of opportunity and appropriability conditions significantly improves the performance of econometric tests on the relationships between market structure (e.g. firm size and degrees of concentration) and innovation (Cohen and Levin 1991). Malerba and Orsenigo (1990) show in the case of Italy that "Schumpeter Mark I" sectors are characterized by high opportunity and low appropriability conditions, which favor the continuous entry of new innovators in the industry, and by low cumulativeness conditions, which do not allow the persistence of monopolistic advantages in the industry by any one innovator. "Schumpeter Mark II" patterns are determined by high opportunity, high appropriability and high cumulativeness conditions, which allow innovators to incrementally accumulate technological knowledge and capabilities and to build up innovative advantages over non-innovators and potential entrants.

The notion of technological regime can also be employed to account for the size distribution of firms at the industry level as well as for differential patterns of turbulence. Indeed, insofar as innovation is a primary force of firm growth and industrial change, there ought to be a direct link between technological regimes and the patterns of industrial evolution. For instance, following Gort and Klepper (1982) and Winter (1984), Acs and Audretsch (1991) argue that sectoral differences in the patterns of entry and exit, in the relationships between size. age, growth and survival - and therefore, on firm size distribution - are to be accounted for by the nature of the relevant technology, defined in terms of accessibility of technological knowledge by firms external to the industry as opposed to incumbents. Acs and Audretsch find indeed econometric evidence that turbulence is higher and survival rates of young firms are lower in industries characterized by an "entrepreneurial" as opposed to a "routinized" technological regime. The latter is defined, following Winter (1984) as a technological environment characterized by high degrees of cumulativeness, appropriability and tacitness of the knowledge base.

2.6 *Intercountry comparisons*

Finally, even more interesting than simply considering the existence of sectoral differences in the patterns of industrial dynamics, is the further observations that the patterns of intersectoral differences look quite similar across (industrial) countries. For traditional variables of industrial structure such as concentration and advertising this remark has been made already by Sutton 1991. As far patterns of innovative activities are concerned, Malerba and Orsenigo (1994a and 1994b) found major similarities in the pattern of innovative activities of a speficic technology in the United states, Europe and Japan.

2.7 *Implications and Problems*

Each of the empirical regularities discussed above are puzzles for the theory in their own right. The more so, if one tries to make sense of all of these facts simultaneously. For instance, the evidence on the sectoral specificities in the patterns of innovation and turbulence and on the persistence of differential innovative performance and profitability over time clearly contrasts with an explanation of the stability of firm size distribution based on some version of Gibrat's Law, whereby independence of the variance of growth from initial size is assumed. Similarly this last assumption is clearly at odds with the reported evidence on the relationship beween size and age on the one hand, growth and survival on the other.

In very general terms, these puzzles have to do with some major anaytical questions, namely:

-The "driving forces" of firms' growth? Are they small, multiple and temporary shocks? Or conversely, can one identify deeper, more persistent factors?
-Microheterogeneity and invariances in aggregate statistics. For example, how does one reconcile the observations on persistent diversity among firms with that of relatively stable Pareto-type size distributions? More generally, what kind of processes lead to such aggregate regularities on the basis of such messy microdynamics?
-Cross-sectional variety in industrial structures and dynamic patterns. What does determine these observed differences? Can one find some underlying variables which shape different dynamic patterns? And what is the degree of detail in the description of industries (agents, technology, demand, etc) that is necessary for providing a satisfactory account of both similarities and differences across sectors?

3. The industry life cycle model: technological change and structural dynamics

3.1 *The industry life-cycle (ILC) model*

A second level of analysis to which industrial economists are interested goes beyond the identification (and explanation) of aggregate regularities in some specific features of structural dynamics. Rather it refers to the ability of reconstructing histories of the evolution of the structure of industries and of discovering regularities in the whole dynamic patterns of structural evolution. The empirical evidence on such level of analysis is however scarce and fragmentary. A first "typical" stylization of industry evolution concerns the never-ending debate upon continuity vs. discontinuity in technological change and industry structure. Another version of this discussion (in our view) is the distinction between Schumpeter Mark I and II model of innovation and industrial change. Also one of the most recent debates in industrial economics concerns the existence of any regularity in the forms of evolution of firm structures, as one can find in the work of Chandler (1992) and Piore and Sabel (1982).

Up to now however there is only one type of stylizations of the dynamics of industry structure which has both a solid empirical backing and has been modelled both in an appreciative and in a formalized way: the industry life cycle (Mueller and Tilton, Klein 1977, Abernathy and Utterback, 1978; Gort and Klepper 1982; Klepper and Graddy 1988, Utterback and Suarez,1992, Klepper,1993). This view identifies three stages in the evolution of an industry. First, the beginning of an industry is characterized by a radical innovation that sets in motion a stream of product innocations. In some cases the product innovation is stimulated by users' needs. in other by advancements in science and technology. In the early period, competition is intense and turbulence high. Competition is mainly on functional product performance. Innovative stimuli come from users and science. Entry barriers are low and R-D and capital requirements limited: several new firms (most of whom are small), enter the industry at an initial stage by introducing and producing new products. Early plants are of a small scale and located near leading users or the sources of technology. Equipment are general purpose, production is inefficient and products are custom. Later in the evolution of an industry, a dominant design emerges (Clark, 1983). The emergence of dominant design locks in the development of future products and originates a stream of process innovations which make the production process more inflexible and at the same time more efficient. Plants become of increasingly large scale, equipment are of special purpose and products become standard. Competition shifts from functional product performance to price and product differentiation. Industrial concentration increases because barriers to entry increase and selection eliminates several existing producers which have not adopted rapidly or forcefully enough the dominant design. Finally, industry maturity is characterized by few incremental innovations (mainly of the process type), high concentration and possibly collusion among established firms.

While some of the specific features of this view of the evolution of an industry- entry, exit and the number of established firms during industry life cycle- have been empirically tested for a large number of industries by Gort and Klepper (1982) and Klepper and Graddy (1990), only recently a formal model of industry life cycle has been proposed by Klepper(1993). The model aims to explain some of the basic feature of the industry life cycle as discussed empirically by the above authors and to shed light on the role of firms capabilities and size in affecting R&D expenditure, innovation and industry structure. In Klepper's model opportunities ofr products and process innovations remain constant. Firms are randomly endowed with distinctive capabilities which do not change over time and which generate product innovations. Adjustments costs are convex. Product differentiation persists for one period, after which all features are incorporated into a single variant of the product. Firms' process innovations reduce unit production costs and their returns are directly proportional to firms output; they are ultimately imitated. Firms do nor behave strategically; they are price takers, act independently and choose R&D and production levels in order to maximize current profits. As far as entrants are concerned all cohorts of potential entrants have the same distibution of innovative expertise. As industry evolves firms enter according to the information (increasing over time) about entry opportunities and the number (increasing) of incumbents, counteracted however by the depletion of potential entrants which have actually entered the industry.

The basic mechanism of the model is the following. Those early entrants that are able to introduce products with distinctive features grow. As a consequence, they have greater incentive to engage in process R-D which then lowers average costs and prices. This increasingly drives less innovative firms out of the industry. Relatedly, entry decreases over time because entrants, compared to incumbents, have an increasing cost disadvantage which ultimately inibits further entry and therefore also product diversity (associated to new entrants as industry life cycle progresses).

This formal model represents effectively the features of the evolution of an industry in terms of number of firms, entry and exit, product and process innovations and R-D policy between two radical product innovations. The industry starts with a radical product innovation, a low capital intensity production process and a lot of subsequent entry with several product innovations. Over time diversity in competing products diminishes, process innovation replaces product innovation, entry decreases and industry concentration increases. In the theoretical model the emergence of dominant design (a key element in the appreciative model) is captured by the decrease in product diversity and the emphasis on process innovation in later stages of industry life cycle.

Klepper's model is very powerful to explain the evolution of specific industries such as the consumer durables ones (automobile, typewriters and Tv and TV tubes). (Tushman,)

However its generalization to all industries presents several problems. First, the evolution of an industry actually collapses to a product life cycle, where products have to be narrowly defined, such as in the case of typewriters. In this case the industry cycle started with the first introduction of the typewriter in 1873 by Remington, experienced a dominant design with Underwood Model 5 in 1899 and was characterized by a period of concentration between 1906 and 1940 with the survival of 5 producers: Remington, Royal, Smith, Underwood and IBM (Utterback and Suarez). If industries are more broadly defined in terms of products or if products are of a system type, however, several of the predictions of the industry life cycle model do not hold anymore (as we will see later).

Second, the sequence of product innovations followed by process innovations does not hold in capital intensive industries such as commodity chemicals, synthetic fibers, plastics, petrolchemicals. In these industries innovations are mainly of the process type. This sequence does not hold also in industries where demand is customized such as in machinery and machine tools and in heavy electrical equipment. In this industries in fact innovation is mainly of the product type.

Third, the industry life cycle model assumes an initial major discontinuity associated with a major product innovation, followed by the emergence and consolidation of a dominant design. This is the case of the auto industry, which started during the 1890s, experienced a wave of entry between 1900 and 1920, had a dominant design first with the all-steel closed body automobile by Dodge and then with Ford Model T and finally was characterized by increasing concentration. Things look differently in other industries. For example in the semiconductor industry (as we will see more in detail later) during the 1950s the emergence of a dominant design- the planar transistor and the planar process- lead to the new discontinuity -the integrated circuit. Also in the integrated circuit period, the introduction of several generations of products were associated with several dominant designs which kept the industry highly turbulent, up to the new discontinuity characterized by the introduction of the microprocessor.

Fourth, the initial discontinuity which originates the industry is always associated with a first major innovator which generates a stream of new entrants. While this could have been so in industries such as typewiters and automobiles, pre-existing conditions differ drastically across industries and highly affect the early stages of the evolution of industries. For example, the automatic teller machines industry has always been characterized by a highly concentrated industry since its beginning. Similarly, the transistor was introduced by a large firm (ATT) and the early entrants were all the major American and European large receiving tube producers.

More importantly, however, this model does not provide us a broad understanding of structural evolution in terms of transformation of products nd processes, changes in the boundaries and organization of firms, modifications of the connections and relationships among firms and between firms and other institutions such as universities, financial institutions and the government. In order to show the type of issues and dimensions involved in structural evolution, we turn to the case of three specific industries.

4. The structural evolution of industries: three cases

Empirical analysis provides few case-studies of the structural evolution of industries which do not allow to draw any major generalizations. These case studies include among others Abernathy (1978), Klein (1977) and Clark (1983) on auto. Dosi (1984) and Malerba (1985) on semiconductors, Orsenigo (1989) and Gambardella (1992) on biotechnology, Dorfman(1987) and Flamm (1988) on computers, Mowery-Rosenberg(1982) and Phillips (1971) on aircraft, Henderson (1988) on photolithographic alignment equipment, Rosenberg (1976) on machine tools. These studies do not necessarily aim to analyze structural evolution at their primary research object. When they do so they focus on different aspects and use different methodologies.

However these studies provide a starting point for the analysis of the structural evolution of industries. In fact it is possible to claim that the evolution of industries is characterized by a few common patterns. For instance technological discontinuities are followed by periods of incremental technical change and later on by new discontinuities. Entry clusters in specific periods of the evolution, not necessarily only after the occurrence of technological discontinuities. Processes of industrial concentration and competence enhancing technical change are followed by periods of competence destroying technological change. Processes of specialization, diversification and vertical integration always take place with various forms and intensity in some stages of the evolution of the industry. Government policies and public institutions play always a major role. Finally, great institutional and organizational differences across countries are present.

In order to develop our empirical understanding more in depth, we will examine in detail a historical account of the structural evolution of three industries: computer, semiconductors and biotechnology.

4.1 *The computer industry*

From a perspective related to Pavitt's taxonomy of innovation and to the features of the relevant technological regimes, the computer industry is a science based industry which has high opportunity, appropriability and cumulativeness conditions

A focus on the structural evolution of the industry points to several features that are not included in the industry life cycle model and which play a relevant role in the evolution of the industry. First of all, the key actors in the industry are more than just firms. There are six types of actors related in different ways: firms, universities and public laboratories, government (including the ministries of industry, trade, and science and technology and the military), suppliers (of semiconductor components, disk drives, printers, and so on), users (consumers, banks, insurance companies, manufacturing firms and so on), and financial institutions (such as banks and venture capital). Each of these actors is characterized by different attributes and competences.

During the pioneering stage of the industry (1940s) the main actors involved in research were Universities and groups of scientists both in the United States and in Europe, with various traditions , competences and commitments. Scientific developments in differential analysis and in abstract general purpose computers (for example the Turing machine) played a major role in advancing the generic knowledge of the scientific community. The scientific developments in universities took place while there was an active industry of mechanical calculating machineries and while vacuum tubes switches substituted electromechanical relays. In the United States, scientists in universities worked in connections with the government which acted both as source of funds and as a major potential user (the military and the Bureau of Commerce). In addition, few private firms were also a source of funds for basic research in computers (IBM for example supported the development of the Mark I computer of Aitken at Harvard in 1944).

The scientific commitment by various American and European Universities to develop digital electromechanical computers ended up in the development of several machines during the 1940s. In the United States, for example, ENIAC, the first digital electromechanical computer introduced, was developed by Eckert and Mauchly in 1946 with the support of the Army at the University of Pennsylvania.

The actual origin of the commercial computer industry is related to the move of the two inventors of ENIAC from university into the business world. In 1946 Eckert and Mauchly decided to establish their own firm, the Eckert-Mauchly Corporation, with the aim of developing general purpose commercial computers for scientific as well as for business accounting uses. Their move became possible because a new technological development took place during this period: magnetic drums memories (which allowed for data storage in computers).

The Eckert Mauchly enterprise failed however because external finance (particularly venture capital) was limited. Some (albeit insignificant) financial support came from firms such as Prudential, Nielson and Northrop Aircraft. Financial needs for the new enterprise however remained relevant. As a consequence in 1950 the Eckert-Mauchly Corporation was acquired by Remington Rand, a cash rich large typewriter firm.

The commercial computer industry started therefore in the early 1950s, with the first entry of Remington Rand, and then of IBM (a major punched cards and tabulating machinery company), and the rest of the BUNCH (Burroughs, the already mentioned UNIVAC Rand, NCR, Control Data, Honeywell), as well as GE and RCA.

During this initial period appropriability conditions remained high because of the presence of legal protection, the relevance of tacit knowledge in developing and producing computers and the importance of complementary assets such as customer assistance and distribution network. The technology and the main actors were soon different from the ones of the pioneering years. Computer technology now made extensive use of magnetic drums memories and later on of transistors, while computers functionality expanded to business uses for calculation and accounting (in addition to scientific uses). Relatedly, in addition to universities and the government, computer firms opened up extensive and articulated linkages with business firms as major users of computers.

The strategies of the seven major mainframe producers which dominated the market from the early 1950s to the early 1970s (IBM, Univac-Sperry, NCR, Control Data, Honeywell and Burroughs) were centered on the introduction of new products, which could then be modified and improved through a stream of incremental innovations. In deciding and shaping their strategies these computer firms had to carefully balance their R&D and investement resources between the continuous incremental improvements of their existing successful products and the development of totally new products.
Rather than focussing on basic research and new scientific breakthrough, the first commercial computer firms aimed to develop general purpose commercial computers and engaged in continuous R&D, while paying considerable efforts to commercialization and post sales-services. The cases of the failure of Remington Rand and the success of IBM illustrate this point. While for example Remington Rand did not invest in R&D on a continuous basis and therefore declined in importance because it was not able to turn out continuously improved computers, IBM rapidly became the new market leader because of its continuous R&D effort in developing new products, coupled with marketing competence and good sale effort in the commercial market. IBM efforts resulted in the tremendous success of IBM 650 (1954) and 1401 (1960) in the market for accounting machines.

At this stage of industry evolution differences emerged in the comparison of the American and the English cases. During the 1940s both countries developed the first scientific computers (such as ENIAC, MARK I and WHIRLWIND I in the United States and the COLOSSUS in the United Kingdom). In the United States however the presence of advanced firms active in mechanical calculating machinery and office equipment rapidly opened up a new link between universities and industry (in addition to the existing one between universities and the government). In the United Kingdom on the other hand, mechanical calculating machinery firms were not numerous and not particularly technologically active, so that in that country a commercial industry started late and with considerable technological and commercial disadvantage with respect to the American one.

During the 1960s IBM competence and involvement in a wide range of mainframe computers lead to the introduction of a radical innovation: compatible modular computers. In the early 1960s IBM was already the dominant firm in the industry and had several computer families on the market. The committment by IBM to reach standardization and modularity was possible because a technological development - microprogramming- had occurred. Microprogramming (developed at Cambridge in 1951) made possible to have the instructions of the central central processing unit of a computer in ROM rather than in hardware. IBM committment resulted in 1965 in the introduction of the first family of modular compatible computers-the IBM 360-. With the IBM 360 the standardization of components and software allowed the exploitation of economies of scale in components production and the consequent upstream vertical integration of computer firms, the supply of a broad line of compatible computers and the introduction of modularity and incremental modifications in computer design.

The introduction of the IBM 360 changed drastically the structure of the computer industry. Higher barriers to entry were erected with respect to new mainframe producers (which now had to be able to supply a broad range of compatible computers) while lower barriers to entry were present for new specialized firms aiming to produce peripherals and components. In addition, now a wider range of customer firms enlarged the demand of computers, which could be used in different applications.

Since the late 1960s greater product variety has been associated with a more complex industrial structure. Two examples are given by the introduction of minicomputers and personal computers. The introduction of the first real time interactive time sharing general purpose minicomputer -the PDP8 by DEC in 1965- opened up new types of demand for computers: research laboratories, manufacturing firms (the monitoring and control of industrial processes) and small businesses. In addition, computers were used for problem solving activities. inserted in computer networks and focussed to specific applications. It must be noted that in the case of minicomputers the basic idea- real time environment- had been around for quite a long time, but its implementation in a product had to wait until a suitable technology and financial institutions ready to support this effort would develop. Minicomputers had a major effect on the structure of the industry. First, they led to the new specialized minicomputer firms. In addition, because at that time (late 1969s and early 1970s) no extensive software support was provided by minicomputer producers, new intermediate actors emerged between the minicomputer producers and the customers: system houses and value added retailers. A similar analysis can be made for another major innovation which took place during the 1970s: the personal computer. In this case too, firms profited from the availability of a new technology at the component level- the microprocessor- which could allow firms to develop products more user friendly and more decentralized in terms of computing capacity and to satisfy the needs of a new type of demand: family, hobby, education uses and small business. As in the case of minicomputers, also in the case of personal computers new firms entered the industry: specialized computer firms (such as Apple. Commodore, Tandy and Compaq) and clones (such as Amstrad).

In the course of the 1970s and 1980s new hardware market segments emerged. In addition to mainframes, present since the origin of the industry, supercomputers and minisupercomputers for scientific work, medium systems such as workstations, small systems such as portable computers are developed. As a consequence a variety of firm strategies emerged. First, firms could be either full line suppliers, which offer a variety of products ranging from mainframes to personal computers, or specialized producers. Second, firms could be vertically integrated in the development of components and systems, or system integrators. Third, firms could follow network strategies for the acquisition of external knowledge and for the joint development of new products. Cooperation involved suppliers, users or other firms in the industry. Fourth, firms may follow strategies of radical innovations or strategies of incremental innovations within certain product families.

Finally, in the later stages of the development of the industry (1970s and 1980s), software emerged as a major component of computer products and software firms became major actors in the computer industry. The event that started that structural change dates back to the decision of IBM to unbundle software products from hardware by pricing software independently from hardware. IBM unbundling decision created a set of products which could be offered independently on the market. New products such as system software, applications tools, cross industry and industry specific application solutions, customized software and software services were created. The structure of the industry was severely affected because new types of firms such as system integrators, software houses and software services firms became major players in the industry and computer firms engaged in software activities had to have much closer and interactive links with users and leading customers. It must be noted that application solutions, custom software and software services required a different knowledge base for innovation than hardware production: an in depth understanding of end-uses applications of information systems in terms of horizontal applications (such as spreadsheet or word processing), vertical applications (such as software for banks, transport, and so on) and specific users applications (custom software). Therefore, in order to be successful in applications, firms had to understand market needs, identify the relevant dimensions of specific market applications, target their products to those dimensions and interact on a continuous basis with users. In software applications the conditions of high opportunity coupled with the pervasiveness of the technology and the high variety of applications implied a high heterogeneity of firms. Even within the same application, firms ranged from vertically integrated computer companies, to diversified electronics producers, to multiproduct software houses, to small specialized firms, to major users whith detailed knowledge about a specific application. In this realm, firms strategies ranged from the aim to introduce major innovations, to the attempt to innovate on a continuous basis by improving and modify existing proprietary software products, to imitation by introducing small improvements in the software packages developed by other firms. In addition, given the complexity of the knowledge base required for innovative activities and the heterogeneity of competences, cooperation among firms and networking strategies became quite widespread by providing complementary and specialized expertise regarding computer hardware or basic operating software, features of specific applications, characteristics of market niches or user requirements.

In sum, in the early 1990s, the structure of the computer industry was quite articulated and complex, far from the concentrated structure predicted by the industry life cycle model for later stages of industry development. Because the development of new computer products requires the integration of complex architectures, advanced system software, very large scale semiconductor components (such as microprocessors and memories), disk drives, terminals, floppy disks, in addition to articulated network interfaces in the ealy 1990s firms may be either full line suppliers (such as IBM), which offer a variety of products ranging from mainframes to personal computers, or specialized producers. Second, firms may be vertically integrated in the development of components and systems (such as IBM), or system integrators (such as Olivetti). Third, firms may follow network strategies for the acquisition of external knowledge and for the joint development of new products, by involving suppliers, users or other firms in the industry. Fourth, firms may follow strategies of radical innovations, incremental improvements or imitation.

4.2 *The semiconductor industry*

According to the taxonomy of patterns of innovative activities and to the features of the relevant technoloigical regime the semiconductor industry falls in between a science based industry and a scale intensive one and has been characterized by high opportunity and appropriability conditions and by an increasing degree of cumulativeness

Its structural evolution however is not fully captured by the basic dimensions of the industry life cycle model.

In the semiconductor industry the main actors have been firms, the government (including the military) and financial institutions.

The industry began with the discovery of the transistor at ATT's Bell Laboratories. In the United States the early days of the semiconductor industry (1950s) were characterized by high opportunity conditions typical of a new industry based on a new scientific field. The knowledge base was rather simple and linked to science (solid state physics and chemistry). Market opportunities were clearly perceived and identified by firms in the industry: hearing aids, telecommunications, radio sets and computers. The future potentials of transistors were also clear. The relevance of the discovery of the transistor for the development of the electronic industry was recognized by a large number of firms, scientists and entrepreneurs both within the existing infant electronics industry and outside it. As a consequence, all the firms in the electronics industry which were producing electron tubes entered the new semiconductor industry (some of these firms were large vertically integrated and diversified producers, such as General Electric, RCA, Sylvania).

In the early days of the industry (1950s) most of the firms in the semiconductor industry would follow strategies of continuous major innovations. Once a firm would develop a new product it would aim at rapidly launching it on the market. In the meantime, its researchers would continuously explore new technological possibilities and aimed at introducing radically new products on the market. New product introduction would frustrate the attempt to focus on process innovation for a given product and to try to incrementally modify existing products and processes. During these years, cases of failures of firms which preferred to stay with existing products or to try to automatize the production process in order to reach a high level of efficiency (rather than innnovate continuously) were common. During the 1950s the structure of the American industry was characterized by both large established firms and new firms. Because opportunities were high the 1950s were characterized by several entrants, both new firms and established firms coming from other industries.

At the end of the 1950s the innovative strategies of two merchant producers- Fairchild and Texas Instruments- resulted in two radical innovations (the planar process and the integrated circuit) which altered the technological environment and the behavior of firms in the industry. The technological regime that emerged with integrated circuits was different from the one that characterized the transistor period. High opportunity conditions were still present. The knowledge base however, became more and more centered on design and engineering rather than on basic science, and became increasingly tacit and firm-specific. In addition, the cumulativeness of technological change increased because firms developed advanced capabilities in specific innovative activities now based on some basic processes and products: silicon (as basic material), planar (as the basic manufacturing process) and integration (as the main product concept). As a consequence of the tacitness of the knowledge base (linked to engineering and technical know-how) and of the cumulativeness of technological change, during the 1960s semiconductor firms enlarged their strategic options, by following strategies of incremental innovations by improving and modifying existing products and process, eventually moving down the learning curve and maintaing lead times over competitors. Some semiconductor firms however continued to follow strategies of radical innovations (followed by a continuous stream of incremental improvements), although in this respect major differences were present. For example, both Fairchild and Texas Instruments were major innovators but had quite different behavior. During the 1960s both Texas Instruments and Fairchild introduced the planar silicon transistor (1961) and moved into TTL quite soon, beginning to develop new types of TTL devices over an extended period. But while Fairchild followed a strategy based on continuous exploration of technological opportunities and high R- D investments (without paying too much attention to the subsequent exploitation of a product) Texas Instruments was able to maintain a successful balance between major innovations and the movement down the learning curve on existing integrated circuit. This proved a quite successful strategy so that Texas Instruments ended up dominating the market for integrated circuits in the early 1970s.

The introduction of the integrated circuit greatly affected the structure of the industry. Several established producers, which either did not have advanced competences, or were successful in transistors or did not believe in the potentialities of the integrated circuit, exit the industry. A new stream of entrants moved into the industry. Entry would occur mainly through the introduction of new products.

The trajectory of miniaturization and integration that was pursued by firms in the industry since the 1960s resulted eventually in the introduction of the microprocessor (another radical innovation) and in the large scale integration and systemic features of semiconductor devices.

In the early 1990s, the semiconductor industry is characterized by three major product groups: products requiring a whole set of innovative and technological capabilities (such as microprocessors), products requiring mainly advanced engineering and production capabilities (such as memories), or products requiring mainly advanced design capabilities able to target specific applications or customers (such as application specific integrated circuits ASICs). In these product and market segments, firms are characterized by specific strategies and organizations. In microprocessors, established as well as new merchant producers (such as Intel. Zilog, Sun and MIPS), and computer producers (such as IBM and Hewlett Packard) follow strategies of introduction of new microprocessors, later modified and improved over the years. On the contrary, in memories, established vertically integrated Japanese firms (such as NEC, Fujitsu and Hitachi) are characterized by advanced engineering and production competence, large investments in manufacturing equipment and strategies based on learning curves and high volume production for their own use and for the external market. In ASIC new small design houses, positioned between users and manufacturers of semiconductors, have emerged. These small and medium size firms (such as Mietec. Advanced Silicon Corporation, Lasarray, Integrated Power Semiconductors, European Silicon Structures) do not have high fixed costs and R&D expenditures and are specialized in the design of integrated circuits based on the understanding of specific applications, user-producer interaction and tailoring design to specific users needs. The production of the semiconductor devices with the masks designed by the design houses then takes place in large or medium size silicon foundries.

One final note regards the fact that the evolution of the industry in terms of structure has been quite different in the United States. Europe and Japan. While in the United States both merchant producers and vertically integrated firms are present, in Europe and in Japan only vertically integrated companies operate.

4.3 *Biotechnology*

In biotechnology, the main actors are firms, universities and financial institutions (venture capital).

The take-off of industrial research in biotechnology immediately followed two key scientific discoveries in the early 1970s, i.e. recombinant DNA and hybridoma technology. These break-throughs opened enormous opportunities for innovation in a large variety of industries, primarily pharmaceuticals.

Innovation implied however the acquisition, understanding and improving of new basic scientific knowledge in a wide variety of disciplines. Moreover, it implied the fusion with other older biologically-based technologies, especially as large-scale production processes are concerned.

In the United States a high rate of entry of new specialised companies (New Biotechnology Firms-NBFs) was made possible by the novelty of the knowledge base , which weakened the entry barrier constituted by the cumulative nature of technical change. The NBFs were usually formed through the collaboration of a scientist and a professional manager backed by venture capital in order to apply the new scientific discoveries to commercial product development. Their specific skills concerned research, but they lacked the experience and the organisation necessary to support crucial aspects of the innovative process, such as manufacturing and - above all- the testing and administrative procedures for the approval of new products and marketing.

The absence of capabilities and structures in these fields impaired also the possibility of fully appropriating the profits deriving from innovations. Appropriability conditions represented a crucial strategic problem of the NBFs. Particularly in the early stages, the relevant knowledge had to a large extent a generic nature and could in principle be codified. Patents and the control of complementary assets represented therefore a crucial requisite for the private appropriation of the profits generated by innovations. Yet, considerable confusion surrounded the conditions at which patents could be obtained.

Established companies faced the opposite problem. They had to acquire and develop the new knowledge, but had the experience and the structures necessary to control testing, production and marketing. As a result, innovative activities in biotechnology involved the development of variegated and complex organsational solutions, in particular of collaborative relationships between the NBFs, established companies and the academic community.

The strategies of the NBFs varied considerably in at least two aspects: in terms of the research directions they pursued and in terms of their attitudes towards vertical integration and collaboration.

As far as the directions of research are concerned, at one extreme one finds companies which tried to develop as soon as possible products which could be sold on the marketplace, attaining an early lead through the specialisation in a specific niche. This strategy implied concentrating on the most immediate application of genetic engineering and on products which did not require large scale production processes or substantial marketing efforts, e.g. diagnostics based on hybridoma technology. Companies like Hybritech and Centocor are good examples of this strategic posture. At the other extreme, one finds companies which tried to develop core technological capabilities in a wide range of areas, exploiting the technological complementarities made possible by genetic engineering. In different ways, companies like Genentech, Biogen and Celltech belong to this category.

As far as vertical integration is concerned, although the aim of of the large majority of the NBFs was to become fully integrated pharmaceutical companies, integration could not be achieved rapidly and costlessly. In the absence of products generating revenues, the NBFs became essentially research companies and specialised suppliers of high technology intermediate products, performing contract research for and in collaboration with established companies. Some of them, however, linked with a large number of contractors trying to avoid to establishing too close a relationship with specific partners (e.g Genentech). Other NBFs restricted instead their linkages to a small group of contractors, with whom long-term, stable relationships were built. Examples of this kind of relationships are the linkages between

Chiron and Ciba Geigy, DNAX with Schering Plough and Ortho Diagnostics with Johnson and Johnson. The strategies of the established companies were in some way specular to those pursued by the NBFs. For them too, entry in the new technology required a gradual process of acquisition of external knowledge and the development of adequate organisational solutions. Their main strategic and organisational problems concerned the timing and the size of their involvement; the integration of the new knowledge into their specific competences and organisations; its utilisation for the development of new products.

The timing and the commitment to biotechnology among large established firms varies markedly as a function of the proximity of their competences to the new technologies, to their diversification strategies and to their technological expectations. Many of them, especially the large integrated European and, above all, the Japanese chemical groups, considered genetic engineering as an important new research tool and a source of opportunities for diversification, rather than a direct source of new products and processes. Its embodiment was however a slow and difficult process, because it implied a radical change in the research procedures, a redefinition of the disciplinary boundaries within the laboratories and, in some case, also in the divisional structure of the company. Collaborative research with the NBFs and with universities allowed these companies, in any case, to get access to the new technology and to experiment alternative directions. The advantages stemming from these interactions could be fully exploited however only through the contextual development of in-house capabilities, which made it possible to absorb and complement the knowledge supplied by external sources. Collaboration with universities, NBFs and internal research were indeed strongly complementary. The cases of Hoffman-LaRoche (HLR) and Genentech illustrate vividly this strategy. HLR entered biotechnology mainly on the basis of its competences and interests in the field of immunology. Subsequently, HLR developed a wide network of linkages with the NBFs (particularly with Genentech), which was eventually acquired in 1990. Genentech was the first to introduce in 1987 on the market the first important product of genetic engineering, i.e the tissue plasminogen activator (t.p.a.). Genentech's product was initially an enormous commercial success and the product was sold at very high prices. Very shortly, however, new similar products were launched by competing companies characterized by higher quality and lower prices. Genentech's effort to come first to the market and to sustain by itself all the commercialization of the product left the company in a difficult financial situation, which ultimately led to the acquisition by HLR.

The variety of strategies and the development of collaborative relationships reflected the novelty, the uncertainty and the fast progress of the technology, the complexity of its knowledge base, the difference in the core capabilities of the major actors. As the technology developed, however, some definite and quite similar strategies gradually emerged. A large fraction of the NBFs became specialised producers of diagnostics based on monoclonal antibodies. Other companies concentrated their efforts on the development of pharmaceutical and -to a lesser extent- agricultural products. In particular, within the field of therapeutics, companies concentrated research in a small range of areas. Established companies gradually tailored their involvement in biotechnology to their wider technological strategies.

In particular, the incentives towards increasing degrees of vertical integration are becoming stronger. As the technology matures, the tacit component of knowledge acquires more relevance and progress becomes more cumulative, making the exchange of knowledge more difficult. Finally, vertical integration raises entry barriers and provides the innovator with strategic complementary assets. Thus, established companies have gradually strengthened their in-house research efforts and many NBFs, and particularly monoclonal antibodies companies, have indeed succeeded in developing over time in-house manufacturing facilities. However, it must be stressed that most firms do not have the need for large scale manufacturing. Only a handful of therapeutic products are actually sold on the marketplace and in any case - again, particularly for monoclonal-based diagnostics - small scale production is often sufficient. Vertical integration, however, seldom reaches marketing .

4.3. *Lessons and questions from the stories of the three industries*

What kind of lessons may be drawn from these three histories? If we focus on structural evolution, several remarks could be advanced which point to major differences from the predictions provided by the industry life cycle model discussed previously. First, the structural evolution highlighted by the three cases is inextricably linked to the continuous transformation of existing products and the emergence of new technologies. This transformation is something different from the sequence of types of innovations proposed by the industry life cycle (product first, process later) does not hold.

In addition, the emergence of a new industry from the existing ones is a key process which may start from quite different initial conditions because of the specific features and technological proximity of existing technologies and products, the characteristics of production and the structure and competence of the industry producing technologically related or substitute products. While in few cases the new is a total rupture from the past and is characterized by totally new entrants, in several cases entrants are firms already active in technologically correlated industries which diversify into the new one.

Moreover the very nature, oranization and boundaries of the firms are also continuously changing during the evolution of an industry. New firms appear on the scene, many of them exiting quickly, a few other surviving, growing and sometimes becoming the new leaders. Old firms change their strategies and forms of organization. Specialization, division of labour as well as lateral and vertical integration are also essential features of this process. Firms merge or generate other companies. New entities specialized in one particular activity appear, whereas at the same time other activities are integrated within the same organization. In this respect the growth of firms' experience and competence in specific technologies and products may greatly affect the direction of technological change, the development of an industry and competition among firms. In fact from the stories told before firm competence and existing links across firms have greatly shaped subsequent directions in industry evolution. For example, the introduction by IBM of the modular IBM 360 has been stimulated and has been dependent upon its competences and specific relationshpis with its customers and suppliers. Relatedly, the success of several firms in the computer industry has been due to the presence of a type of experience and competence adapted and tuned to the existing technology and structure of the industry. This has been called competence enhancing (vs competence destroying) technical change by other authors, (see the case of photolithographic aligners by Henderson and Clark, 1989). In our stories, the cases of two competent firms -the successful IBM (competent in office machinery and punched cards machinery) and the unsuccessful Remington Rand (competent in typewriter)- proves this point during the early stages of the computer industry (in the passage from scientific to commercial computers). Similarly, the failure of Eckert and Mauchly's business enterprise at the beginning of the commercial computer industry is due to the same reason: Eckert and Mauchly were not able to carry out successfully their newly founded business entreprise because they lacked business and manufacturing competence and acted outside their previous environment. Relatedly, in our stories some firms were successful because they were able to rapidly exploit newly created openings in demand and in technology, which the established firms with their experience and competences were not able to fulfill. The example of the specialized personal computer firms able to exploit the invention of the microprocessors and to open up new links with new types of demand such as family, education and small business, is a case in point.

Finally linkages and connections of various types and intensity among firms, between firms, suppliers and users and between firms and other institutions are formed, consolidate and disappear during the evolution of an industry and greaty shape firms actions, activities and growth. Take again the computer industry for example. Here any lack of analysis of the role of cooperative agreements between hardware and software firms or between semiconductor suppliers and computer firms would greatly impair any understanding of the evolution of the computer industry. In general, the relationships between these entities has changed over time change: not only their organization evolve, but one observes also continuous innovation in market relationships. New forms of contracts appear, new specialized markets emerge linking together previously unrelated entities. Transactions are organized in a more systematic way, and interactions become increasingly tailored to the needs of the partners involved. Putting it another way, the economic entities do not just simply multiply or change. They organize themselves into particular patterns of connections.

In sum, one observes over time complex dynamic processes at work involving various firms and institutions connected in various ways. Phases of intense change in structure are often followed by periods of relative stability, where entities and their relationships do not change too drastically, but proceed incrementally. In most cases during the evolution of an industry a major drastic change in products has been associated with a change in industrial structure. For example, the change from the first commercial computers to the modular computers in the early 1960s implied also a drastic change in the relationships among computer firms (in particular between IBM, the other large computer firms and the small compatible computer firms). In several cases the introduction of a radically new product during the evolution of an industry (and not just at the beginning of it, as the industry life cycle assumes) has been associated with the emergence of new types of actors (such as new types of firms, suppliers, users and so on). For example the introduction of minicomputers or personal computers implied the emergence of new types of firms (the specialized producers of minicomputers or personal computers) and new types of users (small business and families).

5. Where do we go from here? A research agenda

The discussion of the structural evolution of industries point to some final conclusions and some directions for future research.

In general a lot more empirical evidence on some of the issues discussed in this paper is required. The modes of entry and the type and sources of entrants, the features of exit, the dynamics of specialization and vertical integration, and so on require a much finer grained empirical scrutiny. One could advance also the statement that a necessary second step is the development of taxonomies of industry evolution in terms of some basic dimensions of structural change.

These key dimensions should include first of all a sensible definition of the boundaries of an industry. For the purpose of analyzing structural evolution, a useful starting point could be the definition of an industry as a form of organization of economic activities at a high level of aggregation, characterized by specific structural relationships between different entities and between such entities and the products that are produced. It must be noted that products are continuously transformed during the evolution of an industry, and may be related to other products both within the industry and outside the industry in terms of technologies or in terms of functions. Reducing the boundaries of an industry to a single product is too reductive and may miss some essential properties of the patterns of industry evolution. Larger industry boundaries allow for the possibility of industry rejuvenation through technological and industrial shocks, with new structures emerging over time from existing ones or from new entrants and the branching out in different periods of new products and industry segments.

In this broader view of structural evolution, firms remain the key actors. Firms however have to be analyzed according to several dimensions at once: competence, innovative activities, productive specialization, boundaries, organizational structure and, finally, connections with other actors.

These connections have to include first of all the relationships that firms have with suppliers and users. These actors not only interact with firms in an industry through the exchange of products, knowledge and people, but in several cases -as in vertical integration- they are involved in the very process of structural change.

In addition to suppliers and users also other types of institutions -scientific institutions, financial instituitions and the government- have to be included in the analysis. These institutions greatly shape the structural changes in an industry, by affecting the stock of scientific knowledge available to firms, the diffusion of new technical knowledge to firms, the amount of R-D carried on by firms, the speed of development and the extent of production. the entry of new firms and the exit of established ones. The inclusions of these actors is particularly relevant for the comparative analysis of the structural evolution of industries across countries.

In conclusion. the analysis of structural evolution has to jointly take into consideration all the various structural dimensions that are usually examined separately in most studies of industrial oragnizations: size, boundaries of firms, entry, growth and exit, specialization, vertical integration, diversification, and formal and informal networks. In fact structural evolution in most cases implies various structural changes taking place at once. with one change triggering or being closely linked to another.

One last word about theory and modelling. The focus of this paper is strongly empirical. We have not discussed the more theoretically-oriented contributions to this issue. Yet, the sort of empirical analysis discussed here needs - in our view - to be strictly complemented by the development of rigorous theoretical efforts aiming at the understanding of the general mechanisms - if any - which generate the regularities and differences in industrial evolution. Conversely, such an effort raises several fundamental questions related to the basic philosophy, methodology and tools of theoretical analysis and strains the scope of current theoretical models.

Over the last decade, interest in modelling industrial change has been growing rapidly. One finds models with strongly different orientation and which use different instruments. Some of these models attempt to extend the basic concepts of equilibrium analysis to complex dynamic environments To this strand belong models such as Jovanovic (1982), Ericson and Pakes (1992) and Jovanovic and Rob (1990) Other models, following Nelson and Winter's (1982) seminal contribution adopt an explicit evolutionary approach to the analysis of industrial change [3]. In these models, neither full rationality nor equilibrium are

[3] Nelson and Winter (1982), Iwai (1984) Silverberg, Dosi and Orsenigo (1988), Winter (1984), Dosi and Salvatore (1992) and Dosi,Marsili,Orsenigo and Salvatore (1993),Eliasson (1986), Chiaromonte and Dosi (1993), Silvemerg and Lehnert (1993), Siverberg and Verspagen (1994).

assumed. Almost all of these formal models are characterized by viewing industries as growing and changing over time in an uncertain environment as the outcome of processes of learning of and market selection on (sometimes heterogeneous) firms. Formally, most of these efforts are modelled as dynamic stochastic systems, whose properties are studied via analytical methods and more often, given the difficulties of deriving robust results, via simulation techniques.

Most of these models, however, focus on the analysis of what we have called "industrial dynamics", i.e patterns of entry and exit, firms' growth, etc. With the noticeable exception of Klepper's model, the modelling of industries life cycles is still largely unexplored. Even more so, as it concerns the theoretical analysis of structural industrial evolution.

Clearly, this state of affairs is due partly to the conceptual and technical difficulties that have to be met. As we mentioned previously, any serious attempt at theorizing should come to grips with concepts such as for example firms'competences. At the same times, it should be able to identify and restrict appropriately the mechanisms which generate particular dynamic paths of the forms of industrial organization.

However, as previously said, we would stress the point that other more important reasons are related to the lack of empirical knowledge of these phenomena, robust stylizations and taxonomies of the patterns of industrial evolution. At a very preliminary level, we still have to be able to identify more precisely what kind of phenomena are to be the objects of the analysis, at which time-scale they do belong and how these phenomena are linked together over the different time-scales.

The lesson coming from Marshall, Schumpeter, Kuznets and other classical economists is - in our view - that a full understanding of the evolution of industries requires the integration of the three levels of analysis discussed in this paper.

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