INNOVATION AND ECONOMIC DYNAMICS

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Contents

Summary

This chapter provides a survey of recent economics research on innovation and dynamic change. First, an overview of different models of innovation is provided. The focus here is on models of product innovation, rather than process innovation. The former kind accounts for the bulk of innovative activities. Two types of innovation are considered: horizontal (expansion in the variety of goods) and vertical (improvements in the quality of goods). Second, applications of the models are provided. The focus of the applications is on policy-oriented issues; for example, the relationship between market size and innovation, which has implications for policies on economic integration, and the role of subsidies to research and development. Another policy issue is patent protection versus open innovation in which researchers do not seek patent rights but instead freely share inventions and discoveries. The analysis of this issue has implications for how best to reward innovation and for how best to disseminate it.

1. Introduction

In this chapter, recent economics research on the determinants of innovation is surveyed.

A key contribution of the economics literature has been to show, among other things, that innovation can respond to economic incentives. Indeed the literature emphasizes that innovation is an intentional activity driven by profit-maximizing entrepreneurs interacting with consumers (or users) who display a preference for new and better quality goods. A better understanding of the economic influences on innovation is important in formulating public policy towards science and technology.

My guide to this research proceeds in two steps: first, a survey of the leading dynamic models of innovation is provided. These models have served as workhorses for much of the recent economic studies on innovation. The models blend research from economic growth theory and industrial organization. Second, these models are applied to address public policy issues; for example, what is the role of market size (or scale)? How do subsidies to research and development (R&D) and stronger patent systems affect innovative activity? Is 'open innovation' an alternative to proprietary, profit-seeking modes of innovation? The chapter illustrates how the dynamic models of innovation can be used to gain some insights on the role of technology policy.

The canonical models surveyed here share some common features. For example, innovation rates are higher if consumers are more patient and willing to save for the future, firms have market power, research workers are more productive, and the economy has more resources. They also share the feature that the private market need not deliver the socially optimal rate of innovation. The private market could under-invest or over-invest in R&D depending on the type of innovation, whether horizontal (expansion in the variety of goods) or vertical (improvements in the quality of goods).

Furthermore, the models predict a 'scale effect', meaning that larger economies have higher rates of innovation. Recent evidence seems to cast doubt on this prediction. Hence the canonical models can be modified so as to eliminate the scale effect. One way is to assume that R&D becomes more difficult to conduct as the level of innovation rises. The equilibrium rate of innovation then depends not on the level of resources but on the growth rate of resources (like labor). Another way to eliminate the scale effect is to assume that larger economies are associated with more industrial sectors so that R&D resources must be spread more thinly across the economy. This has the effect of making the equilibrium rate of innovation depend on, not the scale of R&D, but on the share of R&D inputs in total resources.

Technology policies can be used to influence the long run equilibrium level and/or rate of innovation. But there is weak theoretical consensus on the effects of R&D subsidies. It is plausible for subsidies to have beneficial as well as adverse effects on innovative activities. On patent policies, the consensus seems to be that they stimulate R&D but up to a point. If patent protection is too strong, innovation can be adversely affected due to excessive market power and due to the higher cost of conducting R&D (because of higher licensing and royalty fees). An alternative approach, therefore, to innovation is for individual researchers to forgo patent rights and engage in open innovation (such as 'open source software' or 'open biotech'). In some cases, though, open innovation can be complementary to proprietary (patent-seeking) innovation, particularly if it makes fundamental research tools accessible to all researchers. However, the overall impact of open innovation on the economy-wide rate of innovation is ambiguous due to the possibility that some open innovation may displace for-profit innovation.

R&D subsidies, patents, and open innovation are among the leading technology policy issues in the recent literature – and are suitable issues to analyze using the kinds of dynamic models surveyed in this chapter. Nonetheless, they do not exhaust the full range of influences on innovative activities. Thus the chapter provides some follow-up literature for the interested reader.

The chapter is organized as follows: Section 2 contains a review of the basic models of innovation. Section 3 addresses the issue of scale effects – that is, of whether larger economies have a higher rate of long run innovation. Section 4 discusses the impact of R&D subsidies on innovation, Section 5 the impact of patent rights on innovation, and Section 6 the potential role of open innovation, where innovators do not assert patent claims. Section 7 provides concluding thoughts.

Before proceeding, address the scope of this chapter should be addressed. First, recent work is reviewed, starting about in the early 1990s. For earlier surveys of innovation, the interested reader could consult Kamien and Schwartz (1982) and Tirole (1988, chapter 10). Second, theoretical and conceptual analyses are covered, rather than empirical studies. Third, the focus is primarily on the relationship between research and development (R&D) and innovation, and do not address other determinants of innovation such as human capital, trade policy, financing, and so forth. Fourth, the focus is on product innovations where innovation results in new or improved products, rather than process innovations where innovations result in new or improved methods of production. Most patented inventions tend to be product innovations, whereas process inventions are often protected by trade secrecy laws.

2. Canonical Models

Innovation here has two dimensions: horizontal and vertical. Horizontal innovation involves the creation of new varieties of goods, while vertical innovation improves the quality of existing goods. The goods in question can be final consumption goods or intermediate inputs into production. Thus there are four cases to consider: (i) innovation in the variety of final goods; (ii) innovation in the variety of intermediate inputs; (iii) innovation in the quality of final goods; and (iv) innovation in the quality of intermediate inputs. Table 1 shows a classification of the different types of innovation and the studies that belong under the different categories of innovation. A glossary provides a list of key symbols used in this chapter.

Type of innovation:	**Type of good that innovation targets:**	
	Final Good	**Intermediate Input**
Horizontal Innovation	Grossman and Helpman (1991a) Dinopoulos and Thompson (1998)*	Romer (1990) Jones (1995) Young (1998)* Howitt (1999)*

(Variety Growth)	St. Paul (2003) Grossman and Lai (2004) Angeles (2005)	Segerstrom (2000)* Kwan and Lai (2003)
Vertical Innovation (Quality Ladders)	Grossman and Helpman (1991b) Horowitz and Lai (1996) Segerstrom (1998) Dinopoulos and Thompson (1998)* Li (2001) O'Donoghue and Zweimuller (2004)	Aghion and Howitt (1992) Young (1998)* Howitt (1999)* Segerstrom (2000)* Aghion et al. (2001)

* indicates that both types of innovation are modeled

Table 1. Examples of Innovation Studies by Type

Before going into the four cases, the common elements are discussed. Three key actors are modeled: the consumer, producer, and innovator. The market for innovation consists of consumers that demand goods and producers that supply them. The market provides a value for innovation.

- Demand Side

$$U = \int_0^\infty e^{-\rho t} \ln D_t dt \qquad (1)$$

This equation shows the lifetime utility households derive from the stream of consumption from time zero to infinity, where D is an index of consumption and ρ the time preference rate. For presentational purposes, a logarithmic utility function is assumed throughout this chapter, even though different kinds of functions are used in the literature. The purpose of adopting a common functional form for utility is to make economical use of notation and to minimize technical detail.

The specification for D depends on whether the goods are homogenous or differentiated. If the latter, the differentiation can be in the variety of goods or in the different quality levels of goods:

$$D = \left[\int_0^n c(j)^\alpha \, dj \right]^{\frac{1}{\alpha}} \qquad 0 < \alpha < 1$$

Case of horizontal differentiation (1a)

or

$$D = \exp\left(\int_0^1 \ln q(j)\, c(j)\, dj \right)$$

Case of vertical differentiation (1b)

where c denotes consumption of the *j*-th good, n the measure of variety, and q an index of quality. In (1a), the smaller the parameter α the more substitutable the goods are.

- Production

Producers can use capital (denoted by x) and labor (denoted by L_Y) to produce goods. The capital inputs can be subject to innovation, either in the variety of capital inputs or in the quality of inputs.

$$Y = \left(\int_0^n x(j)^{\beta}\, dj \right) L_Y^{\,1-\beta}$$

Case of horizontal differentiation (2a)

or

$$Y = (q\, x^{\beta})\, L_Y^{\,1-\beta}$$

Case of vertical differentiation (2b)

The parameter β measures the output elasticity (or sensitivity) of output to capital. In some of the models below (particularly where innovation occurs only at the final goods level), capital is not used to produce output. In that situation, it will be assumed that one unit of labor is required to produce one unit of output (and hence $\beta = 0$).

- Research and Development (R&D)

Innovation requires resources, namely labor denoted by L_R.

$$\dot{n} = \frac{L_R}{A} n$$

Case of horizontal differentiation (3a)

or

$$\phi = \phi(A, L_R) = \frac{\phi(L_R)}{A}$$

Case of vertical differentiation (3b)

where ϕ is the probability of successfully developing an improved quality good. In (3a), the instantaneous change in n is a function of the level of n. This indicates the presence of knowledge spillovers. Past innovation (as embodied in the level of n) facilitates further innovation. Equation (3b) also implicitly assumes knowledge spillovers in that the probability of success does not depend on cumulative research effort. The current state of the art captures what the researcher needs to know in order build a better product. In both (3a) and (3b), the parameter A measures productivity. The lower A is, the more efficient researchers are at innovation.

- Resource Constraint

$$L = L_R + L_Y \tag{4}$$

L is the total endowment of labor to be allocated between research and production.

- Market Clearing

Total output produced, Y, is divided between consumption and investment.

$$Y = C + I \tag{5}$$

where investment, I, is used to augment the stock of capital, K. Hence $I = \dot{K}$ and

$$K = \int_0^n x(j)dj \,.$$

Aggregate consumption C is allocated among different varieties of goods:

$$C = \int_0^n p(j)c(j)\,dj \tag{6}$$

where $n = 1$ in the case of quality ladders models (where a continuum of industries exist along the unit interval).

- Consumer Utility Maximization

The utility maximization decision can be broken down into two steps. First, consumers make a static decision in which they optimally allocate their spending, C, across different goods at a given point in time. Assuming symmetry of goods (i.e. $c = c(j)$ for all j)

$$c = \frac{C}{pn}$$

Static Maximization

Second, consumers make a dynamic decision in which they optimally determine the path of their spending, C, over time. This is done by maximizing Eq. (1) subject to a lifetime budget constraint (at time 0). The solution to this dynamic problem is referred to as the *Euler equation*:

$$\frac{\dot{C}}{C} = r - \rho$$

Dynamic Maximization (7)

where r is the interest rate. Total consumption grows (or falls) according to whether the market rate of interest, r, is greater (or less) than the personal rate of interest, ρ. For an introduction to methods of dynamic optimization, the interested reader is referred to Klein (2002).

- Firm Value Maximization

The following pertains to the link between innovation and production. Innovation yields a "blueprint" or a design for a new good or an improved good. Producers pay a fixed cost of F to innovate (or to buy the blueprint from others). The producers are then given a patent right to be the exclusive supplier of this new or improved good. The value of the firm (and value of the innovation) equals the presented discounted value of profits associated with selling this good:

$$V = \int_0^\infty e^{-rt} e^{-\phi t} \pi_t \, dt = \frac{\pi}{r + \phi} \qquad (8a)$$

Note that the discount factor includes the risk ϕ that an innovation by another firm will destroy the stream of profits. In horizontal R&D models, no technological displacement or obsolescence occurs so that $\phi = 0$.

If $V < F$, innovation is not profitable, while if $V > F$, innovators will enter the market to innovate. In the long run, equilibrium requires the following condition to hold.

$$V = F$$

Free-Entry Condition (8b)

The profitability of innovation (given by 8a), the free-entry condition (given by 8b), and the overall resource constraint (given by 4) interact to determine the overall equilibrium rate of innovation. The other ingredients, such as consumer tastes, innovation productivity, and so forth, are embedded or incorporated into these conditions.

With these building blocks, four cases are next analyzed. For each case, the model is solved in order to derive the equilibrium innovation rate for the private market. The equation for the innovative rate provides insight into the underlying determinants of innovation. Then examination of whether the private market rate of innovation is socially optimal is made. In each case, the private market does not necessarily generate the socially optimal rate of innovation. The rest of the chapter then addresses technology policies that can influence private innovation.

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Bibliography

Aghion, Phillippe, Harris, Christopher, Howitt, Peter, and Vickers, John (2001), "Competition, Imitation, and Step-by-Step Innovation," *Review of Economic Studies*, Vol. 68, pp. 467-492. [This paper analyzes the impact of imitation on innovation.]

Aghion, Philippe and Howitt, Peter (1992), "A Model of Growth Through Creative Destruction," *Econometrica*, Vol. 60, No. 2, pp. 323-351. [This paper presents the case 4 model: vertical innovation in intermediate inputs.]

Aghion, Philippe and Howitt, Peter (1998), *Endogenous Growth Theory*, MIT Press, Cambridge MA. [The book presents a comprehensive overview of new growth theory.]

Allen, Robert C. (1983), "Collective Invention," *Journal of Economic Behavior and Organization*, Vol. 4, pp. 1-24. [The article studies open innovation in the blast furnace industry in the 19th century U.K.]

Angeles, Luis (2005), "Should Developing Countries Strengthen their Intellectual Property Rights?" *Berkeley Electronic Journal in Macroeconomics*, Vol. 5, Issue 1, Article 23. [Using a variety growth model (case 1), the paper analyzes the impact of innovative capacity on the optimal strength of patent rights.]

Benassy, Jean P. (1998), "Is There Always Too Little Research in Endogenous Growth with Expanding Product Variety?" *European Economic Review*, Vol. 42, pp. 61-69. [The paper challenges the finding that the private sector always under-invests in horizontal innovation.]

Chesbrough, Henry (2003), *Open Innovation: The New Imperative for Creating and Profiting from Technology*, Harvard Business School Press, Cambridge MA. [This books provides business case studies of open innovation.]

Chui, Michael, Levine, Paul, Murshed, S. Mansoob, and Pearlman, Joseph (2002), "North-South Models of Growth and Trade," *Journal of Economic Surveys*, Vol. 16, No. 2, pp. 123-165. [This contains a survey of the impact of trade on world innovation.]

Dinopoulos, Elias and Thompson, Peter (1998), "Schumpetarian Growth Without Scale Effects," *Journal of Economic Growth*, Vol. 3, No. 4, pp. 313-335. [This paper is an example of the product proliferation approach to removing scale effects and studies the role of R&D subsidies.]

Grossman, Gene and Helpman, Elhanan (1991a), *Innovation and Growth in the Global Economy*, MIT Press, Cambridge, MA. [A detailed treatment of innovation in closed and open economies.]

Grossman, Gene and Helpman, Elhanan (1991b), "Quality Ladders in the Theory of Growth," *Review of*

Economic Studies, Vol. 58, pp. 43-61. [This paper presents the case 3 model: vertical innovation in final goods.]

Grossman, Gene and Lai, Edwin (2004), "International Protection of Intellectual Property," *American Economic Review*, Vol. 94, No. 5, pp. 1635-1653. [This paper studies the optimal strength of patent protection in a two-country world where countries differ in market size and innovative capacities.]

Hall, Bronwyn and Khan, Beethika (2003), "Adoption of New Technology," in Derek Jones (ed.) *New Economy Handbook*, Amsterdam, Elsevier Science, pp. 229-249. [This article surveys the literature on technology adoption.]

Harhoff, Dietmar, Henkel, Joachim, and Von Hippel, Eric (2003), "Profiting from Voluntary Information Spillovers: How Users Benefit by Freely Revealing their Innovations," *Research Policy*, Vol. 32, pp. 1753-1769. [This paper presents a theoretical model why it is optimal to freely reveal innovations.]

Horowitz, Andrew W. and Lai, Edwin (1996), "Patent Length and the Rate of Innovation," *International Economic Review*, Vol. 37, No. 4, pp. 785-801. [This paper uses the case 3 model to study the optimal duration of patent protection.]

Howitt, Peter (1999), "Steady Endogenous Growth with Population and R&D Inputs Growing," *Journal of Political Economy*, Vol. 107, No. 4, pp. 715-730. [This paper is another example of the product proliferation approach to removing scale effects and studies the role of R&D subsidies.]

Issac, Alan and Park, Walter G. (2004), "On Intellectual Property Rights: Patents Versus Free and Open Development," in *The Elgar Companion to the Economics of Property Rights*, Enrico Colombatto (ed.), pp. 383-413. [This paper provides a critical analysis of the open source software movement.]

Isaac, Alan and Park, Walter G. (2005), "Open development: is the "open source" analogy relevant to biotechnology?" in David Castle and Richard Gold (eds.) *The Role of Intellectual Property Rights in Biotechnology Innovation* forthcoming. [This chapter provides a critical analysis of the open biotechnology movement.]

Jones, Charles (1995), "R&D-based Models of Economic Growth," *Journal of Political Economy*, Vol. 103, No. 4, pp. 759-784. [This paper presents evidence casting doubt on the existence of scale effects and presents the 'R&D difficulty approach' to removing scale effects.]

Jones Charles (2005), "Growth and Ideas," in *Handbook of Economic Growth*, Vol. 1B, Phillippe Aghion and Steven Durlauf (eds.) Elsevier B.V., Amsterdam, pp. 1063-1111. [This chapter is a comprehensive survey on endogenous innovation, theory and evidence.]

Kamien, Morton and Schwartz, Nancy (1982), *Market Structure and Innovation*, Cambridge University Press. [This book provides a useful survey of the literature on innovation before 1980.]

Klein, Michael (2002), *Mathematical Methods for Economics* (2nd edition), MA: Addison-Wesley. [This textbook shows how to use dynamic optimization methods, like the method of Hamiltonians.]

Kwan, Yum K. and Lai, Edwin (2003), "Intellectual Property Rights Protection and Endogenous Economic Growth," *Journal of Economic Control and Dynamics*, Vol. 27, pp. 853-873. [This paper uses the case 2 model to illustrate the dynamic tradeoffs associated with stronger patent rights.]

Lerner, Joshua and Tirole, Jean (2002), "The Simple Economics of Open Source," *Journal of Industrial Economics*, Vol. 50, No. 2, pp. 197-234. [This paper surveys the motivation and rationale for participation in open source projects.]

Li, Chol-Won (2001), "On the Policy Implications of Endogenous Technological Progress," *Economic Journal*, Vol. 111, pp. C164-C179. [This paper examines drastic and non-drastic innovation, and the implications for the effects of R&D subsidies.]

Nuvolari, Alessandro (2004), "Collective Invention during the British Industrial Revolution: The Case of the Cornish Pumping Engine," *Cambridge Journal of Economics*, Vol. 28, No. 3, pp. 347-363. [The article studies open innovation in the pumping industry in the 19th century U.K., where pumps were used to remove water from mines.]

O'Donoghue, Ted and Zweimuller, Josef (2004), "Patents in a Model of Endogenous Growth, *Journal of Economic Growth*, Vol. 9, No. 1, pp. 81-123. [This paper studies patent breadth using a Case 3 model.]

Park, Walter G. (1998), "A Theoretical Model of Government Research and Growth," *Journal of Economic Behavior and Organization*, Vol. 34, No. 1, pp. 69-85. [This paper uses a Case 2 model to study the effects of government R&D on innovation.]

Romer, Paul (1990), "Endogenous Technological Change," *Journal of Political Economy*, Vol. 98, No. 5, pt. 2, pp. S71-S102. [This paper presents the case 2 model: vertical innovation in intermediate inputs.]

Saint-Paul, Gilles (2003), "Growth effects of non proprietary innovation", *Journal of the European Economic Association*, Vol. 1, (Issue 2-3), pp. 429-439. [This paper uses the case 1 model of innovation to study the impacts of open innovation.]

Scotchmer, Suzanne (2004), *Innovation and Incentives*, MIT Press, Cambridge, MA. [This book provides a comprehensive analysis of the effects of the patent system and other institutional designs on innovation.]

Segerstrom, Paul (1998), "Endogenous Growth without Scale Effects," *American Economic Review*, Vol. 88, No. 5, pp. 1290-1310. [This paper provides an example of the 'R&D difficulty approach' to removing scale effects, using a case 3 type model.]

Segerstrom, Paul (2000), "The Long-Run Growth Effects of R&D Subsidies," *Journal of Economic Growth*, Vol. 5, No. 3, pp. 277-305. [This paper provides a comprehensive treatment of R&D subsidies on vertical and horizontal innovation.]

Tirole, Jean (1990), *Theory of Industrial Organization*, MIT Press, Cambridge, MA. [This textbook provides a good treatment of microeconomic theories of innovation.]

Von Hippel, Eric (2005), *Democratizing Innovation*, MIT Press, Cambridge MA. [This book provides a guide to user-based innovation.]

Verspagen, Bart (2005), "Innovation and Economic Growth," in *The Oxford Handbook of Innovation*, Jan Fagerberg, David Mowery, and Richard Nelson (eds.), Oxford University Press, pp. 487-513. [This review article compares the new growth theories to evolutionary growth theories.]

Young, Alwyn (1998), "Growth without Scale Effects," *Journal of Political Economy*, Vol. 106, No. 1, pp. 41-63. [This paper is another example of the product proliferation approach to removing scale effects and studies the role of R&D subsidies.]

Biographical Sketch

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