1 Innovation and industrial evolution

1.1 WHAT THIS BOOK IS ABOUT

This book is about technological progress and its relationships with competition and the evolution of industry structures. It presents a new approach to the analysis of these issues, which we have labeled "history-friendly" modeling. This research stream began more than a decade ago and various papers have been published over the years. Here, we build on those initial efforts to develop a comprehensive and integrated framework for a systematic analysis of innovation and industry evolution.[1]

The relationships among technological change, competition and industry evolution are old and central questions in industrial economics and the economics of innovation, a subject matter that dates back to Marshall and of course to Schumpeter. We authors are indeed Schumpeterians in that we believe the hallmark feature of modern capitalism is that it induces, even compels, firms to be innovative in industries where technological opportunities exist and customers are responsive to new or improved products. The evolution of these industries – like computers or semiconductors – is often characterized by the emergence of a monopolist or of a few dominant firms. The speed at which concentration develops varies drastically,

[1] The book is novel in that the original papers have been revised and improved in their structure, code and technical apparatus; moreover, they are presented together to convey to the reader the idea that those models are not simply "stand-alone" efforts but are parts of a broader and more systematic analytical approach. Our aim here is to describe and implement the methodological inspiration and implementation of history-friendly models of industrial evolution. Thus, we do not present here specific extensions of these models that are meant to investigate either specific theoretical points or broader conceptual issues about industrial dynamics. We will briefly mention some of them in the concluding chapter of this book. Nor do we aim at proposing a fully fledged theory of innovation and industry evolution. This is work in progress.

however, across sectors and over time, and, often, monopoly power is not durable. In other significant industries – e.g. pharmaceuticals – no firm actually succeeded in achieving such an undisputed leadership. In some cases, the characteristic drift toward concentration is interrupted by significant exogenous change, such as new technologies appearing from outside the sector.

Long ago, Schumpeter proposed that the turning-over of industrial leadership was a common feature in industries where technological innovation was an important vehicle of competition. In recent years economists studying technological change have come to recognize a number of other important connections between the evolution of technologies and the dynamics of industries' structure. Progress in this area has come from different sources. The availability of large longitudinal databases at a very high level of disaggregation has allowed researchers to unveil robust stylized facts in industrial dynamics and to conduct thorough statistical analyses, which show strong inter-industry regularities, but also deep and persistent heterogeneity across and within industries. New sophisticated models have been created that attempt to explain the regularities. A wealth of case studies of firms and industries has provided detailed new knowledge, puzzles and exciting hypotheses to be further developed. But despite this remarkable progress in recent decades, the subject still resists clear-cut and sweeping generalizations. Our position is that there is significant variety in the key relationships across industries, and over time, and this variety needs to be recognized explicitly.

This book follows an evolutionary approach to innovation and industrial change. Evolutionary theory emphasizes the variety of ways of doing things developed by heterogeneous actors, the selection processes that tend to suppress some of these practices while increasing the role of others, and the continuous generation of new ways of doing things. As we will explain more in detail in Section 1.3, since agents are only boundedly rational and since innovations continuously appear in the economic system, at any time different agents do different things, even when they face similar conditions, and some of them do better than others. Evolutionary economic systems tend to generate innovation, variety and progress with a changing population of heterogeneous economic agents, and with continuous entry and exit. Over the past thirty years, evolutionary economists have illuminated these dynamics with a broad range of first-generation evolutionary models. These models generate a number of empirically observed phenomena, such as the patterns of technology diffusion, the relationships between innovation and market structures and typical distributions for firm size and growth rates. However, few of these models have been focused on the dynamics and evolution of specific industries, technologies or countries.

This is what this book aims to do. It presents a new form of evolutionary modeling that aims to investigate the complex dynamics of particular cases with "History-Friendly Models" (HFM). HFM are inspired by reflections on the empirical analyses of industrial dynamics and industry evolution and on the nature of fruitful theorizing in economics regarding them. We note that, since the time Schumpeter was writing, empirically oriented economists have learned a lot about how technological advance proceeds, and how the industrial structures are themselves changed by technological innovation. But they have also learned that there are important differences among economic sectors. In this book we will describe, in some degree of detail, various aspects of what has gone on in the industries our models deal with. The inter-industry differences and the changes that have occurred over time will be revealed by the case studies we treat. HFM are based on the historical reconstruction of the main elements that characterize the evolution of an industry; on the identification of the key factors that might explain the specific observed patterns; on the construction of a model that incorporates the crucial explanatory assumptions suggested by the historical analysis; on the testing of the ability of such a model to broadly simulate the observed phenomena and to produce distinctively different patterns when one or some of the key assumptions are removed or modified. If and when results are deemed satisfactory, the analysis can proceed further by using the model to address new conceptual (and perhaps more general) questions. New models can be developed for different industries' histories.

We certainly subscribe to the view that it is the task of theorizing to develop a simplified characterization of the phenomena to be explained, highlighting the "essential" aspects and stripping away the peripheral, and then to try to develop an explanation that is consistent with the former. However, we believe that today there is too wide a gap between the complex and messy historical phenomena and the simple and abstract theories used to explain and predict them. If we agree about the need to understand the economic circumstances, and about the need to look toward the future on the basis of a solid understanding of the present and the relevant economic history, then theories that do not illuminate the past properly cannot meet our aspirations. The rest of this introductory chapter is organized as follows. First, we present the broad phenomena that HFM are designed to analyze, i.e. innovation and industrial evolution (Section 1.2). Then in Section 1.3 we provide a roadmap of the book.

1.2 THE SUBJECT MATTER: INNOVATION AND INDUSTRY EVOLUTION

1.2.1 *Innovation and market structure*

Over the past twenty-five years or so, the analysis of industrial change has witnessed significant progress. First, it has now become almost unanimously recognized that innovation – in its various forms – is a fundamental determinant of industrial structures and of their transformations over time. Firm size, market structures and forms of competition affect the incentives and capabilities to innovate and are shaped in turn by innovation. Thus, it is now commonplace to start from the premise that market structure and innovation co-evolve or – in the equilibrium language of neoclassical economics – they are endogenously and simultaneously determined. In this respect, the old debate on the "Schumpeterian hypotheses" concerning the relationship among concentration, firm's size and innovation in its simplest form has been largely superseded. Yet, it has still proven very difficult to establish any robust general result concerning the Schumpeterian hypotheses on the relationships between innovation and market structure. As John Sutton remarks, "there appears to be no consensus as to the form of the relationship, if any, between R&D intensity and concentration" (Sutton, 1998, p. 4). Similarly, Cohen and Levin (1989) argue that the results on the relation between size and innovativeness are "inconclusive" and "fragile," although stronger regularities are found at the sectoral level (see also Pavitt, 1984; Marsili, 2001; Cohen, 2011). Thus, for example, Pavitt *et al*. (1987) found that while innovative firms are likely to be rather small in industrial machinery, big companies prevail in chemicals, metal working, aerospace and electrical equipment, and many "science-based" sectors (such as electronics and pharmaceuticals) tend to display a bimodal distribution with high rates of innovativeness associated to small and very large firms.

Analyses have increasingly emphasized the relevance of various factors that impact the co-evolving relationships among innovation, firm size and market structure. To begin with, it is now acknowledged that technology often develops according to its own internal logic, following trajectories that are only partially responsive to market signals (Nelson and Winter, 1977; Dosi, 1982; Dosi and Nelson, 1995). Moreover, there is no such thing as "technology in general" but rather an array of different technologies, with different properties and characteristics, yielding different patterns of technological advance (Pavitt, 1984). Technologies differ in terms of opportunities for innovation, and in terms of the degree of appropriability of its benefits (Mowery and Rosenberg, 1982; Levin *et al*., 1987; Klevorick *et al*., 1995). Including measures of these variables in the analysis (either statistical or qualitative) almost always improves results and reduces the significance of market structure *per se* (Levin *et al*., 1985; Cohen, 2011). Typically technological change proceeds cumulatively, but in some technologies and industries – pharmaceuticals being a clear example – it is harder to use cumulated knowledge to develop new products and processes. This difference has implications for the evolution of industry structure. In some industries, largely public or semi-public organizations produce much of the relevant knowledge base on which innovation depends, which is in principle available to everybody who has the requisite scientific and technological absorptive capabilities. In other cases, technological advances do not rely much on publicly available knowledge, but on private and firm-specific know-how and expertise. Clearly, innovation can arise in very different industry structures.

As is well known, Schumpeter himself distinguished two (extreme) patterns of innovation. In the first one, as theorized in *The Theory of Economic Development* (1911) and often labeled as Schumpeter Mark I (Freeman *et al.*, 1982), innovation is created by the bold efforts of new entrepreneurs, who are able and lucky enough to displace incumbents, only to be challenged themselves by imitative entrants. At the other extreme, as described in *Capitalism, Socialism and Democracy* (1942) and often referred to as Schumpeter Mark II, the main sources of innovation are instead large corporations, which accumulate difficult-to-imitate knowledge in specific domains, and are therefore able to gain long-lasting and self-reproducing technological advantages (and economic leadership)[2]. Following this intuition, the notion has been developed that innovation and market structure evolve according to different technological regimes. Nelson and Winter (1982a) distinguished between science-based and cumulative regimes. Winter (1984) further developed this concept by modeling the different evolution of industries under an "entrepreneurial" as opposed to a "routinized" regime. Malerba and Orsenigo (1995, 1997) and Breschi *et al.* (2000) provided further empirical evidence concerning the relationships among the properties of technologies, the patterns of innovation and market structure.

2 For more detailed analysis of the evolution of Schumpeter's thought on these matters, and new translations of some of the key materials, see Becker *et al.* (2011).

1.2.2 *Stylized facts about industrial dynamics*

Research on the relationship between market structure and innovation has gone much beyond the almost exclusive focus on concentration and firm size that was common earlier. Empirical analysis has identified a series of "stylized facts" that have substantially changed the conventional way of looking at industries, by highlighting the rich dynamics underlying the changing structures of industries.

First, relatively high rates of entry of new firms are seen in virtually all industries, even those marked by high capital intensity and other apparent barriers to entry. Further, and contrary to what standard economic textbooks would suggest, rates of entry do not appear to be particularly sensitive to the average rate of profit in an industry (Geroski, 1995). And in most industries there is considerable exit as well as entry. Indeed, exit and entry rates tend to be strongly correlated (Dunne *et al.*, 1988). As we will discuss later, both entry and exit tend to be significantly higher in new industries, and decline somewhat as the industry matures. However, even relatively mature industries often are marked by continuing entry and exit.

The vast majority of entrants are small firms, and most of them exit the industry within a few years. Survivors grow faster than incumbents, reaching average levels of productivity gradually over time (around a decade). Only a few outliers in an entry cohort are able to attain superior performances, but, especially in the presence of significant technological and market discontinuities, they sometimes displace the incumbents and become the new industry leaders. Even in relatively mature industries one often observes persistent turbulence and churning in the profile of industrial evolution, due not only to continuous entry and exit flows but also to changes in the incumbents' market shares (Acs and Audretsch, 1989, 1990; Beesley and Hamilton, 1984; Baldwin and Gorecki, 1998; Bartelsman and Doms, 2000; Bartelsman *et al.*, 2005). Even in mature industries there tends to be persistent heterogeneity among firms regarding any available measure of firms' traits and performance: size, age, productivity, profitability, innovativeness, etc. (For overviews see Bloom and Van Reenen, 2010; Syverson, 2011; for a theoretical perspective see Jacobides and Winter, 2012). As Griliches and Mairesse (1997) vividly put it:

> we . . . thought that one could reduce heterogeneity by going down from general mixtures as "total manufacturing" to something more coherent, such as "petroleum refining" or "the manufacture of cement." But something like Mandelbrot's fractal phenomenon seems to be at work here also: the observed variability-heterogeneity does not really decline as we cut our data finer and finer. There is a sense in which different bakeries are just as much different from each other as the steel industry is from the machinery industry.
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> *(Griliches and Mairesse, 1997, p. 23)*

The distributions of these variables tend to be highly asymmetric, and often display fat tails in their rates of change. What is even more interesting though is that heterogeneity is persistent: more efficient firms at time t have a high probability to be highly efficient also at time t+T, and the same applies for size, profitability and (more controversially) innovation. The degree of persistence tends to decline the longer the time span considered, and regression to the mean is usually observed. However, this tendency is weak. Autocorrelation coefficients are quite high and thus heterogeneity decays slowly. Moreover, firms tend in any case to converge to different (notional) steady states: the limiting distributions remain extremely skewed. Although sharply at odds with accounts of firms and industries found in economics textbooks, these dynamic phenomena are hardly mysterious when considered in the light of the underlying processes promoting heterogeneity (Nelson, 1991b and 2008; Jacobides and Winter, 2012; Jacobides *et al.*, 2012). Not surprisingly, positive relationships are typically found among these variables: more efficient firms tend to be also more innovative and profitable and to gain market shares as time goes by. The magnitude of these relationships, however, is extremely variable across samples and across industries. Thus, for example, Bottazzi *et al.* (2010) find no relationship between productivity and profitability, on the one hand, and growth, on the other, in the case of Italy. Innovations tend to have a positive impact on profitability and growth, but not in all industries, and often this effect fades away rather quickly (Brusoni *et al.*, 2006). Firms' expansion appears to be independent from size, possibly with smaller companies exhibiting higher but more variable growth rates. And in general, firms' growth remains very hard to explain. While some studies describe it as driven by small, idiosyncratic and independently distributed shocks – and therefore as essentially erratic – others find highly complex underlying structures (Sutton, 1997; Geroski, 2000; Bottazzi and Secchi, 2006. For an overview, see Dosi, 2007).

These findings suggest that heterogeneous processes drive industry dynamics. Continuous change and turbulence and permanent differences among firms coexist with the emergence of remarkably stable structures at higher levels of aggregation. These results are very well in tune with the basic tenets of a Schumpeterian, evolutionary approach, whereby industries are subject to continuous change and their dynamics are driven by the interaction between processes of learning and selection. However, the strength, speed and directions of these processes vary significantly across sectors and countries. Indeed, various evolutionary models are able to replicate most of these stylized facts at the same time. And also in the more mainstream literature on industrial dynamics, the Schumpeterian and evolutionary metaphors are increasingly and explicitly used (Jovanovic, 1982; Aghion and Howitt, 1992; Ericson and Pakes, 1995; Klette and Kortum, 2004; Luttmer, 2007).

1.2.3 *The evolution of industries and the industry life cycle*

In another, conceptually distinct, stream of analysis, economists have investigated the properties and patterns of the evolution of industries over time. The main focus is on questions like these: How do variables such as concentration, the patterns of entry and exit or the rates and directions of innovation, change over time? Can we observe regularities and/or differences among industries? And what are the microeconomic determinants of these patterns? How can the distinctive aspects of specific industry histories be analyzed and explained? A large literature is now available that investigates the history of different economic sectors in different countries, for different spans of time. Perhaps not surprisingly, these studies are extremely heterogeneous in their inspirations and methodologies, the majority of them being grounded in management, but also in business history, and of course in economics. Most of them, though, share a distinct multidisciplinary orientation. For example, see Klein (1977), Abernathy (1978), Clark (1985) and Klepper (2002b) on autos; Dosi (1984) and Malerba (1985) on semiconductors; Orsenigo (1989) and Gambardella (1995) on biotechnology and pharmaceuticals; Dorfman (1987), Flamm (1988) and Bresnahan *et al.* (2012) on computers; Klepper and Simons (2000a, 2000b) on TV sets and on tires; Greenstein (2010) on the Internet; Phillips (1971) and Mowery and Rosenberg (1982a) on aircraft; Henderson and Clark (1990) on photolithographic alignment equipment; and Rosenberg (1976) on machine tools. See also the cases of seven industries collected in Mowery and Nelson (1999). The study of the evolution of specific industries addresses fundamental questions. What are the sources of firms' competitiveness? How durable can industrial leadership be? Is the emergence of particular leaders the inevitable outcome of the evolution of technology and the general forces driving competition, or is it the result of firm-specific strategies, behaviors and forms of organization? Or is it simply luck? Why is it that, in some instances, episodes of sustained dominance are observed, while in others leadership is transient or even absent?

No unique answer has so far been given to these questions. The main and more popular attempt to draw some generalization about the patterns of industrial evolution is the "industry life cycle (ILC) model" (Abernathy and Utterback, 1978; Gort and Klepper, 1982; Abernathy and Clark, 1985; Klepper and Graddy, 1990; Agarwal and Gort, 1996; Klepper, 1996, 1997). This model is beautifully simple