The Value of Industry Studies: Impact of Luigi Orsenigo's Legacy on the Field of Innovation and Industry Evolution

Junguo Shi and Bert M. Sadowski

Abstract New solutions in artificial intelligence and machine learning require researchers to study, in greater depth, the nature, and dynamics of emerging industries like biotechnology or pharmaceuticals. With his pioneering work, Luigi Orsenigo has demonstrated, in great detail, how new technologies create technological opportunities, change appropriability conditions, and cumulativeness in these emerging industries. Rooted in the evolutionary economics tradition, this approach is better suited in explaining the patterns of innovation, technological change, and the growth in very dynamic industries. In this context, our article reviews the evidence of Luigi Orsenigo's contribution to the economics of innovation, to the tradition of history-friendly models, and to the discussion on the sectoral system of innovation. It concludes by pointing at some unresolved questions in these traditions and new fruitful alleys for future researchers.

Keywords Innovation · Industrial dynamics · Neo-Schumpeterian · History-friendly model · Sectoral system of innovation

1 Introduction

With the emergence of artificial intelligence (AI) and machine learning (ML), a renewed interest has surfaced in studying the nature and the dynamics of growth of firms in the biotechnology and pharmaceutical industry (Buvailo, 2018). This

J. Shi (✉)
School of Finance & Economics, Jiangsu University, Zhenjiang, China

Institute of China Studies, Seoul National University, Seoul, South Korea
e-mail: junguoshi@outlook.comm

B. M. Sadowski
School of Innovation Sciences, Eindhoven University of Technology, Eindhoven, the Netherlands
e-mail: B.M.Sadowski@tue.nl

A. Pyka, K. Lee (eds.), *Innovation, Catch-up and Sustainable Development*, Economic Complexity and Evolution, https://doi.org/10.1007/978-3-030-84931-3_5

interest in the role of AI- and ML-driven solutions in early-stage drug discovery has not only been vital for understanding the market entry of small firms but also the growth patterns of large conglomerates in the industry. This explains the onset of a renaissance of ideas originally developed by Luigi Orsenigo 20 years earlier. His pioneering research on the pharmaceutical and biotechnology industry has shed some new light on the field of economics of innovation and technological change by linking emerging technological opportunities to industrial dynamics while examining the effects of science and technology policy, industry–university relations as well as firm collaborations on these processes. In contrast to the neoclassical economic literature, his research was focused on studying the nature of emerging technologies, the role of market structure, the degree of industry concentration, and the function of government intervention in explaining the growth of industries. This renewed interest has also been echoed by newly established research centers in Asia, where researchers utilized these ideas to create a better understanding of these dynamic industries.

During his scientific career, Luigi Orsenigo has undertaken a number of in-depth empirical industry studies that were outstanding in terms of originality and variety of themes ranging from analyzing the nature of biotechnology in order to develop micro-foundations of the emerging industry, from linking the role of intellectual property rights to the concepts of national and sectoral systems of innovation (Dosi & Malerba, 2018). He developed an in-depth understanding of the technology, which allowed him to provide a sound empirical basis for new theoretical insights. In the following, we examine quantitatively how this research has diffused throughout the international academic community and attracted, in particular, in Asia increasing attention. The ideas and concepts were vital in stimulating new insights in the economics of innovation and technological change by developing new frameworks to (a) study industrial dynamics, in particular, in the biotechnology and pharmaceutical industry; (b) model industrial change in a history friendly manner; and (c) study processes of innovation and technological change on a sectoral level.[1]

2 The contribution of Luigi Orsenigo's research

2.1 General statistics

In this paper, we mainly use the original 40 papers published by Luigi Orsenigo in renowned journals as our research sample. We find 2024 papers citing Luigi Orsenigo's publications in both Scopus and WOS systems, which are distributed across 560 journals (with self-citation excluded). Figure 1 presents a sharp increase

[1] In Luigi Orsenigo's lifelong academic research, he developed theory and methodologies with his co-authors. We use the term *legacy* to discuss his contribution to the academy through the joint works.

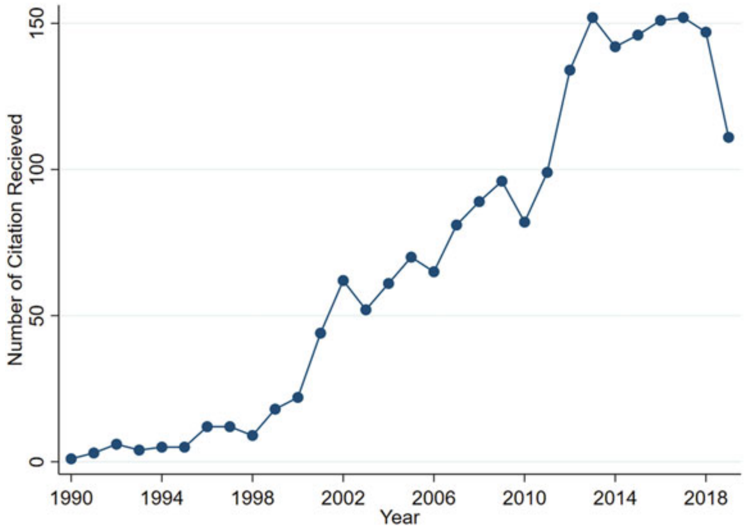

Fig. 1 Growth of papers citing Luigi Orsenigo's publication

in citation during the past two decades. Using indicators like a total number of papers, total citations, g-index, and h-index, we found 30 journals which are intensely citing Luigi Orsenigo's publications and received high citations (see Table 1).

We cluster these 30 journals into the following categories: (1) The most influenced area is (Neo-)Schumpeterian related research journals, namely *Research Policy, Industrial and Corporate Change, Journal of Evolutionary Economics, Economics of Innovation and New Technology, Small Business Economics,* and *Structural Change and Economic Dynamics*. These journals mainly publish papers related to innovation studies that intensely explore Schumpeterian ideas. This is consistent with Luigi Orsenigo's research contribution in the Neo-Schumpeterian tradition. In addition, *Cambridge Journal of Economics* is a journal that welcomes contributions from heterodox economics. (2) The second cluster shows journals related to broadly innovation studies, namely *Technovation, Technological Forecasting and Social Change, International Journal of Technology Management, Science and Public Policy, Technology Analysis and Strategic Management, R&D Management,* and *Journal of Technology Transfer*. These journals deal with issues related to innovation studies. Different from cluster (1), it is not necessary to develop a theory falling in Schumpeterian economics tradition. They focus more on management issues related to innovation. (3) Geography-based fields, like *Regional Studies, Entrepreneurship and Regional Development,* and *Journal of Economic Geography*. Papers published in these journals are mainly fall into the so-called Evolutionary Economic Geography which can be regarded as one branch of Neo-Schumpeterian tradition. (4) Environmental related journals, namely *Ecological Economics, Journal of Cleaner Production, Environmental Innovation* and

Table 1 Influenced journals citing Luigi Orsenigo's publication

Journal name	Total papers	Total citations	g-index	h-index
Research Policy	178	13,053	112	60
Industrial and Corporate Change	126	5539	72	39
Journal of Evolutionary Economics	92	2166	44	26
Technovation	47	1892	43	23
Economics of Innovation and New Technology	66	1316	35	20
Technological Forecasting and Social Change	78	1352	34	21
Small Business Economics	43	1149	33	19
Industry and Innovation	44	832	28	14
Regional Studies	27	971	27	11
Cambridge Journal of Economics	25	1253	25	16
International Journal of Technology Management	26	569	23	8
Strategic Management Journal	19	3980	19	14
Structural Change and Economic Dynamics	31	406	19	11
Science and Public Policy	22	342	18	11
Technology Analysis and Strategic Management	34	370	18	10
European Planning Studies	26	363	18	9
R and D Management	20	315	17	9
Organization Science	15	1832	15	12
Scientometrics	17	234	15	9
Journal of Technology Transfer	14	169	13	5
Ecological Economics	12	419	12	10
Entrepreneurship and Regional Development	11	142	11	7
Journal of Cleaner Production	11	145	11	6
International Journal of Industrial Organization	10	586	10	8
Journal of Economic Geography	9	1289	9	7
Journal of Economic Behavior and Organization	9	124	9	6
Environmental Innovation and Societal Transitions	9	157	9	5
Applied Economics	9	95	9	3
Organization Studies	8	400	8	7
Review of Industrial Organization	8	117	8	6

Societal Transitions. This is an emerging field in Neo-Schumpeterian studies in recent years. This means our society needs more and more innovation to address the current environmental challenges. With the development of manufacturing in Asian economies, environmental problems like acid rain, air pollution, urban sprawl, waste disposal, water pollution, and climate change are received wide concern. It needs to be addressed by the new advanced technologies, like green ICTs, AI, and MI. (5) Industrial organization clusters, like *International Journal of Industrial Organization, Journal of Economic Behavior and Organization, Review of Industrial Organization,* and other related journals like *Applied Economics, Organization Science,* and *Organization Studies*. This reflects the application of the theory of Sector Innovation Systems (one of the contribution by Luigi Orsenigo) into mainstream economics journals.

We also calculate the author distribution in each region citing Luigi Orsenigo's publications. We map this result in Table 2. In general, the authors are mainly from European and north American areas. In Europe, Italy, the United Kingdom, Netherlands, Germany, France, Spain, Sweden, and Demark, count for almost 60% of the papers. Several well-known research institutes like SPRU, UNU-MERIT, LEM, ECIS, IKE, are in these areas, and united cooperated by some projects like ISS, GLOBELICS, DRUID, EUSPRI, or DIME. Asia, Latin America, and Australia are emerging regions for Luigi Orsenigo's research, particularly in China and Korea.

In the following, we will discuss Luigi Orsenigo's main contributions and raise some prospects in each aspect.

2.2 Economics of Innovation and Technological Change in the Biotechnology and Pharmaceutical Industry

In order to explain the dynamics of industrial innovation in the pharmaceutical and biotechnology sector, Luigi Orsenigo examined the institutions and market structure by studying in great detail the network of emerging small firms and their interaction with large companies in the industry (Orsenigo, 1989a). In his thesis, he further developed the economics of innovation and technology change by using concepts like technological opportunities, regimes, learning, market selection, institutions to explain the industrial dynamics in the industry. By using the development of biotechnology as a benchmark, he demonstrated that the nature of biotechnology and the patterns of industrial innovative activities in this emerging industry are interrelated. He showed, in addition, why the role of technological regimes, scientific advances, industry–university relationships, government and public policies have to be considered in order to explain industrial dynamics in the biotechnology sector. These key variables he used later to develop the concept of sectoral systems of innovation. His in-depth understanding of the technology and the industry enabled him to provide ample evidence for his propositions. This empirical basis generated a solid foundation for his follow-up research on the biotechnology industry and allowed him to develop new insights into the economics of innovation and technological change. By leaning on his extensive network of colleagues, he received valuable suggestions to further improve his ideas and encouragement for a wider popularization of his insights.

Table 2 Geography distribution of authors citing Luigi Orsenigo's Publication

Europe (Total number 1931)	Italy	UK	Netherlands	Germany	France	Spain	Sweden	Denmark	Finland	
	383	361	213	194	157	149	107	51	49	
	Norway	Portugal	Austria	Belgium	Switzerland	Greece	Poland	Russia	Czech Republic	
	47	41	36	34	34	21	14	14	7	
	Hungary	Luxembourg	Estonia	Cyprus	Serbia	Iceland	Macedonia	Romania	Croatia	
	5	5	2	2	1	1	1	1	1	
Americas (Total number 451)	United States	Canada	Brazil	Argentina	Colombia	Chile	Uruguay	Mexico	Peru	Dominican
	319	58	32	15	10	7	4	3	2	1
Asia (Total number 261)	China	Korea	Taiwan	Malaya	India	Singapore	Iran	Turkey	Israel	
	68	61	43	14	12	12	10	9	7	
	Macau	Hong Kong	United Arab Emirates	Pakistan	Indonesia	Thailand	Iraq	Bahrain		
	7	6	3	2	2	2	2	1		
Africa (Total number 20)	South Africa	Cameroon	Nigeria	Tunisia	Ghana					
	10	4	3	2	1					
Austilia (Total number 73)	Australia	New Zealand								
	62	11								

In his follow-up research, Luigi Orsenigo devoted his energy in developing a better understanding of the nature of biotechnology and of processes of convergence between the biotechnology and pharmaceutical industry by examining, in particular, the dynamics of firm collaboration (Barbanti et al., 1999; Orsenigo et al., 1998, 2001), differential processes of innovation and industry evolution (Malerba & Orsenigo, 2002), the role of technological regimes (Garavaglia et al., 2012) and innovation policies (Rosiello & Orsenigo, 2008). As a result, several books and book chapters edited by Luigi Orsenigo appeared focusing on economics of innovation and technological change in the biotechnology and pharmaceutical industry such as *The Economics of Biotechnology* (McKelvey & Orsenigo, 2006), and *The Emergence of Biotechnology. Institutions and Markets in Industrial Innovation* (Orsenigo, 1989b). Due to his original way of thinking in this field, he was invited as editor of special issues in academic journals like the *International Journal of Biotechnology*.

As the development of biotechnology increasingly generates technological opportunities for a variety of sectors as well as provides already a significant contribution to economic output (OECD, 2009), topics addressed by Luigi Orsenigo like technological regimes, university–industry linkage, IPR, innovation policy are still fundamental in understanding the dynamics in the industry. In addition, there are new themes like catching up for emerging country firms or convergence among different technological areas in biotechnology which research still needs to address. His techno-economic understanding of the evolution of biotechnology and the pharmaceutical industry has been central to his way to study innovation and industrial evolution in greater detail not only in terms of methodology but also in the way it spurred theory development. In the following, we discuss his contribution to methodology, in particular to the development of history-friendly models (HFMs), and the concept of Sectoral System of Innovation (SSI).

2.3 Impact on History Friendly Model Development

With Luigi Orsenigo, research in the evolutionary theory tradition has taken agent-based simulation models (ABMs) to a new level by including history-based details into account in formal complex modelling exercises. As complexity has been at the heart of modern adaptive and dynamic economic systems (Tesfatsion, 2001), simulations provided researchers with tools to translate complex economic relationships of agents and their interactions into economic models. In order to explore the complexity of industrial dynamics, ABMs have been a suitable option available to economists to undertake such complex analysis (Garavaglia, 2010). As ABMs have been considered as a convenient way of exploring evolution in economics, these models have been criticized as limited in their explanatory power (see Yoon and Lee (2009) for a detailed review). As a result, a search process for more elaborated methodologies for ABMs started driven by two different, but complementary theoretical traditions. One tradition, e.g., Silverberg et al. (1988), Bottazzi et al. (2001), Winter et al. (2000), Fagiolo and Dosi (2003) and Dosi et al. (2006), focused on more general models to explore fundamental principles of evolutionary economics, explaining as many observed phenomena as possible with as few assumptions as possible. In this tradition, more general models were developed that had the potential to cover areas of neoclassical economics like the business cycle or economic growth theories, in more realistic ways. These models were aimed at providing more fundamental results to evolutionary economics (Orsenigo, 2007). A second theoretical tradition, in contrast, was aimed at studying the evolution of industries in greater detail. In this tradition, Luigi Orsenigo and his colleagues developed a family of the HFMs focusing on the evolution of industries and on "stylized" facts that have been identified and examined by historical analyses and case studies in order to add history-based details to the formal representation (Malerba et al., 1999).

The "stylized" facts in HFMs that are included in ABM are derived from qualitative theories about mechanisms and factors affecting innovation and industry evolution. These mechanisms and factors are generated based on empirical research in industrial organization, business strategy and organization, and by analyzing histories of industries. The objective in using these "stylized" facts is to link empirical evidence to stand-alone simulation models in order to generate new insights into formal theory. In this respect, HFMs are aimed at exploring whether particular mechanisms and forces built into the model can generate (explain) the patterns predicted. The model building in the HFMs tradition is guided by verbal explanations and appreciative theorizing.

As a variety of models have been developed for different industries in a history-friendly fashion, the challenge for Luigi Orsenigo was to generate some more general determinants of industry development. Comparisons between different models became a way forward to generate new and more general hypotheses about the factors shaping the interactions between technological change and industrial evolution. Almost two decades have passed between the first HFM (Malerba et al., 1999) and later HFMs focusing on a greater variety of industries. Luigi Orsenigo and his colleagues developed different history-friendly models focusing on the evolution of three industries: computers, semiconductors, and pharmaceuticals (Malerba et al., 2016). As a result of their analysis, they were able to generate a new HFM style of analysis that combined the investigation of technological progress and its relationships with competition and the evolution of industry structures. Based on their joint effort to develop this methodology, they won the prestigious Schumpeter Prize from the International Joseph A. Schumpeterian Society in 2012.

In comparing these three industries, Luigi Orsenigo and his colleagues were able to use several topics and factors to explain industrial dynamics, like the role of segmented demand, user–producer interaction, public policy, entry and the dynamics of concentration, IPR, technological regimes, vertical structure of production, and market selection. Table 3 lists the main HFMs publications written by Luigi Orsenigo with his colleagues.

Luigi Orsenigo's work has been influential for the analysis of other industries like the synthetic dye industry (Brenner & Murmann, 2003) or the DRAM industry (Kim & Lee, 2003) and to explore new topics, e.g., product portfolio (Mäkinen & Vilkko,

Table 3 The main HFMs publications by Orsenigo

Author(s)	Title	Journal	industry	year
Malerba, F., Nelson, R., Orsenigo, L. and Winter, S.	'History-friendly' models of industry evolution: the computer industry	Industrial and Corporate Change	Computer	1999
Malerba, F., Nelson, R., Orsenigo, L. and Winter, S.	Competition and industrial policies in a 'history friendly' model of the evolution of the computer industry	International Journal of Industrial Organization	Computer	2001
Malerba, F., Nelson, R., Orsenigo, L. and Winter, S	Product Diversification in a "History-Friendly Model of the Evolution of the Computer Industry	in E. Larsen and A. Lomi (eds.), "Simulating organizational societies.", Cambridge (Ma.), MIT Press	Computer	2001
Malerba, F. and Orsenigo, L.	Innovation and market structure in the dynamics of the pharmaceutical industry and biotechnology: towards a history-friendly model.	Industrial and Corporate Change	Pharmaceutical & Biotechnology	2002
Malerba, F., Nelson, R., Orsenigo, L. and Winter, S. G.	Firm Capabilities, Competition and Industrial Policies in a History-Friendly Model of the Computer Industry	in C. Helfat (ed.) "The SMS Blackwell Handbook of Organizational Capabilities. Emergence, Development and Change", Blackwell, Oxford	Computer Industry	2003
Garavaglia, C., Malerba, F., Orsenigo, L. and Pezzoni, M.	Entry, Market Structure and Innovation in a History-Friendly Model of the Evolution of the Pharmaceutical Industry	in G. Dosi and M. Mazzuccato (eds.), Knowledge Accumulation and Industry Evolution. The Case of Pharma-Biotech", Cambridge University Press	Pharmaceutical Industry	2006
Malerba, F., Nelson, R., Orsenigo, L. and Winter, S.	Demand, Innovation and the Dynamics of Market Structure: the Role of Experimental Users and Diverse Preferences	Journal of Evolutionary Economics	Computer Industry	2007
Malerba, F., Nelson, R., Orsenigo, L. and Winter, S.	Public policies and changing boundaries of firms in a "history-friendly" model of the co-evolution of the computer and semiconductor industries	Journal of Economic Behavior & Organization	Computer & semiconductor	2008
Malerba, F., Nelson, R.,	Vertical integration and disintegration of	Industrial and Corporate Change	Computer & semiconductor	2008

(continued)

Table 3 (continued)

Author(s)	Title	Journal	industry	year
Orsenigo, L. and Winter, S.	computer firms: a history-friendly model of the coevolution of the computer and semiconductor industries			
Garavaglia, C., Malerba, F., Orsenigo, L. and Pezzoni, M.	Technological regimes and demand structure in the evolution of the pharmaceutical industry	Journal of Evolutionary Economics	Pharmaceutical industry	2012
Garavaglia, C., Malerba, F., Orsenigo, L. and Pezzoni, M.	Innovation and Market Structure in Pharmaceuticals: An Econometric Analysis on Simulated Data	Jahrbücher für Nationalökonomie und Statistik	Pharmaceutical industry	2014

2014), the dynamics and evolution of technologies (Fontana et al., 2008), successive changes in industrial leadership (Fontana & Zirulia, 2015; Landini et al., 2017; Yu et al., 2020) and the evolution of National Innovation Systems (Yoon, 2009). In addition to analysis on the micro and meso levels, HFMs have recently been used to analyze at macro level, e.g., to study catch-up of a latecomer with an incumbent country (Landini & Malerba, 2017). There still is some work to be done in this area to follow Luigi Orsenigo's style of HFM modelling (Malerba, 2011; Garavaglia, 2010; Yoon & Lee, 2009). First of all, more industries should be considered that are quite different compared to the already examined one's (such as business service industries or agro-food environmental friendly industries) in order to model the specificities and dynamics of these industries. Secondly, a stronger focus should be on deriving factors affecting technological change, the dynamics of market structure, industrial leadership, the vertical and horizontal structure of production, and the division of innovative labor in industries. In this context, the work on selection and on the role of institutions will become more important. These more "general models" can be considered as the second generation of ABMs adopting HFM frameworks. Finally, it would be interesting to study "future counterfactuals," in which the researcher investigates potential future conditions that could lead to different outcomes. This prospect is highly ambitious but it may contribute to stimulating a debate about the normative role of simulation models in economics (Garavaglia, 2010).

2.4 *Sectoral Systems of Innovation*

The development of the concept of sectoral systems of innovation provided in evolutionary economics a new framework for examining factors that affect innovation in sectors that are based on three building blocks: knowledge and technologies, actors and networks, and institutions (Malerba, 2005). Luigi Orsenigo explored these factors further in greater detail during his academic career. The idea that knowledge is of crucial importance for the performance and growth of firms, regions, and countries became in recent years widely acknowledged in the literature (Nelson, 1982). As a result, research has increasingly focused on the question of how knowledge can be characterized and what is the impact of knowledge on the economy. This led to a number of studies focusing on a better conceptualization of knowledge, its relevant dimensions and economic consequences as well as the mechanisms through which knowledge leads to greater economic welfare (Malerba & Orsenigo, 2000). An important area of research has been on tacit and codified knowledge (Nelson & Winter, 1982). By using a distinction between tacit and codified knowledge, the literature has been increasingly recognized that the concept of knowledge is more complex and multifaceted. Thus, the types and forms of knowledge are likely to exert in quite different ways effects on the organization of economic activities, productivity, and the overall rates of the technological and economic process. Malerba and Orsenigo (2000) argued that the distinction between tacit and codified knowledge constitutes only a part of the categorization of the dimensions of knowledge relevant to an understanding of innovative activities of firms and the evolution of industries. They further identified other main dimensions of knowledge that are relevant for an understanding of a firms' innovation processes and the evolution of industries. The authors emphasized, in addition, the relevance of competencies and some further properties of knowledge, like technological regimes, different domains of knowledge (in terms of technology, demand, and applications), and knowledge complementarities (and the related issues of coordination and the integration of these complementarities).

Luigi Orsenigo proposed that there are persistence and heterogeneity of innovative activities at the firm level determining patterns of technological change in different industries as well as countries. In their paper, Malerba et al. (1997) computed indicators of persistence and heterogeneity using the OTAF-SPRU patent database at the firm level for five European countries over the period 1969–1986 for 33 technological classes to answer the following questions, i.e., are persistence and heterogeneity associated with higher degrees of concentration in innovative activities, stability in the ranking of innovators, and lower degrees of entry and exit in the population of innovators? Or, do the patterns of innovation depend on other variables like firm size and industrial concentration? Moreover, they focused on the question of what are the relationships between the patterns of innovative activities, their determinants, and the technological specialization of countries. The results of their analysis show that persistence and asymmetries are important (and strongly related) phenomena that affect the patterns of innovative activities across countries and sectors, while the role of market structure variables is less clear. Furthermore, international technological specialization is associated with the competitive core of persistent innovation. In Cefis and Orsenigo (2001), the authors further examine the persistence of innovative activities at the firm level from a comparative perspective by using a new data set composed of panel data for France, Germany, Italy, the UK, Japan, and the USA. Using a transition probability matrix approach, they found empirical evidence for the existence of persistence in innovative activities. However, the significance of these results was not very high at the aggregate level and there were signs that persistence was declining over time. However, both innovators and non-innovators had a high probability to remain at their positions and persistent innovators were responsible for a disproportionately high share of innovative activities. In this context, the authors showed that persistence in innovative activities is rather strong. The observed trends could be found in all countries in the sample, even there were also some country-specific properties of these processes. In addition, the authors found that there was heterogeneity across industries and with respect to firm size. Furthermore, intersectoral differences were invariant across countries, suggesting that persistence is (at least partly) a technology-specific variable. Persistence tends to increase with firm size, but the relationship between firms' size and persistence is strongly country specific.

By using empirical data, Malerba and Orsenigo (1995) demonstrated that Schumpeterian patterns of innovation are technology-specific and are related to specific technological regimes. Their empirical analysis based on patent data from four countries found that patterns of innovation activities differ systematically across technological classes, while remarkable similarities emerge across countries for each technological class. These results strongly suggested that "technological imperatives" and technology-specific factors (which are closely linked to technological regimes) play a major role in determining the patterns of innovative activities across countries. In a later study, Malerba and Orsenigo (1996) investigated—based on patent data of 49 technological classes from six countries—these patterns of innovation activities at technological and country levels in greater detail. In this paper, two groups of technological classes were identified: "*Schumpeter Mark I*" and "*Schumpeter Mark II*." These innovative activities in these two groups were structured and organized in a different way. The first group was characterized by a *widening pattern* in which the concentration of innovative activities was low, innovators were small, the stability in the ranking of innovators was low and the entry of new innovators was high. The second group represented a *deepening pattern* in which concentration of innovative activities was higher than in the first group, innovators were larger in terms of size, there was more stability in the ranking of innovators, and the rate of entry was lower. The first group composed of mechanical technologies and traditional sectors, while the latter group included chemicals and electronics. These results suggested that technology-related factors (such as technological regimes, defined in terms of conditions of technological opportunity, appropriability, cumulativeness, and properties of the knowledge base) play a major role in determining the specific patterns of innovative activities of a technological class across countries. Within these constraints, country-specific factors introduce variances across countries in the pattern of innovative activities for a specific technological class. In addition, the authors also examined the relationships between specific features of the patterns of innovative activities and international technological specialization. Technological advantages appear in general to be linked to higher degrees of asymmetries among innovators, higher stability of the ranking of innovators, smaller economic size of the innovating firms, and lower entry rates of new innovators. These relationships, however, are across the two groups of technological classes. In the Schumpeter Mark I (widening) technological classes, international technological specialization was associated with relatively higher degrees of asymmetries among innovators and entry of new innovators (as well as smaller firm size) while in the Schumpeter II (deepening) technological classes, international technological specialization was linked to the existence of a stable but competitive core of persistent innovators. To further confirm these conclusions, Luigi Orsenigo conducted additional studies using other databases to further characterize technological regimes and Schumpeterian patterns of innovation (Breschi et al., 2000; Malerba & Orsenigo, 1996, 1997). In focusing on the relationship between technological regimes and patterns of innovative activities, he studied, in addition, how technological regimes influence industrial evolution (Dosi et al., 1994, 1995, 1997; Malerba & Orsenigo, 1999). Earlier studies had already revealed the effects of more specific determinants of technological regimes on firm behavior (Malerba & Orsenigo, 1993).

In their 2013 article, Luigi Orsenigo and his co-authors examined the moderating role of demand and technological regimes in shaping the relationship between consumers switching costs and first-mover advantage (Capone et al., 2013). Their research results showed that the extent to which switching costs can be an effective mechanism in generating first-mover advantage depends on demand regimes, i.e., whether demand is homogeneous or fragmented. The dimensions of technological regimes do not matter when demand is homogenous. However, in the case of fragmented demand, these regimes can be key determinants of the existence of advantages for early movers.

Luigi Orsenigo found some exceptional cases that did not follow the general role of technological regimes and industrial dynamics. The pharmaceutical industry—one of Luigi Orsenigo's favorite study subjects—represented such an exception. The pharmaceutical industry has been described as a sector characterized by high R&D and marketing expenditure. These characteristics would suggest that—as a first approximation—the industry should be characterized by a high degree of concentration. However, the concentration has been consistently lower over the whole history of the growth of the industry. Furthermore, competition in the industry does not occur among many small (relative to the market) firms of approximately similar size. Rather, the industry is largely dominated by a core of innovative firms which have remained quite small and stable for a prolonged period of time. To understand the structure and dynamics in the industry, Luigi Orsenigo had to delve deeper into the analysis of the determinants by developing a modified version of his previous "history-friendly" model of the evolution of the pharmaceutical industry (Malerba & Orsenigo, 2002; Garavaglia et al., 2012). The simulation results presented in the paper in 2012 (Garavaglia et al., 2012) demonstrated that technological regimes remain the fundamental determinants of the patterns of innovation. Furthermore, the authors showed that the demand structure played a crucial role in preventing the emergence of concentration through a partially endogenous process of discovery of new submarkets. In addition, they indicated that it is not simply market fragmentation as such that produces these results, but rather the entity of the "prize" that innovators can gain relative to the overall size of the market. Finally, the paper provided some evidence on the proposition that emerging industry leaders start-up as innovative early entrants in large submarkets.

By looking at the networks of actors in the transformation of industries, Malerba and Orsenigo (2008) explored the notion of how user–producer interaction affects innovation and the dynamics of market structure in industry evolution. In Malerba and Orsenigo (2010), they extended this analysis by examining how the benefits of user–producer interactions influence the rates of innovation and the evolution of market structure in two related industries under alternative contractual arrangements, namely the length and the exclusivity of the contracts. In the 2010 paper, they showed that (a) there is a trade-off between the exploitation of past experience and the exploration of new suppliers; (b) even if externalities are existing, advantages arising from interactions do not spill over to other firms; (c) imperfect information and agents heterogeneity are crucial factors in determining the consequences of alternative contractual arrangements on industry dynamics; and (d) vertical interdependencies influence the effects of specific firms' decisions across industries and over time, so that the resulting dynamics can be characterized as an interacting path-dependent process.

In an earlier academic report, Luigi Orsenigo and his co-author focused on university–industry collaboration in Sweden and provided an analytical overview of the trends in the governance of public R&D in Sweden during the period 1990–2005 (Jacob & Orsenigo, 2007). In addition, the report examined three of the most, to date, influential perspectives on policy namely the concepts of systems of innovation, Mode 2, and Triple Helix.[2]

In one of his earlier studies, Luigi Orsenigo analyzed the evolution of partnership agreements among firms in biotechnology industry (Barbanti et al., 1999). The study showed that there is a strong complementarity between internal and external research. In addition, as there are co-existing processes of specialization and consolidation of competencies, there is not necessarily a contradiction between increasing degrees of vertical integration and increasing collaboration. This trend toward collaboration is reinforced by the fact that the experience accumulated in managing collaborative relations improves their attractiveness. The analysis supports the idea of the emergence of a very structured and hierarchical network, made by the expansion of constellations of firms, linked together by a relatively small number of key agents. In Bruno and Orsenigo (2003), Luigi Orsenigo further analyzes the links between industry and academia by using data on the performance of university departments and institutes involved in attracting funding from industrial sources. It shows that conventional political strategies to support industry–academia links by building up intermediary organizations might fail as industry is mainly interested in excellent academic quality.

[2] System of innovation is oriented toward the macro level, and the Mode 2 argument is concerned almost exclusively with the conditions for the organization and production of knowledge.

Luigi Orsenigo expanded his research and focused on the dynamics of the network of collaborative agreements in R&D in the pharmaceutical and biotechnology industry after the "molecular biology revolution" (Orsenigo et al., 1998, 2001). In Orsenigo et al. (1998), he and his co-authors found that the topological properties of network structure remained relatively unchanged while the size of the network was increasing over time due to net entry. Moreover, the evolution of the network occurred without relevant deformations in the core-periphery profile. With regards to the age-dependent propensity to collaborate, the extent of inter-generational collaboration was much more significant compared to intra-generational collaboration. In addition, the propensity of firms of a given generation to enter into collaboration with firms of a different generation increased with the distance between the two, while the total number of intra-generational collaborations decreasing over time and tending to decrease for most recent generations. The paper then moves a step forward in the direction of establishing a connection between the structure and evolution of knowledge bases and the structure and evolution of organizational forms in innovative activities in a science-intensive industry. In Orsenigo et al. (2001), this research is taken a step further by investigating how the underlying relevant technological conditions induce distinguishable patterns of change in the structure and the evolution of an industry. The graph-theoretic techniques introduced in the paper were mapping the major technological discontinuities on changes observed at the level of dominant organization forms. The paper concludes that there might be more applications in other domains, whenever the identification of structural breaks and homological relationships between technological and industrial spaces are considered important issues.

In summary, Luigi Orsenigo touched on almost all aspects and elements of the concept of sectoral systems of innovation, provided original insights into the further development of the concept by using new methodologies. His studies provided new directions for theory development. Future studies must examine other industries and check whether existing within this tradition is sufficient to explain their development. There are a variety of emerging research questions related to industrial evolution which can be analyzed within this framework.

3 Innovation, Industrial Change, and Economics Evolution

Professor Luigi Orsenigo was a remarkably talented and influential scholar, well known for his contributions in developing conceptual frameworks to analyze innovation and study industrial dynamics as well as providing empirical evidence on evolutionary processes especially in focusing on the evolution of the biotechnology industry. Luigi Orsenigo's lifelong work was focused on studying innovation and industrial dynamics from an evolutionary economics perspective leading to valuable contributions within the Neo-Schumpeterian tradition. This article has attempted to capture three important elements in his pioneering research in the areas of the economics of innovation by focusing, in particular, on biotechnology and the pharmaceutical industry, in the area of history-friendly models, and in the area of the sectoral system of innovation. His studies in these three areas have highlighted hitherto unknown mechanisms of sectoral development that caused industries to evolve and transform over time. Luigi Orsenigo was without any doubt a leading authority in these areas of research. With his contribution to theory development, he was pushing the frontiers in modelling technological change and innovation forward. Based on analytical rigor, he combined both empirical and theoretical works.

His work provided for the plethora of innovation studies a strong and coherent intellectual framework aimed at a more general understanding of the relationship between innovation and industrial evolution. Luigi Orsenigo developed history-friendly models that combined advanced agent-based simulation techniques with "stylized" facts of a specific industrial history. By using a variety of methodologies, he made a series of path-breaking contributions leading to a better understanding of the mechanisms of industry evolution. Interestingly, recent research has applied in greater detail agent-based simulation techniques to the catch-up growth of Asian companies (Li et al., 2019; Yu et al., 2020).

Based on his contributions, some research avenues for future scholarly work can be identified. First, HFMs can be used to develop and analyze more general assumptions about the determinants of the evolution of market structures. As HFMs are developed in order to provide original insights and suggestions for the study of the evolution of industrial structures, particularly their dynamic properties, there is a need to examine in greater detail the sources of increasing returns in markets. There surely is ample scope for constructing new models of different industries with their respective histories and generate new theoretical questions. HFMs might, therefore, provide better tools for progress to a more general and a more empirically as well as historically founded theory of industry evolution and economic change. The fundamental contributions in this area have been discussed in Sect. 2. Publications based on HFMs have increased the understanding of factors affecting the relationship between innovation and market structure in an evolutionary and (Neo-)Schumpeterian tradition. Luigi Orsenigo and his colleagues developed their research in the hope that HFMs might be a tool to foster dialogue and cross-fertilization between different traditions in the literature by identifying not only differences but also similarities in the different frameworks. A promising area of future work has therefore been to compare results generating by HFMs with the empirical evidence and the prediction of other models.

Second, Luigi Orsenigo has developed his theory based on the nuanced investigation of the biotechnology industry. Within an emerging bioeconomy, biotechnology already significantly contributes to economic output but the growth of biotechnology remains an interesting field of investigation. With the introduction of information and communication technologies, some traditional topics that Luigi Orsenigo has discussed like technological regimes, university–industry linkage, IPR, innovation policy, and some new themes like catching up from emerging countries, technological convergence among different areas, are still worthy of research. As a science-based industry, the technological regimes within biotechnology and the pharmaceutical industry are characterized by high R&D input, high marketing investment, and high uncertainty about the potential of the technology, however, more factors that facilitate the development of the industry need to be further explored. For example, many different agents are involved in the process of exploitation of new opportunities in the industry, scientists, large incumbent companies as well as new emerging firms, government regulators, universities, and research institutes. The agents have established a variety of complex relationships, encompassing cooperation and competition, contractual and hierarchical forms of interaction. Open questions in this tradition are related to the role of knowledge flows and spillovers among different agents, the function of different channels of technological spillovers influencing the dynamics of industry. Luigi Orsenigo has investigated how technological conditions and the knowledge base can induce distinguishable patterns of change in network dynamics (Orsenigo et al., 1998, 2001). Later this has been taken up by Malerba (2007) in order to point at some possible research opportunities about collaborations in innovation and R&D network. Research found also that there is a rich-club phenomenon in the evolution of cooperation networks among different agents owing to its technological regimes. Further research must address factors like collaborative capability, cohesive effect, even some geographic proximity factors, that are contributing to his kind of network dynamics. The recent weighted social network technique provides as a good tool to investigate these questions related to the structural change of cooperation network in biotechnology and the pharmaceutical industry. In addition to the cooperation network, identifying the technological trajectories or core knowledge of this industry has been fundamental to explore research questions related to knowledge flows and industrial dynamics. In this tradition, main path analysis, which is based on evolutionary theorizing of the growth of technological paradigms and technological trajectories (Dosi, 1982), and the exploration of different technological contexts based on patent data (e.g., Verspagen, 2007) and paper information (Hung et al., 2014) are useful tools for further research in this tradition.

Thirdly, Luigi Orsenigo has contributed to the concept of sectoral systems of innovation. Several steps need to take to further enrich this concept. First, the current structure should be replenished and adjusted to suit different contexts. For example, Lee and Lim (2001) extended the original sectorial systems of innovation framework to the context of catch-up in developing or latecomer countries. Some modifications or adaptations are necessary to make these models "friendlier" to different contexts. In contrast to the original framework, it will increasingly become important to categorize technological regimes in terms of uncertainty and fluidity of the technological trajectory, the frequency of innovation, and the need to access external knowledge bases. In this respect, the role of scientists, the relationship between science and technology, as well as market structure in upstream or downstream industries, different knowledge base and competence, and some other elements should also be considered in the framework of sectoral systems of innovation. Second, the framework should be used to analyze more industries not only technological intensity industries but also in some low technological industries, not just in manufacturing sectors but also in service sectors (one notable exception has been Castellacci (2008)). Third, as the elements in the sectoral system of innovation are co-evolving, the analysis of these elements still remains a necessity. For example, Luigi Orsenigo discussed in some of his papers that the role of technological regimes is exogenously determined and related parameters are not able to change the whole industry history. Some progress in this area has been made (e.g., Malerba & Mani, 2009). Future extensions should be encouraged like considering the coevolution of technological regimes and industry dynamics in simulation models. Finally, public policy proposals may be developed on how to affect the transformation of sectoral systems, the innovation and diffusion processes, and the competitiveness of firms, regions, and countries. In this context, Luigi Orsenigo has started to analyze the failure or side effects of public policy (Malerba et al., 2008). A sectoral system perspective may help to identify mismatches and blocks that parts of the system exert on the rest and it may help overcome vicious cycles that block systems in their growth, development, and transformation. In the evolutionary (and innovation system) tradition, this work should go hand in hand, and be continuously confronted with in-depth empirical work.

In contrast to the neoclassical paradigm on technological change and market structure, Orsenigo's contribution to the importance of innovation and the dynamics of industrial change are increasingly vital in understanding the structure and the growth of indigenous companies in Asia. In order to develop a better understanding of the growth of companies in China (Guo et al., 2019), South Korea (Giachetti & Marchi, 2017; Lee & Lim, 2001) or Japan (Lee, 1996), a focus on the determinants of technological change and market structure at the sectoral level has shown surprising results. As a number of studies have developed new insights on the firm-internal dynamics of these companies (Lee & Malerba, 2017), a few papers have been able to show in a rigorous empirical manner that the interaction between firms across different sectors has been vital to their growth (Lee, 1996).

Surely there is much more to Luigi Orsenigo's work than his emphasis on cross-disciplinarily. He influenced with his synthesis of existing knowledge about innovation and industrial dynamics with new insights theoretical development. In studying the legacy of Luigi Orsenigo, it seems that much of what is on the research agenda today actually consists of relatively modest elaborations on the themes he has taken up there much earlier. We hope that future scholarly work will benefit from developing new answers to the currently unresolved research questions and will utilize the new insights which Luigi Orsenigo identified during his career.

References

Barbanti, P., Gambardella, A., & Orsenigo, L. (1999). The evolution of collaborative relationships among firms in biotechnology. *International Journal of Biotechnology, 1*(1), 10–29.

Bottazzi, G., Dosi, G., & Rocchetti, G. (2001). Modes of knowledge accumulation, entry regimes and patterns of industrial evolution. *Industrial and Corporate Change, 10*(3), 609–638.

Brenner, T., & Murmann, J. P. (2003). The use of simulations in developing robust knowledge about causal processes: Methodological considerations and an application to industrial evolution. In *Computing in economics and Finance*. Society for Computational Economics.

Breschi, S., Malerba, F., & Orsenigo, L. (2000). Technological regimes and Schumpeterian patterns of innovation. *The Economic Journal, 110*(463), 388–410.

Bruno, G. S., & Orsenigo, L. (2003). Variables influencing industrial funding of academic research in Italy: An empirical analysis. *International Journal of Technology Management, 26*(2–4), 277–302.

Buvailo, A. (2018). *How big pharma adopts AI to boost drug discovery*. BiopharmaTrend.com 8 October 2018.

Capone, G., Malerba, F., & Orsenigo, L. (2013). Are switching costs always effective in creating first-mover advantage? The moderating role of demand and technological regimes. *Long Range Planning, 46*(4–5), 348–368.

Castellacci, F. (2008). Technological paradigms, regimes and trajectories: Manufacturing and service industries in a new taxonomy of sectoral patterns of innovation. *Research Policy, 37* (6–7), 978–994.

Cefis, E., & Orsenigo, L. (2001). The persistence of innovative activities: A cross-countries and cross-sectors comparative analysis. *Research Policy, 30*(7), 1139–1158.

Dosi, G. (1982). Technological paradigms and technological trajectories: A suggested interpretation of the determinants and directions of technical change. *Research Policy, 11*(3), 147–162.

Dosi, G., Fagiolo, G., & Roventini, A. (2006). An evolutionary model of endogenous business cycles. *Computational Economics, 27*(1), 3–34.

Dosi, G., & Malerba, F. (2018). In memory of a friend and distinguished scholar: Luigi Orsenigo (1954–2018). *Economia e Politica Industriale, 45*(2), 109–109.

Dosi, G., Malerba, F., Marsili, O., & Orsenigo, L. (1997). Industrial structures and dynamics: Evidence, interpretations and puzzles. *Industrial and Corporate Change, 6*(1), 3–24.

Dosi, G., Malerba, F., & Orsenigo, L. (1994). Evolutionary regimes and industrial dynamics. In *Evolutionary and neo-Schumpeterian approaches to economics* (pp. 203–229). Springer.

Dosi, G., Marsili, O., Orsenigo, L., & Salvatore, R. (1995). Learning, market selection and the evolution of industrial structures. *Small Business Economics, 7*(6), 411–436.

Fagiolo, G., & Dosi, G. (2003). Exploitation, exploration and innovation in a model of endogenous growth with locally interacting agents. *Structural Change and Economic Dynamics, 14*(3), 237–273.

Fontana, R., Guerzoni, M., & Nuvolari, A. (2008). Habakkuk revisited: A history friendly model of American and British technology in the nineteenth century (No. 2008, 064). Jena economic research papers.

Fontana, R., & Zirulia, L. (2015). "... then came Cisco, and the rest is history": A 'history friendly' model of the Local Area Networking industry. *Journal of Evolutionary Economics, 25*(5), 875–899.

Garavaglia, C. (2010). Modelling industrial dynamics with "history-friendly" simulations. *Structural Change & Economic Dynamics, 21*(4), 258–275.

Garavaglia, C., Malerba, F., Orsenigo, L., & Pezzoni, M. (2012). Technological regimes and demand structure in the evolution of the pharmaceutical industry. *Journal of Evolutionary Economics, 22*(4), 677–709.

Giachetti, C., & Marchi, G. (2017). Successive changes in leadership in the worldwide mobile phone industry: The role of windows of opportunity and firms' competitive action. *Research Policy, 46*(2), 352–364.

Guo, L., Zhang, M. Y., Dodson, M., & Gann, D. (2019). Huawei's catch-up in the global telecommunication industry: Innovation capability and transition to leadership. *Technology Analysis & Strategic Management, 31*(12), 1395–1411.

Hung, S. C., Liu, J. S., Lu, L. Y., & Tseng, Y. C. (2014). Technological change in lithium iron phosphate battery: The key-route main path analysis. *Scientometrics, 100*(1), 97–120.

Jacob, M., & Orsenigo, L. (2007). Leveraging Science for innovation: Swedish policy for university-industry collaboration 1990–2005, SNS Förlag Report.

Kim, C. W., & Lee, K. (2003). Innovation, technological regimes and organizational selection in industry evolution: A 'history friendly model' of the DRAM industry. *Industrial and Corporate Change, 12*(6), 1195–1221.

Landini, F., Lee, K., & Malerba, F. (2017). A history-friendly model of the successive changes in industrial leadership and the catch-up by latecomers. *Research Policy, 46*(2), 431–446.

Landini, F., & Malerba, F. (2017). Public policy and catching up by developing countries in global industries: A simulation model. *Cambridge Journal of Economics, 41*(3), 927–960.

Lee, K. R. (1996). The role of user firms in the innovation of machine tools: The Japanese case. *Research Policy, 25*, 491–507.

Lee, K., & Lim, C. (2001). Technological regimes, catching-up and leapfrogging: Findings from the Korean industries. *Research Policy, 30*(3), 459–483.

Lee, K., & Malerba, F. (2017). Catch-up cycles and changes in industrial leadership: Windows of opportunity and responses of firms and countries in the evolution of sectoral systems. *Research Policy, 46*(2), 338–351.

Li, D., Capone, G., & Malerba, F. (2019). The long march to catch-up: A history-friendly model of China's mobile communications industry. *Research Policy, 48*(3), 649–664.

Mäkinen, S. J., & Vilkko, M. K. (2014). Product portfolio decision-making and absorptive capacity: A simulation study. *Journal of Engineering and Technology Management, 32*, 60–75.

Malerba, F. (2005). Sectoral systems of innovation: A framework for linking innovation to the knowledge base, structure and dynamics of sectors. *Economics of Innovation and New Technology, 14*(1–2), 63–82.

Malerba, F. (2007). Innovation and the dynamics and evolution of industries: Progress and challenges. *International Journal of Industrial Organization, 25*(4), 675–699.

Malerba, F. (2011). *Modelling innovation and the evolution of industries: History-friendly models*. Presentation in GLOBELICS ACADEMY.

Malerba, F., & Mani, S. (2009). *Sectoral systems of innovation and production in developing countries: Actors, structure and evolution*. Edward Elgar Publishing.

Malerba, F., Nelson, R., Orsenigo, L., & Winter, S. (1999). 'History-friendly' models of industry evolution: The computer industry. *Industrial and Corporate Change, 8*(1), 3–40.

Malerba, F., Nelson, R., Orsenigo, L., & Winter, S. (2008). Public policies and changing boundaries of firms in a "history-friendly" model of the co-evolution of the computer and semiconductor industries. *Journal of Economic Behavior & Organization, 67*(2), 355–380.

Malerba, F., Nelson, R., Orsenigo, L., & Winter, S. (2016). *Innovation and the evolution of industries-history-friendly models*. Cambridge University Press.

Malerba, F., & Orsenigo, L. (1993). Technological regime and firm behaviour. *Industrial and Corporate Change, 2*, 45–71.

Malerba, F., & Orsenigo, L. (1995). Schumpeterian patterns of innovation. *Cambridge Journal of Economics, 19*(1), 47–65.

Malerba, F., & Orsenigo, L. (1996). Schumpeterian patterns of innovation are technology-specific. *Research Policy, 25*(3), 451–478.

Malerba, F., & Orsenigo, L. (1997). Technological regimes and sectoral patterns of innovative activities. *Industrial and Corporate Change, 6*(1), 83–118.

Malerba, F., & Orsenigo, L. (1999). Technological entry, exit and survival: An empirical analysis of patent data. *Research Policy, 28*(6), 643–660.

Malerba, F., & Orsenigo, L. (2000). Knowledge, innovative activities and industrial evolution. *Industrial and Corporate Change, 9*(2), 289–314.

Malerba, F., & Orsenigo, L. (2002). Innovation and market structure in the dynamics of the pharmaceutical industry and biotechnology: Towards a history-friendly model. *Industrial and Corporate Change, 11*(4), 667–703.

Malerba, F., & Orsenigo, L. (2008). User-producer relationships, innovation and the evolution of two related industries, paper presented at the DIME Conference on Innovation and Industrial Dynamics, Bocconi University, Milan, 2008.

Malerba, F., & Orsenigo, L. (2010). User–producer relations, innovation and the evolution of market structures under alternative contractual regimes. *Structural Change and Economic Dynamics, 21*(1), 26–40.

Malerba, F., Orsenigo, L., & Peretto, P. (1997). Persistence of innovative activities, sectoral patterns of innovation and international technological specialization. *International Journal of Industrial Organization, 15*(6), 801–826.

McKelvey, M., & Orsenigo, L. (2006). *The economics of biotechnology* (Vol. 198). Edward Elgar.

Nelson, R. R. (1982). The role of knowledge in R&D efficiency. *Quarterly Journal of Economics, 93*, 453–470.

Nelson, R. R., & Winter, S. (1982). *An evolutionary theory of economic change*. Harvard University Press.

OECD Publishing. (2009). *The bioeconomy to 2030: Designing a policy agenda*. Organisation for Economic Co-operation and Development.

Orsenigo, L. (1989a). *Institutions and markets in the dynamics of industrial innovation: The theory and the case of biotechnology*. Thesis, .

Orsenigo, L. (1989b). *The emergence of biotechnology: Institutions and markets in industrial innovation*. Pinter Publishers Ltd..

Orsenigo, L. (2007). History-friendly models of industrial evolution. In H. Hanusch & A. Pyka (Eds.), *Elgar companion to neo-schumpeterian economics*. Edward Elgar Publishing Limited.

Orsenigo, L., Pammolli, F., & Riccaboni, M. (2001). Technological change and network dynamics: Lessons from the pharmaceutical industry. *Research Policy, 30*(3), 485–508.

Orsenigo, L., Pammolli, F., Riccaboni, M., Bonaccorsi, A., & Turchetti, G. (1998). The evolution of knowledge and the dynamics of an industry network. *Journal of Management & Governance, 1*(2), 147–175.

Rosiello, A., & Orsenigo, L. (2008). A critical assessment of regional innovation policy in pharmaceutical biotechnology. *European Planning Studies, 16*(3), 337–357.

Silverberg, G., Dosi, G., & Orsenigo, L. (1988). Innovation, diversity and diffusion: A self-organisation model. *The Economic Journal, 98*(393), 1032–1054.

Tesfatsion, L. (2001). Introduction to the special issue on agent-based computational economics. *Journal of Economic Dynamics and Control, 25*(3–4), 281–293.

Verspagen, B. (2007). Mapping technological trajectories as patent citation networks: A study on the history of fuel cell research. *Advances in Complex Systems, 10*(01), 93–115.

Winter, S. G., Kaniovski, Y. M., & Dosi, G. (2000). Modeling industrial dynamics with innovative entrants. *Structural Change and Economic Dynamics, 11*(3), 255–293.

Yoon, M. (2009). A History-friendly model on the relationship between NISs and performances in frontier industries of Korea and Taiwan. In: *2009 Convention of the Korean Association of Technology Economics and Management*.

Yoon, M., & Lee, K. (2009). Agent-based and "history-friendly" models for explaining industrial evolution. *Evolutionary and Institutional Economics Review, 6*(1), 45–70.

Yu, P., Shi, J., Sadowsk, B., & Nomaler, Ö. (2020). Catching up in the face of technological discontinuity: Exploring the role of demand structure and technological regimes in the transition from 2G to 3G in China. *Journal of Evolutionary Economics*. https://doi.org/10.1007/s00191-020-00673-9