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Franco Malerba , Richard R. Nelson , Luigi Orsenigo , Sidney G. Winter
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Innovation and the Evolution of Industries

The revolutionary impact of technological innovation on the dynamics of industrial structures has been one of the distinguishing features of modern capitalism. In this book, four leading figures in the field of Schumpeterian and evolutionary economic theory draw on decades of research to offer a new, "history-friendly" perspective on the process of creative destruction and industrial change. This "history-friendly" methodology models the complex dynamics of innovation, competition and industrial evolution in a way that combines analytical rigor with an acknowledgment of the crucial role of history. The book presents a comprehensive analysis of the determinants and patterns of industrial evolution and investigates its complex dynamics within three key industries: computers, semiconductors and pharmaceuticals. It will be of great value to scholars and students of innovation and industrial change, from backgrounds as varied as economics, management, history and political science. Its coverage of new methodological tools is also useful for students who are new to evolutionary economic theory.

FRANCO MALERBA is Professor of Applied Economics at Bocconi University in Milan and President of ICRIOS. He is the former president of the International Schumpeter Society and of EARIE (European Association of Research in Industrial Economics). He is an Editor of the journal *Industrial and Corporate Change* and author of a large number of articles and several books on industrial economics, innovation and the dynamics and evolution of sectors.

RICHARD R. NELSON is George Blumenthal Emeritus Professor of International and Public Affairs, Business and Law at Columbia University, and heads the program on Science, Technology, and Global Development at the Columbia Earth Institute. He is a seminal figure in evolutionary economics and is the coauthor of *An Evolutionary Theory of Economic Change* with Sidney Winter.

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SIDNEY G. WINTER is the Deloitte and Touche Emeritus Professor of Management at the Wharton School, University of Pennsylvania. With Richard Nelson, he coauthored the highly cited book *An Evolutionary Theory of Economic Change*. He was the winner of the Viipuri Prize in Strategic Management in 2008 and the Global Award for Entrepreneurship Research in 2015.

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Innovation and the Evolution of Industries

History-Friendly Models

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Preface and acknowledgments

This book is about innovation and the evolution of industries. It is the result of more than a decade of exciting collaboration and intense interaction among the four of us. Although we have been publishing articles on this topic over the years, the book represents an original contribution, in that the chapters are new or revised significantly from previously published articles. This book is also novel in that for the first time it provides the reader with a consistent, integrated and complete view of the nature and value of what we call "history-friendly" models, which aim at a deeper and more articulated theoretical analysis as well as empirical understanding of the dynamics of technologies, market structure and industries.

It all started during the nineties, as the four of us met at conferences in Europe and the United States. While listening to presentations and discussing papers, we were always impressed by the richness of industry and firm case studies, which told complex dynamic stories and highlighted the key role played by technological and organizational capabilities and learning in innovation and the evolution of industries. Often, powerful qualitative theories lay behind these cases. In the late nineties, Malerba and Orsenigo developed detailed studies of the evolution of respectively the computer industry and pharmaceuticals for the book Dick was putting together with David Mowery, *The Sources of Industrial Leadership* (Cambridge University Press, 1999). During this time in our meetings with Sid, we often discussed the industry histories that were being put together for the book.

Thus it was natural for the four of us to start talking about the relationship between the rich qualitative theories that were associated with the industry histories and the then prevalent terse and

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compact modeling of industry dynamics. We started to discuss how formal models could complement appreciative theory and histories. So, the idea was launched to start a research project that would try to capture and represent in a formal way the gist and richness of the different patterns of industrial evolution as described in the histories that we were familiar with, and the theories that went with these histories, by developing models that would highlight the specific dynamics of those sectors. At that time we became also convinced that this research inquiry would represent a second generation of evolutionary models, following the seminal contributions originated by the book by Nelson and Winter (1982) and by the efforts of a long list of evolutionary scholars such as Stan Metcalfe, Giovanni Dosi, Gerry Silverberg, Peter Allen, Esben Andersen, Paolo Saviotti, Bart Verspagen, John Foster and, more recently, Thomas Brenner, Koen Frenken, Peter Murmann, Andreas Pyka, Claudia Werker, Murat Yildizoglu, Keun Lee and others.

This was the first step into an exciting period where we encountered an unexplored terrain. Meetings and discussions would not only take place during conferences and workshops where any random subset of three out of the four of us were present. A long series of ad hoc meetings of "the Gang of Four" (as Tim Bresnahan used to call us) was initiated in Milan, New York or Washington. These meetings took place frequently at our university sites (Bocconi University, Columbia or Wharton School) or at our homes, on both sides of the Atlantic. In fact often the Gang of Four would invade one house and would camp out there for a couple of days, where discussions on industries and models would be interrupted for enjoyable lunches and dinners with our spouses Pamela, Katherine, Roberta and Alice. Within our group, and with other friends (and our families!), the "New York week-ends" became famous: Franco and Luigi would take the Milan-New York flight (economy, of course) on Saturday morning, arrive in New York at noon, work with Dick and Sid from Saturday afternoon to Sunday early afternoon, and then take the Sunday evening flight New-York Milan, in order to arrive early

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Monday morning in Milan and go directly to class. And the frequent Milan meetings, when not hosted in one of our apartments, turned the hotel in which Dick and Sid stayed into the "Nelson and Winter Hotel."

Of course, as one can imagine, the discussion on history-friendly models did not occupy all our time together. Often our discussions about our project took place during long pleasant walks, such as those in Washington starting from Sid's home or the ones from Dick's house on the way to Columbia University. Other times, in New York, our Sunday morning discussions were interrupted when AC Milan was playing: so we would gather in front of the TV, with an audience whose comments reflected history and culture: tension, excitement and big shouting by the Italian side, gentle and profound intellectual comments about the game by the American side. And beyond the usual topics of conversation (politics, the economy or recent books), we often ended up having long discussion on sports, where Sid would lead on football, Dick would talk about tennis and the likely winner of the US Open and Dick and Sid would engage with Stevie and Dani (Malerba) on the difference between Italian basketball and American NBA.

For the completion of this book, we greatly benefitted from the excellent work of our great coauthors for some of the chapters. A very special thanks goes to Gianluca Capone – who provided a fundamental and intelligent contribution in working on the code, fixing the notation and checking the consistency between history, text, models and code. Christian Garavaglia and Michele Pezzoni have substantially contributed to Chapter 5 and coauthored related papers. Davide Sgobba and Luca Bonacina have tremendously helped on the simulation side and have worked hard on the final simulations for the book. Along the way, the cause of clarity was advanced by the editorial efforts of Mendelle Woodley, while Dario Lamacchia, Alessia de Stefani, Giorgio Tripodi and Verdiana Venturi pushed it further in their editing of the final manuscript.

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This book benefitted from the comments, suggestions and feedbacks from our invisible college, composed by friends and colleagues with whom we have been interacting over the years. The list is too long to name all of them. At the risk of forgetting some key names, we would like to thank (in strict alphabetical order) Franco Amatori, Esben Andersen, Cristiano Antonelli, Ashish Arora, Tim Bresnahan, Gianluca Capone, Uwe Cantner, Bo Carlsson, Paul David, Richard Day, Kurt Dopfer, Giovanni Dosi, Gunnar Eliasson, Jan Fagerberg, Giorgio Fagiolo, Dominique Foray, John Foster, Lou Galambos, Giovanni Gavetti, Horst Hanusch, David Lane, Richard Langlois, Daniel Levinthal, Richard Lipsey, Brian Loasby, Francisco Louca, Luigi Marengo, Mariana Mazzucato, Maureen McKelvey, Stan Metcalfe, David Mowery, Alessandro Nuvolari, Hiro Odagiri, Vanessa Oltra, Carlota Perez, Gary Pisano, Jason Potts, Daniel Raff, Sandra Tavares Silva, Ed Steinmueller, Aurora Teixeira, Pierangelo Toninelli, Nick Von Tunzelmann, Marco Vivarelli, Paul Windrum and Ulrich Witt. We would like to remember here our dear friends Chris Freeman, Keith Pavitt and Nate Rosenberg, giants in the economics of innovation and history of technology. Paul Geroski and Steve Klepper passed away while the book was being written: we want to recognize here our intellectual debt to their key contributions to the field of industrial dynamics.

Cespri (later ICRIOS) of Bocconi University provided a stimulating and friendly environment, with the presence of Stefano Breschi, Stefano Brusoni, Nicoletta Corrocher, Lucia Cusmano, Roberto Fontana, Alfonso Gambardella, Francesco Lissoni, Maria Luisa Mancusi, Roberto Mavilia, Fabio Montobbio, Andrea Morrison and Fabrizio Onida. In particular, among CESPRI researchers, Marco Guerzoni, Nicola Lacetera, Andrea Pozzi and Lorenzo Zirulia gave a significant contribution in the writing of the code, running simulations and performing history-friendly exercises. We also recognize the precious contributions by Luca Berga, Anna De Paoli, Luca Giorcelli and Alessandro Politano in developing the code.

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Along this long journey we presented our work on history-friendly models in a lot of places: the International Schumpeter Society Conference in Rio; the Madrid EARIE Conference; the Pretoria Globelics Conference; the DIME Conference in Maastricht; and then at workshops and seminars at INSEAD, SPRU, Open University, University of Edinburgh, Beta Strasbourg, UNU-Merit, Wharton School, Harvard Business School, University of Manchester, Max Plank Gesellschaft, University of Jena, University of Queensland, TUE Eindhoven, Universidad Complutense de Madrid, Zentrum für Interdisziplinäre Forschung Bielefeld, University of Porto and others too numerous to list.

We gratefully acknowledge the financial support received from Bocconi University, Columbia University, Italian CNR, FIRB – Italian Minister of University and Research, and the Mack Institute for Innovation Management at the Wharton School.

Chris Harrison, Phil Good, Jeevitha Baskaran and Adam Hooper of Cambridge University Press and three anonymous referees have been quite helpful with comments and suggestions in the last stage of the preparation of the final manuscript. We thank them.

After all these remarks and thanks to all these friends, colleagues and collaborators who have shared this exciting enterprise in one way or another, we acknowledge that the responsibility for the remaining errors and mistakes is ours alone.

It is also customary to acknowledge in the end the support from the authors' families. In this case, the recognition goes much beyond any standard formulation. At least as the Italian subset is concerned, our children grew up with Dick, Sid and the book. And our wives Pamela, Katherine, Roberta and Alice were a fundamental component of the Gang of Four. We dedicate the book to them.

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Codes

The codes of the models, with related instructions and comments, are available at http://download.unibocconi.it/ICRIOS/HistoryFriendlyModelsCodes.zip and at www.cambridge.org/malerba

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Some remarks about notation

The formal representation of the history-friendly models presented some notable issues, first of all because of the huge amount of variables and parameters defining the models: some of these elements were common or at least analogous across the models, while others referred to completely different domains. In order to reduce the number of the main symbols to a manageable size, we adapted from computer programming languages the idea of overloading notation: a main symbol can have slightly different meanings according to the presence or absence of further details, such as superscripts and subscripts. For example, the symbol T indicates the total number of periods of a simulation, T_k indicates the period of introduction of technology k, and T^I the minimum number of periods a firm has to stay integrated after its decision to switch to internal production of components. In general, we use as subscripts the indices for elements (products, firms, markets, technologies) that take different values, without changing the meaning of the main symbol. Instead, we use as superscripts further identifiers of the main symbols that are not instances of a general category: for example, PT is the symbol of patents and E is the symbol of exit. In a very limited number of cases an identifier can be used both as a subscript identifier (TR and MP in most of the cases are used as instances of component technology k) and as a superscript identifier (TR and MP are used as superscripts of the main symbol α, as they refer to different parts of the same equation).

Upper and lowercase letters are considered as different, although whenever it is possible they take related meanings: for example, i indicates the propensity to integrate and I the corresponding probability. The symbols used for specific variables and parameters

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are not used across models, unless these variables and parameters have the same or a very similar meaning and role in the different models. The values that parameters take and the range of values that heterogeneous parameters and variables can take are indicated in the tables in the Appendices. To this purpose, we use standard notation: (a; b) indicates a point with coordinates a and b; [a, b] indicates a continuous set from a to b; {a, . . ., z} indicates a discrete set containing all elements from a to z; $\mathbb{R}_+$ indicates the set of nonnegative real numbers; $\mathbb{N}$ represents the set of natural numbers.

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