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Theory of Innovation

A New Paradigm of Growth

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That thou art

Once on a full moon night I saw the moonlight dancing in the rain.
All of a sudden He came out and stood in front full of smiles
And joy. Stop not, Go Forward: said Sri Ramakrishna, my Ishta,
my Ideal. May I follow him all my life.

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Preface

Modern economies today have undergone a dramatic change, thanks to the upsurge of computer and communication technology. Technology frontier today is driven by the information frontier and innovation provides the key catalytic driving force. Schumpeter views innovation as challenges: challenge to the Walrasian competitive equilibrium, challenge to the modern entrepreneurs, and challenge to management. Managing innovations in many forms and adopting forward-looking business strategies are important today for success in modern business enterprise. This new paradigm of industry growth and the impact of endogenous innovation provide the central focus of this volume. Technology diffusion, human capital deepening, dynamic efficiency, and market growth provide the key components of the modern theory of innovation. This theory has several basic features: (1) to explore a comprehensive theory of innovation extending the Schumpeterian perspective, (2) to develop a new theory of management that has been called the corporate lattice model, (3) to explore the need for collaborative ventures in R&D investment, (4) to discuss the many profound impacts of the Internet and associated technology, and (5) to explore the dynamic efficiency generated by the innovation frontier and its impact on economic growth under rivalrous competition.

Today's business leaders are aware that in this knowledge economy the quality of their workforce drives the value of their shares. According to a Brookings Institution study nearly 85 % of a company's assets are related to knowledge and talent. Because talent works at every level of the business corporation, the changes necessary to develop that talent extend to nearly every aspect of the company's activities. The shortage of critical talent now and in the near future is one big challenge for the managers today. The US Department of Education estimates that 60 % of all new jobs in the early twenty-first century will require skills that only 20 % of the current US workforce possess. Skill development and emphasis on innovative growth provide the key elements of successful management today. Need for effective collaboration is all the greater in this framework. Given the ever increasing pace of global business working together collaboratively becomes critical to keeping pace with innovation-intensive competition. Rather than focusing on defending a few key ideas or stocks of knowledge, companies must use the flows of knowledge generated by innovation to continuously accelerate newer and better ideas. This volume seeks to explore a comprehensive view of innovations in all its aspects. Schumpeterian models of innovation are extended in terms of modern theory and various challenges before modern management are discussed in some detail.

I would like to take this opportunity to express my deep appreciation to my wife who provided constant support and to my Guru for his encouragement. Both told me to remember that if even one student gets benefit from reading my book, I should continue to write it. My grandchildren—Jayen, Shiven, Aria, and Myra—helped me by always asking me what I am writing about. I had a hard time explaining to them, hoping that one day they would understand when they are grown up. May they lead an innovative life.

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Chapter 1
Theory of Innovation

Innovation in a broad sense involves developing new processes, new products, or new organizational improvements for an industry. It can take many forms, but in every form, it tends to reduce unit costs and/or helps to expand market demand. Some of the important types of innovation are as follows:

1. Technology-based innovation
2. Endogenous v. exogenous innovation
3. Innovation in selection mechanism in industry growth
4. Innovation through technology consortium

Technology-based innovations include such forms as (a) product innovations, (b) industrial R&D investments, and (c) technology transfers through imitations and improvement. Endogenous innovation involves market incentives for developing the propensity to invest for innovations. The expected rewards for winning the technology race and the likely protection of monopoly products through patent laws provide the basic ingredients of such market incentives. Basic research in academic and nonprofit institutions provides an example of exogenous innovation. This type of R&D research provides the general background, which may sometimes lead to new products or new processes later on. Solow's growth model assumed all technological progress as exogenous, though eventually it led to an upward shift of the production frontier involving significant productivity gains for industry and the overall economy.

The next two types of innovations involve less tangible phenomena. The evolutionary selection mechanism chooses firms through dynamic market efficiency and the patent system. This mechanism recognizes both the cumulative nature of technological change and the endogenous aspects of market structures. The patent system is the second policy instrument of technological selection. It defines property rights which support the incentives for technological innovations. For example, the pharmaceutical industries undertake large R&D investment due to such incentives. In the technology literature it has been recognized that a patent system with a *limited scope* promotes technology and knowledge diffusion, which innovations with a *broad scope* encourage more experimentation in technological research.

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Innovations in human capital generally occur through learning by doing. Three types of measures of learning by doing are used in the econometric literature. One is the cumulative research experience embodied in cumulative output, where the latter is often taken as a proxy for technological progress, e.g., the empirical studies of industrial productivity growth by Norsworthy and Jang (1992) have found the cost of reducing effort of such technological progress to be substantial in microelectronics, telecommunications, and related industries. The second measure is cumulative experience embodied in specific strategic inputs like specialized capital. A third measure of experience in knowledge capital may be due to the imitation process, whereby the spillover of knowledge from technologically advanced firms to others is captured by the followers. Growth miracles in Southeast Asia in the last three decades have shown evidence of such innovations in knowledge transfer.

The impact of innovations on industry growth has significant economic implications for theory and experiences of economic growth of nations. It is useful to critically review this framework here.

A major impact of innovation is to reduce unit costs of production and distribution. Hence it reduces prices and thereby improves competitive advantage. Creative destruction is the process by which old sources of competitive advantage are destroyed and replaced with new ones. In Schumpeter's theory of innovation the innovative role of the entrepreneur is to exploit the shocks or discontinuities that destroy existing sources of advantage. Porter (1990) in his *The Competitive Advantage of Nations* views competition as an evolutionary process. Firms initially gain competitive advantages by altering the basis of static competition. They win not just by recognizing new markets or technologies but also by moving aggressively to exploit them. A firm's home nation plays a critical role in shaping managers' perceptions about the new opportunities that can be exploited. The domestic economic framework shaped by technical and scientific education helps put pressure on firms to innovate, invest, and improve R&D activity. Thus innovation increases comparative advantage of small countries in international trade that are rich in technological knowledge. As examples one may refer to countries like Taiwan and Finland. The world Economic Forum Report edited by Porter (2004) has computed a growth competitiveness index (GCI) based on three components: infrastructure development, quality of public institutions, and the adoption of the best practice technology of the world. Its report for 2002–2004 showed the following ranking:

Clearly Taiwan's record of performance is most impressive. We may note also that in terms of the average number of annual US patents per million people, the top rankings in the world in 2004 were (1) USA, (2) Japan, and (3) Taiwan. One of the

	Rank		Technology rank
	2002	2003	2003
Taiwan	6	5	3
Finland	1	1	2
Korea	25	18	6
USA	2	2	1
China	38	42	65

major forms of innovation involves R&D and the associated investment process in knowledge creation and diffusion. Research in "knowledge capital" captures the external economies of R&D done by other firms. Thus the external benefits of R&D investment in developed countries spill over to other developing economies. This provides one main reason of growth miracles in Southeast Asia over the last three decades. The R&D race provides for the winner quasi-monopoly profits in the short and medium term. This increases the market power and dominance of large firms. Schumpeter emphasized this aspect in his dynamic theory of evolution of firms under innovation. A dominant established firm's incentive to innovate may be weaker than that of a smaller firm or a potential entrant. The sunk cost and replacement effects weaken the established firm's incentive to innovate. The efficiency effects of R&D-based innovation strengthen the dominant firm's incentive to innovate compared to a potential entrant's incentive. The reason is that the incumbent can lose its monopoly, if it does not innovate, whereas the entrant will become at best a duopolist if it succeeds in innovative venture.

1.1 Technology and Efficiency

Innovation as technology is most important for its efficiency effect. The technology process comprises several stages. Pure research, oftentimes in academic and public institutions, provides the basics of applied research. In this general sense, knowledge may be viewed as capital, which provides the basis of a complementary input in the production function. Technology creation and diffusion help an economy to build new types of dynamic efficiency such as innovative efficiency and access efficiency. Innovative efficiency occurs through competitive advantage gained through new knowledge. Access efficiency begins through globalization of markets, where networking and scale economies in knowledge-intensive products such as computer hardware and software, telecommunications, and pharmaceuticals have intensified the innovation capabilities of modern firms. In modern times economies have undergone a dramatic transformation from large-scale material manufacturing to the design and use of new technologies, software innovations, and social networking like Facebook in telecommunications. These new innovations are all characterized by increasing returns and scale economies, and also these have positive feedback and strong complementarity effects through knowledge diffusion and transmission. There exist five main reasons for the recent upsurge of these new innovations: (1) high fixed costs with low variable costs so that the marginal cost is very small, (2) network effects by which the value of a product increases with the number of users, (3) high switching costs which imply that users tend to stay with the product of technology for a minimal time, (4) externalities of new processes diffused to other countries and other industries through spillover effect of R&D investments in knowledge capital, and, finally, (5) nanotechnology has spread the speed of miniaturization to various products and services with a complementary impact on various interrelated products and services.

Recently Nachum (2002) tested several hypotheses over US panel data for 1989–1998 comprising 650 firms in order to test the role of innovative activity on foreign direct investment by multinational firms. One of his significant findings is that the impact of innovative investment is much stronger for IR (increasing returns) dominated industries than for the DR (diminishing returns) industries. Also networking, entrepreneurship, and flexible organizational structure of the IR industries played a similar role.

It is interesting to note that the innovative role of modern IR industries was predicted by the Schumpeterian model of innovation. Schumpeter distinguished between five types of innovations as follows:

1. Product innovation, where a new type of product or service is added to the list of goods requiring a change in the production routine.
2. Process innovation, which entails a change in the production function or the production routine. This frequently involves a change in the input mix and input quantities.
3. Organizational innovation, which involves change in the managerial routines leading usually to a change in market structure, e.g., a reorganization of a price cartel.
4. Market innovation, where a product is introduced to new markets like selling abroad.
5. Input innovation, which involves new raw material or new intermediate good, e.g., new sources of energy or new types of uses of the existing inputs.

The central dynamic role in these innovations is played by the entrepreneur in Schumpeter's model. The Schumpeterian entrepreneur (S-entrepreneur) plays a dynamic leadership role as soon as a significant innovation is made in the previously stationary equilibrium economy. In his words the entrepreneur is the king, the banker, and the ephor of the market. He is the "king," because he has the will and energy to initiate the transformation of the system of routine. He initiates a selective pressure on the incumbent firms, who either go bankrupt, exit the market, or adapt to the change. The essence of the entrepreneurial function comprises economic activities of the following types:

1. The production of new products or services or new qualities of goods.
2. The introduction of new production technologies.
3. The creation of new forms of industrial organization at different levels of business, e.g., increasing use of venture capital or hedge fund investment in today's stock market.
4. The opening up of new markets, e.g., globalization and widespread use of networking methods in business communication and finance.
5. The opening up of new sources of supply through widening of the supply chain and global investment by multinational firms. The tide of significant economic growth in the newly industrialized countries (NICs) of Southeast Asia over the last three decades bears eloquent evidence of this openness process in international trade.

6. The diffusion of new innovation in different sectors and the spillover effects of modern technology alluded to by Schumpeter have been strongly emphasized in recent growth literature.

This list of economic activities of the innovating S-entrepreneur may be augmented by two recent developments. One is the concept of "hypercompetition" introduced first by D'Aveni (1994) and the other the concept of "evolutionary efficiency" studied in evolutionary biology and applied recently in evolutionary growth theory in economics. In software research and other high-tech fields of today's business, intense competitive pressure has generated four types of dynamic efficiency analyzed in some detail by D'Aveni. There are *production efficiency* in terms of a decline in unit costs, *innovation efficiency* in terms of R&D investment and race for patents, *access efficiency* where the innovating firm races up the escalation ladder and through mergers and buy-ups keeps out potential entrants, and *resource efficiency*, where the companies seek to expand their resource base through multinational world markets. Hypercompetitive firms must use their fixed assets and accumulated resources to build their next temporary base of competitive advantage. Thus IBM bet the company on the 360 series computer and the bet paid off in the 1960s through increased market dominance and large profits due to specific competitive advantage. But its resource base could not sustain this dominant position very long due to its failure to diversify. Small competitors like Apple and Microsoft became giants by seizing the new opportunities for developing PCs by their diversified resource base and its efficiency.

One has to note that a new innovating firm's ability to gain competitive advantage over others depends on the presence of "the market for research ideas" in the industry. Teece (1986) identifies two basic elements behind the market for ideas. One is that the technology is not easily expropriable by others. This may be due to the requirement of large fixed investment in R&D, e.g., new medicine or drugs. The second element is the existence of specialized assets in the company such as specific product capabilities or core competence that must be used in conjunction with the innovative product. The dynamic side of the competition is an evolutionary process, where the innovating firms gain competitive advantage by altering the P=MC basis of static competition. They win not just by recognizing new market or new technologies but also by moving aggressively to exploit them. They sustain their advantages by increased investment for improving the existing sources of advantages and for creating new ones. These advantages form the basis of the concept of "core competence" of a firm, which is so strongly emphasized by the management science experts. The traditional economists have failed to emphasize these managerial aspects of dynamic efficiency in the competitive framework.

1.2 Endogenous Aspects of Innovation

Endogeneity of industrial innovation has three basic sources:

1. The market structure and its impact on the development of new technology

2. Endogenous growth theory and the impact of capital accumulation
3. Knowledge diffusion and its impact on the spillover of new technology in globalization

The market structure basically embodies profitability and its long-run sustenance. The profit incentives guide the entrepreneurs along the path of innovation in various forms. Schumpeter emphasized the distinction between innovative and noninnovative agents or firms. This distinction allows the Schumpeterian entrepreneur (S-entrepreneur) to play a more dynamic role in industry growth than the Walrasian entrepreneur (W-entrepreneur). The W-entrepreneur is a core noninnovative agent who adapts promptly to a change of the economic system thus contributing to the equilibrium of the system. By contrast the S-entrepreneur disturbs the static competitive equilibrium by buying or using resources to change one or more parameters of the economic system. The S-entrepreneur wants to change what to others appears to be a given production routine and if necessary the related consumption routines. The S-entrepreneur can base the evaluation of the profitability of his project on the Schumpeterian conjecture that the other firms do not adapt quickly. This conjecture of Schumpeter, very similar to Cournot's conjecture, is in sharp contrast to the extremely flexible behavior of W-entrepreneurs. Andersen (2011) has argued that Schumpeter ultimately wanted to endogenize economic institutions, science and invention, and parts of behavioral psychology in his dynamic evolutionary process of innovation.

Recently innovations flow has been modeled as a stochastic process for the competitive R&D race. If we assume that successful innovations arise as a result of a Poisson stochastic process with an intensity u, then the probability of a firm innovating successfully during period dt is udt. The expected monopoly profit (π) for the successful S-entrepreneur may then be written as

$$\pi(n, u) = r(n)u - c(u, f), \tag{1.1}$$

where $r = r(n)$ is the instantaneous monopoly surplus (profit) obtained by the winner of the innovation race and $c(u, f)$ is the firm's cost function which is assumed to be convex on the intensity u and fixed cost f. Here the monopoly profits or surplus is assumed to depend on the number of firms in the industry. Fölster and Trofimov (1997) maximized the profit function (1.1) with respect to intensity u and the result is an optimal profit function which is S-shaped. This type of profit function implies that the positive effect of R&D innovations sometimes dominates the negative effect of increased competition. Spence (1984) viewed R&D investments basically as fixed costs, which reduce unit cost. In many instances, e.g., new medicines, the R&D expenditures take the form of developing new products at cheaper prices. In this environment market structures are likely to be concentrated and imperfectly competitive. What is significant about R&D innovations is not only product differentiation and scale economies but also the spillover effects of externality effects. The benefits of R&D spread to other firms through learning by doing and knowledge diffusion. Spence modeled this process in terms of the dependence of unit costs $c_i(t)$ of firm i on the accumulated knowledge $z_i(t)$, where

$$\dot{z}_i(t) = m_i(t) + \theta \sum_{j \neq i} m_j(t) \tag{1.2}$$

the dot denotes the time derivative and $m_i(t)$ the current expenditure of firm i on R&D. The parameter θ $(0 \leq \theta \leq 1)$ captures spillover effects where unit cost

$$c_i(t) = F(z_i(t)) \tag{1.3}$$

is a declining function of $z_i(t)$. In this model the case $\theta = 0$ represents no spillovers, while $\theta = 1$ represents the case when the benefits of each firm's R&D are shared completely. Spence derives an important relationship in this model relating the industry's total investment in R&D as a function of z as follows: R&D costs at the industry level

$$= zn/(1 + \theta(n - 1)). \tag{1.4}$$

This is a symmetric case with all firms alike. For a given level of z and $n > 1$, the R&D costs of the achieved amount of cost reduction decline as θ increases. As n tends to infinity, R&D costs tend to the upper limit of $1/\theta$ when θ is positive. For zero θ the R&D costs are proportional to the number of firms. Two implications are important. One is that the spillovers reduce the industry level costs of R&D for achieving a given level of cost reduction, though they may reduce the incentives for cost reduction. But the incentive reduction may be restored through appropriate policies of state subsidies. Secondly, when n decreases, the market becomes more concentrated. The incentive for temporary monopoly profit tends to be more dominant. The impact of ignoring spillovers is to make the investment decisions of firms more aggressive, because the anticipated return is perceived to be higher than it actually is. Due to this spillover effects, knowledge diffusions have intensified in recent years through software technology and increased direct investment by multinational corporations.

Recent developments in endogenous models of economic growth emphasized two key sources on endogeneity. One is knowledge creation associated with investment. A firm that increases its physical capital learns simultaneously how to produce more efficiently. This positive effect of experience on productivity is called "learning by doing," a term first coined by Arrow (1962). The second is the spillover effect from a firm to the industry and from industry to the overall economy. Consider for example the simplest endogenous growth model known as the AK model where output Y is

$$Y = AK, \tag{1.5}$$

where A is technology and K is capital including both physical and human capital. If A is assumed to be constant, so that there is no technological progress in the Solow sense, then one obtains in per capital terms $y = Ak$, $y = Y/L$, $k = K/L$. This implies that the growth rates of income y and capital k are equal

$$g_y = \Delta y/y = g_k = \Delta k/k = \dot{k}/k$$

and the savings investment equilibrium implies

$$g_y = \dot{y}/y = sA - (n + \delta) = g_k.$$

Thus the AK model can display positive long-run per capita growth without any technological progress, where technological progress is measured by a positive value of $\dot{A}/A$. Per capita income growth can occur even with zero technological progress. Note also that a higher savings rate s and a higher level of A can increase the long-run growth rate in this endogenous model of growth.

The key to endogenous growth in the AK model is the absence of diminishing returns in the factors that can be accumulated. Both Arrow (1962) and Romer (1990) attempted to eliminate the tendency for diminishing returns by assuming that knowledge creation was a side product of investment. A firm that increases its physical capital learns simultaneously how to produce more efficiently. This positive effect of experience on productivity is called learning by doing. Also each firm's knowledge is a public good that any other firm can access at negligible costs. In other words once discovered, a piece of knowledge spills over almost instantly across the whole economy. Lucas (1993) used this idea in explaining the Asian growth miracle, where countries like Taiwan, South Korea, Singapore, and China grew at a faster rate over the last three decades.

Empirical data seem to show that growth in knowledge capital, openness in trade, and foreign investment in these newly industrializing countries (NICs) of Southeast Asia have greatly contributed to their success rate. For example, South Korea's export growth rate of 22.9 % over the period 1965–1987 accompanied the average income growth rate of 6.4 %. China's reform of its national innovation system started in the 1990s. A good measure of R&D intensity is the ratio of R&D expenditure to GDP. By this measure China's R&D intensity rose from 0.74 in 1991 to 1.23 in 2003. Now in 2011 it exceeds 2.0. For Korea it rose from 1.92 to 2.96 during 1991–2004. Taiwan's contemporary knowledge-based economy has revealed remarkable growth of the information technology (IT) sector than China and other NICs of Asia. From 1995 to 1999 Taiwan's IT industry ranked third in the world after the USA and Japan. The overall R&D intensity rose from 1.78 in 1995 to 2.16 in 2003 and has exceeded 3.00 in 2011.

Recent empirical studies have shown that the R&D investment generating new industrial knowledge capital know-how in the USA has spread to the developing countries, and the successful NICs in Southeast Asia have taken full advantage of it. Many incremental innovations that come in small steps, e.g., in software and communication fields, have generated new innovations in these NICs and this is intensified by the boom in exports of technology-intensive products and processes.

It has to be noted that the knowledge diffusion process embodied in endogenous growth theory is rarely the dramatic breakthroughs that Solow and Schumpeter may have had in mind, but rather small improvements and small dispersal of a new process or product in which novelty and imitation imperceptibly get mixed up into one another. Two aspects of this incremental diffusion process deserve special mention. One is that technical knowledge is itself a kind of capital good embodied as K in the AK model. It can be stored over time because it does not get completely used up whenever it is put into the production process. The second important element is the impact of incremental innovation in terms of economies of scale and economies of scope associated with R&D investment. The innovation through R&D expenditures exceeds 5 % of total sales at many high-tech companies such as Intel, Microsoft, GlaxoSmithKline, and GE. The pharmaceutical companies spend upwards of $500 million to successfully develop a new drug. This contains a substantial indivisible investment, implying that every unit cost will decline very rapidly as the sales of the drug increase. Thus R&D expenditures also entail substantial economies of scale, since ideas developed in one research project create positive spillovers to another project. This happens more often in pharmaceutical and software firms.

1.3 Selection and Industry Evolution

Industry evolution depends basically on the selection mechanism operating through innovations and dynamics of the market structure. New technology and the process of entry and exit of firms are important forces here. Several factors play critical roles in the selection process. First, we have the evolutionary approach which emphasizes the firm's ability and competence to alter the market structure significantly. Following the Schumpeterian theory of technological innovations where size begets size and the cumulative processes of innovations generate significant scale economies. Here industrial dynamics would be characterized frequently by nonlinear and path-dependent processes, where random events like a new incremental innovation or a new software may have lasting and irreversible effects on the dynamic evolution of the selection process. Secondly, firms differ significantly in their commitment and ability to innovate. Thus innovations are largely endogenous to the firm through R&D investment and learning by doing. Thirdly, the evolutionary forces of selection which allow only some firms to survive and grow are subject to initial stochastic mechanisms which play an active dynamic role. Thus Jovanovic (1982) and Mazzucato (2000) have considered cost efficiency under innovation depending on a stochastic parameter. Uncertainty represented by the stochastic parameter is generally very high in the early stages of the industry life cycle, when the product design has not yet been standardized. In this phase the flexibility of small new firms allows them to be the leaders in cost reduction and new innovative experiments