Handbook of the Economics of Innovation

Introduction

Bronwyn H. Hall and Nathan Rosenberg

29 December 2009

Although innovation and the production of new goods and services have almost always been a part of economic activity, economic research on innovation has been to some extent scattered among a number of quite disparate economic fields, including macro-economics (growth accounting), industrial organization (the strategies and interactions of innovative firms), public finance (policies for encouraging private sector innovation), and economic development (innovations systems and technology transfer). However, as Verspagen and Werker (2003) have recently shown using survey data, a large and fairly tightly clustered network of economists working on innovation and technical change has developed, a network that includes both those working within the "evolutionary" paradigm, and those using more traditional methods of analysis. By now, this community of scholars has generated a large body of work on the topic, some of which is multi-disciplinary. Thus it seemed to the editors to be an appropriate time to provide a comprehensive overview of the field, bringing together chapters by scholars working in a number of subfields of economics and closely related disciplines in order to provide a coherent picture of the entire landscape of the economics of innovation. In undertaking the production of this handbook, we had several goals beyond the desire to provide a good overview of an increasingly important research area. We hoped to encourage the economics profession to view the economics of innovation as a distinct area of applied economics, and also to encourage researchers working in one of the many subfields in this area to become aware of work by researchers studying similar topics, but who operate in different research domains and perhaps use different methodologies.

When our handbook project was initiated it bore the title *The Economics of Technical Change*. However, as the volume approached publication, it became apparent that the research done in this area had in fact broadened to include new economic dimensions of great significance that did not fit comfortably under the rubric of "technical change." Thus although this term continues to appear abundantly in these pages, the editors have decided to use the broader term "economics of innovation" to describe the subject matter within. The term "innovation" includes technical change, and also includes many dimensions of economic change that do not fall easily into the category of technical change. The older term conjures up hardware and long assembly lines, but not the software of the digital world of computers, the internet, social networking, nor the reorganization of work that has followed innovation in these areas. But software can also be used in much broader senses to refer to anything that is not hardware. This usage can encompass research carried out in universities and industrial and government labs, or the new ideas that may emerge from the human brain (which some would refer to as "wetware"), but which Romer (1990), for example, has labeled simply as ideas. In so doing, Romer's usage has shaped much of the language of economists over the last couple of decades. To some extent, the evolution of

usage from technical change to innovation parallels the rise in the importance of non-manufacturing sectors in developed economies, and also the importance of productivity and welfare-enhancing change that is not the product of organized Research and Development.

Innovation economists owe a great debt to Joseph Schumpeter, who can be said to be the father of the field, and whose work contains much verbal theorizing on the topic that is still influential today. In the preface to the Japanese edition of his 1937 book *The Theory of Economic Development,* Schumpeter sketches out what is probably the most precise and succinct statement of his own intellectual agenda that he ever committed to print. That agenda focuses not only upon the understanding of how the economic system generates economic change, but also upon how that change occurs as the working out of purely endogenous forces:

> If my Japanese readers asked me before opening the book what it is that I was aiming at when I wrote it, more than a quarter of a century ago, I would answer that I was trying to construct a theoretic model of the process of economic change in time, or perhaps more clearly, to answer the question how the economic system generates the force which incessantly transforms it … I felt very strongly that … there was a source of energy within the economic system which would of itself disrupt any equilibrium that might be attained. If this is so, then there must be a purely economic theory of economic change which does not merely rely on external factors propelling the economic system from one equilibrium to another. It is such a theory that I have tried to build.[1]

It should be noted that these words were published in 1937, when Schumpeter was, as we know, already at work on *Capitalism, Socialism, and Democracy*. In fact, *Capitalism, Socialism, and Democracy* is the fulfillment of precisely the intellectual agenda that Schumpeter articulated in the passage to his Japanese readers that was just quoted.

Of course, an account of how and why economic change took place was precisely something that could not be provided within the "rigorously static" framework of neo-classical equilibrium analysis, as Schumpeter referred to it. Schumpeter also observed that it was Walras' view that economic theory was only capable of examining a "stationary process," that is, "a process which actually does not change of its own initiative, but merely produces constant rates of real income as it flows along in time." As Schumpeter interprets Walras:

> He would have said (and, as a matter of fact, he did say it to me the only time I had the opportunity to converse with him) that of course economic life is essentially passive and merely adapts itself to the natural and social influences which may be acting on it, so that the theory of a stationary process constitutes really the whole

[1] Schumpeter (1937), p. 158.

> of theoretical economics and that as economic theorists we cannot say much about the factors that account for historical change, but must simply register them.[2]

The critical point here is that Schumpeter directly rejects the view of Walras that economic theory must be confined to the study of stationary processes, and that it cannot go farther than demonstrating how departures from equilibrium, such as might be generated by a growth in population or in savings, merely set into motion forces that restore the system to an equilibrium path. In proposing to develop a theory showing how a stationary process can be disturbed by internal as well as external forces, Schumpeter is suggesting that the essence of capitalism lies not in equilibrating forces but in the inevitable tendency of that system to depart from equilibrium – in a word, to disequilibrate. Equilibrium analysis fails to capture the essence of capitalist reality. Lest there be any doubt about Schumpeter's position on this critical matter, we cite his own forceful formulation: "Whereas a stationary feudal economy would still be a feudal economy, and a stationary socialist economy would still be a socialist economy, stationary capitalism is a contradiction in terms."[3]

As we look over the collection of chapters in this volume, it is clear that this basic understanding of the importance of internally generated economic change for the progress of the economy and the weaknesses of static economic analysis in the face of this phenomenon occupies much of the research in innovation economics. A number of themes that are common to at least several of the chapters touch on this and related ideas.

The first and perhaps the most important theme is the essential dynamism of the innovative process -- knowledge, inventions, and innovations created today build on those created in the past, and the benefits of an innovation are often not felt until it undergoes a dynamic, cumulative learning and diffusion process. An understanding of this phenomenon underlies almost all of the chapters, and is perhaps most obvious in those by Thompson on learning by doing, Bresnahan on general purpose technologies, Teece on the innovative firm, and Stoneman and Battista on diffusion. The fact that the central process in which we are interested has dynamic and hysteresislike properties means that static economic modeling will be of limited value for analysis; this awareness is reflected in many of the papers and a few of them put forth alternative modeling approaches.

Three of the chapters, those by Dosi and Nelson, Teece, and Soete et al. explicitly take as their starting point the limitations of neoclassical theory in analyzing innovation at the industry, firm, or country level. In addition, the chapters by Soete et al. and Steinmueller argue that Arrow and Nelson's market failure rationale for science and technology policy, although valid, is an incomplete guide to policy because it overemphasizes the importance of assigning property rights to innovators and ignores the systemic nature of the needed policies. For example, subsidies for R&D will fail to have the desired result if it takes time to produce trained scientists and engineers, or if the education system is simply not capable of producing them. It is probably safe to say that the topic of innovation systems and

[2] Ibid., pp. 2-3.

[3] Schumpeter (1951), p. 174. On these matters, see Rosenberg (2010).

institutions is in its infancy empirically; see Röller and Mohnen (2005) for a study of complementarities in European innovation policies. Although numerous studies in the management of innovation literature have been informed by the "new" institutional economics, empirical study at the economy-wide level has lagged behind, probably because of the formidable modeling and data obstacles.

A second major theme of this volume is the importance of the needs of innovation policy in driving the research agenda of the economics of innovation. We can see this reflected in the chapters by Foray and Lissoni on university research and public-private interaction, Rockett on intellectual property rights, Hall, Mairesse, and Mohnen on the measurement of returns to R&D, Hall and Lerner on the financing of innovation, Popp, Newell, and Jaffe on the environment, and Pardey, Alston, Ruttan on innovation in agriculture. The extensive study of these particular topics has to a great extent been driven by the questions raised in the implementation of various policies toward science and technology, questions that have often been accompanied by more tangible resources to encourage the analysis. In addition to the chapters mentioned, there are several chapters in the final section of the handbook that are directly addressed to policy topics. Steinmueller and Soete, Verspagen and ter Weel address the broad topics of technology policy in general and the systems of innovation approach to its analysis, whereas Mowery discusses one of the most important sources of spillovers from government R&D: the defense sector.

The close relationship between the economics of innovation and policy questions has two related causes. First, as reviewed by Hulten in the chapter on growth accounting, the economic growth literature of the past fifty or so years has identified technical change as a major contributor to productivity growth (Abramovitz, 1956; Solow, 1957). Second, the invention and innovation that are the source of technical change also create knowledge that can spill over to entities that were not responsible for the original creation, and this transfer occurs without a priced transaction taking place. As Arrow (1962) and Nelson (1959) pointed out long ago, this fact immediately suggests a need for policy to encourage the appropriate level of investment in these activities. Because such knowledge transfers can be diffuse and do not necessarily take place in a well-defined market, policy attention needs also to be directed to spillovers across sectors and across national boundaries; attempts to measures these spillovers are prominent in the chapter by Hall, Mairesse, and Mohnen. The importance of cross-national spillovers for technology transfer and development, where these spillovers are mediated via trade and foreign direct investment, also appears in the chapters by Keller and Fagerberg, Srholec, and Verspagen.

A third theme with prominence in several chapters is the importance of the digital revolution that has led to major innovations in information and computing technology (ICT) that have impacted all sectors in the economy. Broadly speaking, the semiconductor and attendant innovations have all the characteristics of a General Purpose Technology, as described by Bresnahan in his chapter. The specific evolution of the computing and internet sector during the past 50 years is dealt with in the chapter by Greenstein. In general, these technologies are highly cumulative and interactive, requiring a great deal of interoperability between components made by different firms, which has increased the importance of standards, collaboration among firms, and network effects in adoption. This

in turn has led to a renewed interest in markets for technology (Arora and Gambardella), user and firm collaboration and networks (von Hippel; Powell and Gianella), and the functioning of the patent system (Rockett). In the case of patents, the complexity of ICT products has meant that the patent system operates very differently for firms in that sector than for those in the traditional patenting sectors such as chemicals and pharmaceuticals; this point is discussed in the chapter by Scherer and touched on elsewhere in the handbook.

One of the consequences of the digital revolution has been the successful entry of innovative new firms that have grown rapidly and are now among the largest in the world. For example, in the United States almost 40% of the top 200 R&D-performing firms in 2005/2006 were founded after 1980, while 32% of the top 200 R&D-performing firms in 1980 had exited by 2005 (Hall and Mairesse, 2009). This is certainly suggestive of the Schumpeterian view that "how capitalism administers existing structures" is essentially irrelevant, since "the relevant problem is how it creates and destroys them."[4] As Schumpeter goes on to say in the same passage:

> The first thing to go is the traditional conception of the *modus operandi* of competition. Economists are at long last emerging from the state in which price competition was all they saw. As soon as quality competition and sales effort are admitted into the sacred precincts of theory, the price variable is ousted from its dominant position. However, it is still competition within a rigid pattern of invariant conditions, methods of production and forms of industrial organization in particular … that practically monopolizes attention. But in capitalist reality as distinguished from its textbook picture, it is not that kind of competition which counts but the competition from the new commodity, the new technology, the new source of supply, the new type of organization which commands a decisive cost or quality advantage and which strikes not at the margins of the profits and the outputs of the existing firms but at their foundations and their very lives.[5]

The transformation of the industrial landscape of innovating firms during the past quarter century certainly confirms the view expressed in this passage. The picture thus painted of the nature of competition is very much to the forefront in the chapters by Teece and Dosi and Nelson, while empirical study of the competitive forces that he emphasized is to be seen in the chapters by Cohen, who considers the firm size-innovation relationship, and Greenstein, who studies the computing industry. The chapter by Hall and Lerner, which reviews the literature on internal finance for innovation, addresses yet another Schumpeterian topic, the importance of past profits in financing future innovation.

A quite different area of development in the economics of innovation is that of the data sources necessary for its study. The analysis of innovation and innovative activity requires data other than conventional economic data: in addition to the usual economic quantities, data on types of innovation, inventions, technologies, arrangements among firms and

[4] Schumpeter (1960), p. 84.

[5] Op. cit.

between firms and research institutions such as universities are needed. Several authors are concerned with the development of new data sources containing such non-economic data, possibly merged with the usual currency-denominated economic data such as GDP and R&D spending. The pioneers in this area of development were Mansfield (1968) and Pavitt and co-workers at SPRU (Pavitt, 1984; Townsend et al., 1981) for innovation survey data, and Schmookler (1966) and Griliches (1990) for patent data. The chapters by Nagaoka et al. on patent data and Mairesse and Mohnen on innovation survey data review these sources of data and their uses, but their value is also apparent elsewhere in the handbook, for example in the chapter by Powell and Gianella on collective invention, that by Cohen on empirical studies of innovation, and that by Arora and Gambardella on markets for technology.

Finally, we would like to draw the reader's attention to the fact that some of the papers in this volume are not authored by economists but by those in related fields such as management and sociology. This is not an accident, but reflects the nature of the field, for reasons that again go back to Schumpeter's critique of the static neoclassical framework, a framework that was dominant in economics during some of the time that this field developed. And, of course, we took this into account when selecting chapters for the volume.

The structure of the handbook to some extent follows the "linear model" of innovation, which remains a useful way of thinking about the subject, in spite of the fact that many have pointed out the feedback loops that exist in the system. (e.g., see Rosenberg 1982).[6] The first section of the book provides an overview, with papers on the economic history of innovation, the evolutionary approach to its analysis, and an overview of empirical work on innovation in firms. The next long section centers on the inventive process and its incentives, looking at the role of science and research organizations, the reward systems, networks, collaboration, and user invention, and including a couple of industry case studies on the information technology and pharmaceutical sectors. This is followed by sections on commercialization and diffusion, with papers on financing, firm strategies, the particular case of general purpose technologies and their diffusion, and the role of international trade in diffusing innovation across borders.

The fifth section of the handbook looks at the innovation process and outcomes in agriculture, energy, and environment, as well as the role of innovation in economic development. Then we turn to the problem of measuring innovation input and output, beginning with macro-economic growth accounting, and the micro-economic measurement of the returns to R&D investments. The next two chapters explore two measurement approaches using non-economic and qualitative data that are specifically tailored to the innovation area: patent data and data from innovation surveys. The final section of the handbook contains three papers on innovation policy, two that look at the system as a

[6] Kline and Rosenberg (1986) critiques the linear model, whereas Balconi et al. (2009) offer a nuanced defense of its value in analysis.

whole, and one centering on the considerable impact of defense-related R&D spending on innovation in general.

Acknowledgements

The editors wish to acknowledge the numerous contributions of Rina Gordon Rosenberg in bringing this project to a happy ending. We are also grateful to Jacques Mairesse and Richard Nelson for careful reading of an earlier draft of this introduction. The second editor thanks the staff at the Stanford Institute for Economic Policy Research for valuable assistance.

References:

Abramovitz, M. (1956), Resource and Output Trends in the United States since 1870. *American Economic Review* 46 (2), 5-23.

Arrow, K. (1962), Economic Welfare and the Allocation of Resources for Invention. In *The Rate and Direction of Inventive Activity*, edited by R. R. Nelson. Princeton, NJ: Princeton University Press.

Balconi, M., S. Brusoni, and L. Orsenigo (2009), In defence of the linear model: An essay. *Research Policy,* in press.

Griliches, Z. (1990), Patent Statistics as Economic Indicators: A Survey. *Journal of Economic Literature* 28, 1661-1707.

Hall, B. H., and J. Mairesse (2009), Measuring corporate R&D returns. Presentation to the Knowledge for Growth Expert Group, Directorate General for Research, European Commission, Brussels, January.

Kline, S. and N. Rosenberg (1986), An overview of innovation. In Landau, R. (ed.), *The Positive Sum Strategy. Harnessing Technology for Economic Growth*, 275–306.

Mansfield, E. (1968), *The Economics of Technological Change*. New York: W. W. Norton and Co.

Nelson, R. R. (1959), The Economics of Invention: A Survey of the Literature. *Journal of Business* 32, 101-127.

Pavitt, K. (1984), Sectoral Patterns of Technical Change: Towards a Taxonomy and a Theory, *Research Policy*, 13(6), 343-373.

Röller, L.-H., and P. Mohnen (2005), Complementarity in Innovation Policy. *European Economic Review* 49 (6), 1431-1450.

Romer, P. M. (1990), Endogenous Technological Change, *Journal of Political Economy* 98(5, pt. 2), S71-S102.

Rosenberg, N. (1982), How Exogenous is Science? In *Inside the Black Box*, edited by N. Rosenberg. Cambridge, UK: Cambridge University Press.

Rosenberg, N. (2010), Schumpeter and History. In Rosenberg, N., *Studies on Science and the Innovation Process*, New Jersey: World Scientific Publishing Co.

Schmookler, J. (1966), *Invention and Economic Growth*. Cambridge, Mass.: Harvard University Press.

Schumpeter, J. A. (1937), Preface to the Japanese edition of *Theorie der Wirschaftlichen Entwicklung*, translated by I. Nakayama and S. Tobata, Tokyo: Iwanami Shoten. Reprinted in *Essays of J. A. Schumpeter*, R.V. Clemence (ed.), Cambridge, MA: Addison-Wesley (1951), p. 158.

Schumpeter, J. A. (1943), *Capitalism, Socialism, and Democracy*, second edition. London: George Allen & Unwin, Ltd.

Schumpeter, J. A. (1951), Capitalism in the Postwar World. Reprinted in *Essays of J. A. Schumpeter*, R.V. Clemence (ed.), Cambridge, MA: Addison-Wesley (1951), p. 158.

Solow, R. (1957), Technical Change and the Aggregate Production Function. *Review of Economics and Statistics* 39, 312-320.

Townsend, J., F. Henwood, G., Thomas, K., Pavitt, and S. Wyatt (1981), Innovations in Britain since 1945. Science Policy Research Unit, University of Sussex: Occasional Paper No. 16.

Verspagen, B. and C. Werker (2003), The Invisible College of The Economics of Innovation and Technological Change, *Estudios De Economía Aplicada* 21(3), 203-220.

Volume I

1. Introduction and overview

1.1 *Introduction to the handbook* – Bronwyn H. Hall and Nathan Rosenberg

1.2 *The contribution of economic history to the study of innovation and technical change: 1750-1914.* – Joel Mokyr

1.3 *Technical change and industrial dynamics as evolutionary processes* – Giovanni Dosi and Richard R. Nelson

1.4 *Empirical studies of innovative activity and performance* – Wesley M. Cohen

2. Invention and innovation

2.1 *The economics of science* – Paula E. Stephan

2.2 *University research and public-private interaction* – Dominique Foray and Francesco Lissoni

2.3 *Property rights and invention* – Katherine E. Rockett

2.4 *Stylized facts in the geography of innovation* – Maryann P. Feldman and Dieter F. Kogler

2.5 *Open user innovation* – Eric von Hippel

2.6 *Learning by doing* – Peter Thompson

2.7 *Innovative conduct in computing and internet markets* – Shane Greenstein

2.8 *Pharmaceutical innovation* – F. M. Scherer

2.9 *Collective invention and invention networks* – Woody Powell and Eric Gianella

3. Commercialization of innovation

3.1 *The financing of R&D and innovation* – Bronwyn Hall and Josh Lerner

3.2 *The market for technology* – Ashish Arora and Alfonso Gambardella

3.3 *Technological innovation and the theory of the firm: The role of enterprise level knowledge, complimentarities, and (dynamic) capabilities* – David J. Teece

Volume II

4. Diffusion

4.1 *The diffusion of new technology* – Paul Stoneman and Giuliana Battisti

4.2 *General purpose technologies* – Timothy Bresnahan

4.3 *International trade, foreign direct investment, and technology spillovers* – Wolfgang Keller

5. Innovation outcomes

5.1 *Innovation and economic development* – Jan Fagerberg, Martin Srholec, and Bart Verspagen

5.2 *Energy, the environment, and technological change* – David Popp, Richard G. Newell, and Adam B. Jaffe

5.3 *The economics of innovation and technical change in agriculture* – Philip G. Pardey, Julian M. Alston, and Vernon W. Ruttan

6. Measurement of innovation

6.1 *Growth accounting* – Charles Hulten

6.2 *Returns to R&D and productivity* – Bronwyn Hall, Jacques Mairesse, and Pierre Mohnen

6.3 *Patent statistics as innovation indicators* – Sadao Nagaoka, Kazuyuki Motohashi, and Akira Goto

6.4 *Using innovation surveys for econometric analysis* – Jacques Mairesse and Pierre Mohnen

7. Policy towards innovation

7.1 *Systems of innovation* – Luc Soete, Bart Verspagen, and Bas ter Weel

7.2 *Economics of technology policy* – *W.* Edward Steinmueller

7.3 *Military R&D and innovation* – David C. Mowery