Chapter 2
Innovation Models

Models of innovation emphasize for the most part the endogenous character of industry growth. How does a firm grow? How does it affect industry growth? What role does the market play in this framework? These issues are central to the formulation of innovation models in recent times. Innovation models vary by types of innovations and the way they affect industry growth. However most innovations have some common characteristics as follows:

1. It involves new and productive ways of industry growth through production, distribution, communication, or organization.
2. R&D investment comprises the core component of most innovations, and it may involve both theoretical and applied research. However theoretical research does not directly yield industrial results till it is applied through knowledge diffusion across firms and industries commercially.
3. Technical change and the diffusion of human capital play a central dynamic role in most industrial innovations, although creating a new firm or a new organization may be equally important for starting an innovation.
4. All endogenous innovations are motivated by the market incentives of profit and economic efficiency under dynamic competition.

In order to analyze these common characteristics of innovation we have to discuss the innovation diversity. This diversity involves various forms of innovations, which are all dynamic in character in the sense that they have economic impact and evolution over time.

2.1 Innovation Diversity

Innovations may take many forms depending on the gestation period of developing it and on its evolutionary impact over time. Four broad types are usually distinguished:

J. Sengupta, *Theory of Innovation: A New Paradigm of Growth*,
DOI 10.1007/978-3-319-02183-6_2,

1. Technology-based innovations
2. Knowledge diffusion and human capital based innovations
3. Introduction of "new combinations" which creates a fundamental impulse in capitalist development to generate new consumers' goods, new methods of production or transportation, new markets, or new forms of industrial organization
4. Finally, innovation as evolutionary learning through adaptive efficiency in dynamic competition and/or Cournot–Nash market structure.

It is useful to discuss these four varieties of innovations, since they involve some of the basic features of modern industry growth in several fields such as information and communication industries, pharmaceuticals, and bioengineering fields.

Technical change in the form of new techniques of production or new processes or software development is mostly used to characterize technical inventions which alter the shape of the production and cost frontiers of firms and industries. In Solow's model of neoclassical growth this comprises the major form of technological progress. The technology process comprises several stages. The first is technology creation and diffusion. Research and its interactions through diffusion of both theoretical and applied knowledge are important here. An empirical estimate by Cohen and Levinthal (1989) over 1,302 sample units in the US manufacturing sector shows that the effects of innovations on R&D intensity of the basic and applied sciences are significantly different. This means that the role of diffusion and learning differs significantly across industry fields. Increasing technological opportunity through the basic sciences evokes more R&D spending than does increasing technological opportunity through applied sciences. The second important aspect of the new technology process is its impact on new types of dynamic efficiency such as innovation efficiency and access efficiency. Innovation efficiency occurs through the competitive race in the knowledge arena. The drive for imitation and the first mover advantages provide the incentives for capturing the industry spillover effects. Access efficiency occurs through globalization of markets through mergers and technology consortium. Finally, new technology changes the market structure dramatically, especially in the high-tech fields, e.g., through software development and miniaturization of new technical gadgets.

Although new technology is more visible in its physical impact, the human capital based innovation has more long-run impact on the overall economic growth of nations. In recent times competition has been most intense in modern high-tech industries such as semiconductors, microelectronics and personal computers. The empirical study by Jorgenson et al. (2000) noted two significant impacts of the growth of computer technology on the overall US economy. First, as the computer quality improves, more computer power is being produced from the same inputs, i.e., learning by doing through human capital and cumulative experience on the job increases the skill inputs. Secondly, the computer-using industries are now using skilled labor working with better and more efficient computer equipment and the related communications equipment like the iPad, thus increasing labor productivity in the high-tech and other manufacturing and service industries. For example, the average industry productivity growth (i.e., total factor productivity growth) has achieved a rate of 2 % per year over the period 1958–1996 for electronic equipment, which includes semiconduction and communications equipment. This trend has continued over the recent period 2000–2010 although at a slightly lower rate. High productivity growth led to falling unit costs and prices. For instance, average PC prices declined by 18 % per year from 1960 to 1995 and by 27.6 % over 1995–1998. Recent estimates suggest a rate of decline of 15 % over 2000–2010. Learning by doing through the use of innovations in human capital has greatly contributed to this high growth phenomena. We consider now three types of learning phenomena involving knowledge diffusion. One is the cumulative research experience embodied in cumulative output, where the latter is very often used as a proxy measure of technological progress. The second measure is cumulative experience embodied in strategic inputs such as capital goods or R&D inputs. Finally, the experience in "knowledge capital" available to a firm due to a spillover from other firms may be embodied in its cost function through cumulative research inputs.

In order to characterize efficiency through human capital utilization we use nonparametric efficiency models through a set of linear programming models, also known as DEA (data envelopment analysis) models. These models characterize Pareto efficiency and screen the efficient firms over the inefficient ones. The unifying theme of these models is a convex hull method of characterizing the production frontier without using any market prices and also the cost frontier which uses market prices to determine the optimal level of inputs. Consider the problem of testing the relative efficiency of a reference firm h in a cluster of N firms, where each firm produces s outputs (y_{rj}) with two types of inputs: m physical inputs (x_{ij}) and n human capital inputs as knowledge capital (z_{wj})

$$
\begin{aligned}
&\min u + v \\
&\text{subject to (s.t.)} \\
&\sum_{j=1}^{N} x_j \lambda_j \leq u x_h; \ \sum_{j=1}^{N} Z_j \lambda_j \leq v Z_h \\
&\sum Y_j \lambda_j \geq Y_h; \ \sum \lambda_j \geq 1, \lambda_j \geq 0 \\
&j = 1, 2, \ldots, N.
\end{aligned}
\tag{2.1}
$$

Here x_j, Z_j, and Y_j are the observed input and output vector for each firm j. Let $\lambda^* = (\lambda_j^*), u^*, v^*$ be the optimal solutions of the LP model (2.1) with all slack variables zero. Then the reference unit or firm h is technically efficient (without using any market prices) if $u^* = 1.0 = v^*$. If however u^* and v^* are positive but less than unity, then it is not technically efficient at the 100 % level, since it uses excess inputs $(1 - u^*) x_{ih}$ and $(1 - v^*) z_{wh}$. Overall efficiency (OE_j) of a firm combines both technical (TE_j) or production efficiency and the allocative (AE_j) or price efficiency as follows: $\mathrm{OE}_j = \mathrm{TE}_j * \mathrm{AE}_j$. For overall efficiency one may solve the cost minimizing model:

$$\begin{aligned}\min \mathrm{TC} &= c'x + q'z \\ \text{(s.t.) } X\lambda &\le x;\ Z\lambda \le z \\ Y\lambda &\le Y_h;\ \lambda' e = 1, \lambda \ge 0.\end{aligned} \tag{2.2}$$

Here e is a column vector with N elements, each of which is unity, prime denotes the transpose, c and q are unit cost vectors of the two types of inputs x and z which are now the decision variables, and $X = (X_j)$, $Z = (Z_j)$, and $Y = (Y_j)$ are appropriate matrices of inputs and outputs. Overall efficiency (OE_h) computed from (2.2) is $\mathrm{TC}_h^*/\mathrm{TC}_h$; the allocative efficiency is $\mathrm{AE}_h = \mathrm{TC}_h^*/(u^* + v^*)\mathrm{TC}_h$ where TC_h and TC_h^* are the observed and optimal costs for firm h. Clearly the inefficient firms have minimal total costs with maximum overall efficiency. These firms would tend to lead in industry growth and attain a more dominant position.

Now consider the special characteristics of the research inputs z associated with human capital. Since these inputs tend to affect unit costs nonlinearly we can rewrite the objective function of model (2.2) as

$$\min \mathrm{TC} = \sum_i \left[\left\{ c_i - f_i \left(\sum_w q_w z_w \right) \right\} x_i + \frac{1}{2} d_i x_i^2 \right] + \left(\frac{1}{2} \right) \sum_{w=1}^{n} g_w z_w^2. \tag{2.3}$$

Subject to the constraints of the model (2.2). Here f_i is the unit cost reduction with $f_i < c_i$ and the component cost functions are assumed to be strictly convex. If the firm is efficient with positive input levels and zero slack variables, then we must have $\partial L/\partial z_w = 0 = \partial L/\partial x_i$ where L is the Lagrangian function. The Kuhn–Tucker necessary conditions for optimality are then

$$\begin{aligned} f_i q_w x_i + \gamma_w &\le g_w z_w;\ z_w \ge 0 \\ f_i \left(\sum q_w z_w \right) + \gamma_i &\le c_i + d_i x_i;\ x_i \ge 0. \end{aligned}$$

Here γ_i and γ_w are the Lagrange multipliers for the first two constraints. Here the complementarity of the two inputs x and z is explicitly shown and the learning parameter f_i captures the productivity impact of human capital.

A more general version of the model arises when we incorporate the time profile of output generated by the cumulative experience through human capital investment. Let $z(t) = (z_w(t))$ be the vector of gross investments and $k(t) = \int_0^t z(s)ds$ be the cumulative value where

$$\dot{k}_w(t) = z_w(t) - \delta_q k_w(t) \tag{2.4}$$

with dot denoting the time derivative and δ_w is the fixed rate of depreciation. The long-run cost minimization model now becomes

$$\min J = \int_0^\infty e^{-rt}\left[c'(t)x(t) + C(z(t))\right]\mathrm{d}t \tag{2.5}$$

s.t. (2.4) and the constraints of (2.2).

Here $C(z(t))$ is a scalar adjustment cost which is generally assumed to be nonlinear in the current theory of investment. On applying Pontryagin's maximum principle, the optimal long-run cost frontier of the efficient firm can be determined, which can explicitly show the interdependence of the two inputs: the physical and human capital based research inputs.

Introduction of new combinations of inputs and creation of new markets have become a major source of high-tech development in the field of communications. Miniaturization and multifunction-based features have currently dominated the iPhones, iPad markets and competition is very intense here, where different types of technologies are converging. Drawing on a data set of more than 2,000 observations on "significant innovations and innovating firms" in the UK over the period 1945–1980, Pavitt (1984) identified five major categories of innovations as follows: (1) supplied dominated, (2) production intensive, (3) science based, (4) information intensive, and (5) technological trajectory based. Lancasterian and post-Lancasterian characteristic-based approach to the definition of product represent a powerful tool to operationalize a set of innovation modes. Innovation is viewed here not as an end result but as an ongoing process. Rather than identifying "types" of innovations, this framework allows us to identify different "models" of innovation and their dynamics. Some of these dynamics are as follows:

(a) *Radical innovation*: It is defined by the creation of a new set of vectors of competencies, technical and service characteristics.
(b) *Improvement innovation*: It occurs when the set of vectors of characteristics remains unchanged, but the quality value of their single elements increases through technical characteristics or improvements in certain competence vectors.
(c) *Incremental innovation*: This occurs when a new characteristic of the product or process is added or modified. It is not the traditional notion of a sort of residual.
(d) *Ad hoc innovation*: From the supplier viewpoint this innovation means contributing to the whole set of competencies, making significant change in the vector of competencies, and improving the immaterial knowledge elements of the technical characteristics vector.
(e) *Recombination innovation*: This might involve creation of a new product or new process as a combination of characteristics of one or more products, or through fragmentation of the characteristics of a preexisting product or process.
(f) *Formalization innovation*: This occurs when one or more characteristics of new products or processes are formatted or standardized. This occurs most frequently in the service-oriented industries and communication industries.

Evolutionary learning and spillover knowledge across firms, industries, and nations emphasize the most creative role of innovation dynamics. This is supremely important in today's world of high technology. Modern endogenous growth theory assumes that an economy automatically benefits from its investments in new knowledge, because knowledge is a public good that can be used by an entire economy. The USA is thought to commercialize new knowledge better than Europe. The successful NICs in Asia have performed much better than Europe and Latin America. Investment in new knowledge is only a necessary condition for endogenous growth: this new knowledge must be exploited and put to commercial use so that it can translate into stronger competitiveness and cumulative economic growth. The contribution of Acs et al. (2009) has extended the microeconomic foundations of the macro models of endogenous growth through the knowledge spillover theory of entrepreneurship, which holds that knowledge creation can lead to knowledge spillovers, creating technological opportunities. These opportunities can be exploited by new entrepreneurs and businesses. New product innovations may be generated from both incumbent firms and start-ups. The incumbent firms may produce incremental innovations from the flow of knowledge, whereas start-ups may exploit knowledge spillovers to produce major or radical innovations. One major impact of spillovers and external economies of knowledge creation is that it generates significant scale economies which spread across national boundaries. By the comparative advantage principle of international trade theory, the size becomes an important factor. Through mergers and acquisitions businesses exploit the advantage of market expansion throughout the world.

Thus innovations tend to provide many channels of potential market power, which challenges the basic premises of competitive equilibrium. In the present day world of innovations and their spillover effects various forms of noncompetitive market structures have evolved in recent times and correspondingly many dynamic models of innovations have been formulated. Scale economies and learning by doing have comprised the basic elements of such innovation models. Economies of scale are usually measured in two ways: either through a production function showing increasing returns to scale or a total cost function showing declining long-run average cost. Four major sources of economies of scale have been distinguished in economic literature: (1) indivisibility of specific inputs like the plant or knowledge capital sometimes measured by the size of the plant or capital stock, (2) learning by doing through cumulative experience embodied in labor or human capital, (3) the industry stock of R&D and knowledge capital, and (4) economies of scope due to integration of managerial and technical functions. External economies (EO) are important for two reasons. One is that it captures the effects of technological diffusion across firms and related industries. This spread effect may arise through both output of EO and its linkage effect through complementarities. Knowledge, e.g., software technology, helps other firms grow. Consider a linear cost function for firm j as $c_j = ay_j$, where y_j is output. The industry cost function in the symmetric case is $C = aY$, where $Y = \sum_{j=1}^{n} y_j$ and $C = \sum_{j=1}^{n} c_j$. The industry effect is then captured by relating the constant a in the firm cost function to the industry output as

$$a = a_0 Y^{r-1}, a_0, r > 0.$$

In a competitive framework the individual firm equilibrium is given by $p = MC = a$, which is subjective to the firm. The objective condition of equilibrium however allows for external economies and is given by $p = arY^{r-1}$. If r is positive but less than one, then the equilibrium price will fall as total industry output increases. Also the marginal cost of each firm would fall as total industry output rises. The price fall would generate market expansion and global trade would be augmented through diffusion of knowledge and external economies. The major factor in technology and knowledge diffusion is the interindustry spillover in the high-tech industries today. Bernstein and Nadiri (1988) estimated the effects of these spillovers on production processes by specifying a variable cost function for each industry as a truncated translog function with no own of squared second-order terms:

$$\ln(c_v/w_m) = f(\ln w_l, \ln w_p, \ln y, \ln K_t^i, \ln K_t^j, \text{other terms}).$$

Here c_v is variable cost, w_m = price of materials, w_l = wage rate, w_p = rental rate on capital, y = output, K_t^i = industry's R&D capital, and K_t^j is other industry's R&D capital. The empirical estimates for Us industries such as electrical products, scientific instruments, chemical products, and transportation equipment showed two general findings. One is that the variable cost for each high-tech industry was significantly reduced by R&D capital spillovers. Secondly, the technology industries had higher rates of cost reduction, e.g., computers and telecommunication industries.

Due to these spillover effects and external economies various forms of noncompetitive market structures have developed in recent times in these high-tech industries. Following Schumpeter's innovation approach D'Aveni (1994) has characterized this noncompetition framework as hypercompetition. Whereas the competition paradigm emphasizes pricing as the basic strategy with a fixed technology, hypercompetition stresses the dynamics of innovation in both technology and market structure. This is very similar to Schumpeterian innovation theory, where innovations shift the production and distribution frontier and the opportunity to make quasi-monopoly profits through the innovation process provides the basic endogenous motivation for increased investment for human capital. The shift from perfect competition to noncompetition market structure brought about by innovations allows market rivalry and increased market entry for the successful innovations. By innovations the firms tend to occupy a dominance in the market structure. This dominance creates two types of impact on industry performance. One is the leader–follower interdependence analyzed in the Stackelberg model and the second is the entry preventing strategy adopted by the successful innovators as dominant firms.

2.2 Innovation Models of Industry Growth

Dynamics of innovation efficiency characterize the process of industry growth through a number of factors such as new technology, new source of supply, and/or a new type of organization or communication network. We discuss here four specific types of models of innovation dynamics as follows:

1. A quasi-competitive model of innovation
2. A model of technical innovation and diffusion
3. A dynamic Cournot–Nash model with spillover effects
4. A demand-induced model of innovation

The relationship between innovation and industrial evolution has always been central in Schumpeterian work on innovation. Recent trends have extended this discussion in several ways. We discuss here a few of these trends:

(a) In some models such as Sutton (1998), technology and demand-related factors set bounds on industrial structures, entailing Nash equilibrium on industry-specific entry processes. No specific attention is paid to the learning process of firms.
(b) The competitive process in some recent models of industry dynamics becomes proactive in weeding out the heterogeneity in firm distributions.
(c) More intensive on the learning processes of firms in industrial dynamics are the evolutionary models of Nelson and Winter (1982) and Dosi et al. (1995).
(d) Progress has been made at a more macrolevel by linking innovation and industry evolution to structural change and the changing structural composition of the economy. The work of Metcalfe (1998), Dosi (2001), Montobbio (2002), and others. DeBresson and Andersen (1996) and his associates have empirically estimated an innovative-interaction matrix between sections which are suppliers of innovative activity and the sectors which are users.

For discussing these models we follow separate notations in each case according to each author or authors.

A. A Quasi-Competitive Model

We consider a short version of the competitive model of innovations due to Amendola and Musso (2000) and discuss the noncompetitive features underlying it, which make it quasi-competitive.

The model shows that competition operates through innovation, where innovation is a means of reducing production and distribution costs or for capturing new markets. Innovative choices do not consist in the instantaneous development and adoption of new technologies, new products, and/or new organizational forms. They involve in general the substitution of the new for the old and this takes time. Hence the problems of coordination naturally arise. The Walrasian adjustment mechanism in competitive framework assumes various stringent equilibrating processes for demand supply adjustments through price and cost changes. The selection mechanisms provide some alternative methods of relaxing the stringent assumptions of the perfectly competitive model. Consider for example the following situations: (1) firms must pay a sunk cost to enter the market; (2) all firms do not have the same market information; (3) not all firms have the access to the same technology; and (4) buyers do not have the same information about the different sellers. In each of these cases some assumption of perfect competition is violated. Two consequences of this imperfect situation are that different firms would have different levels of cost efficiency and firms would attempt to learn about their own efficiency through competitive market signals. The competitive selection model implies that different firms earn different profit rates even in the long run. By competitive selection the firms that remain active and efficient have a level of efficiency that is higher than the average. Finally, the quasi-competitive selection model is consistent with the empirical situation that the firm size distribution is neither single valued nor indeterminate as the perfect competition model would imply.

The model due to Amendola et al. (2000) discusses the time structure of production processes and analyzes the sequential interaction of competing firms $(i = 1, 2)$ in a process of restructuring of productive capacities.

At each time point t the production capacity of a firm i is represented by the intensity vector $X^i(t)$ and the level of activity constrained by available financial resources:

$$F^i(t) = m^i(t-1) + h^i(t-1) + f^i(t),$$

where $m^i(t-1)$ and $f^i(t)$ are internal and external financial resources with $h^i(t-1)$ as the money balances accumulated in the past. Since $m^i(t)$ is the monetary proceeds from the sale of final output and prices are fixed within each given period, one could write $m^i(t) = \min\left[p^i(t), d^i(t), p^i(t)s^i(t)\right]$ where $s^i(t)$ and $d^i(t)$ are the current real supply and demand for firm i and $p^i(t)$ is the price. Excess supply results in an accumulation of undesired stocks $c^i(t)$ for the firm. The current final output is then

$$q^i(t) = s^i(t)\theta c^i(t-1), 0 < \theta \leq 1$$

which can also be written as

$$q^i(t) = u^i(t) \sum_k B^i_k(t) x^i_k(t)$$

with u^i being the rate of utilization of productive capacity inherited from the past and $B^i_k(t)$ denotes the output coefficients of the production process. The aggregate market demand $D(t)$ is determined as

$$D(t) = (1 + \hat{g}) D(t-1) p^v, v \leq 0,$$

where p is average market price with an exogenously determined growth rate $\hat{g}$. The evolution path followed by each firm is actually determined by the behavior of the decision variables, namely, the rate of starts of new production processes x^i, the rate of utilization of productive capacity u^i, the price of final output $p^i(t)$, the wage rate, the ratio of external financial resources $f^i(t)$ to $m^i(t)$, and the rate of scrapping. Each firm determines its current utilization of productive capacity $u^i(t)$ so as to adjust its current supply to the expected final demand $\hat{d}^i$:

$$u^i(t) = \min\left[1, \frac{\hat{d}^i(t) - (c^i(t-1) - c_d^i(t))}{\sum_k B_k^i(t)x_k^i(t)}\right].$$

The price charged by each firm is determined in such a way as to cover the cost of production when using the up-to-date technology adopted at the desired rate of capacity utilization. This price can be adjusted in the Walrasian fashion in reaction of the market disequilibrium as

$$\bar{p}^i(t) = p^i(t)\left[1 + r^i \frac{d^i(t-1) - s^i(t-1)}{s^i(t-1)}\right].$$

The performance of each firm $0 \le r^i \le 1$ is measured here by its unit margins, i.e., as the ratio of the difference between the price and the current unit cost of output. Unit margins on average equal to zero means that firms realize normal profits. Unit margins would be necessarily negative at the beginning of any innovation process involving higher construction costs.

Two aspects of this model require further discussion. One is the impact of the innovation process on price competition. This is analyzed in this model by a series of simulation experiments. The second is the interaction between technology and the innovation process as it affects the Walrasian adjustment process. Competition is really successful when price and quantity adjustments are carried out which make it possible to obtain normal profits, i.e., when these adjustments do not result in waste of productive resources. Thus viewed competition not only coexists with increasing returns but helps the firms to capture them.

Four simulations are performed to simulate the impact on the innovation process of a price competition between the two firms. In the first simulation the two firms ($i = 1, 2$) innovate one after the other but with the same frequency. With no financial constraints and fixed nominal wages, both firms remain on the market. Both firms realize positive unit margins from innovations. Now if firm 1 (the first mover) innovates more frequently than firm 2, the latter exits from the market. Simulation 3 allows a larger asymmetry in innovation frequencies. This allows firm 1 to reestablish a definitive competitive advantage, which may be compensated by a larger asymmetry in price reaction by firm 2. A sustained price competition allows the less innovative firm to stay on the market. Then any first mover expecting to be confronted by a stiff price competition has very little real incentive to innovate. Simulation 4 shows that a very strict financial constraint makes it possible to reestablish the incentives required by a pure innovation strategy.

The technology innovation process is basically a qualitative change, i.e., a change which takes place through distortions of productive capacity which imply the appearance of problems of coordination between supply and demand. In order to explore how competition operates as an ordering force, it is not appropriate to consider a static world, where competing firms are making similar products in given and unchanged cost conditions. Instead it is more appropriate to envisage firms which undertake innovative activities as in Richardson (1997). The dynamics of this innovative world of competition is at the core of the Walrasian adjustment process. Dramatic changes in new technology have made the adjustment process multidimensional. For example, new products are increasingly being modularized and standardized and suppliers of components are increasingly involved in innovation. An important challenge comes from networks. This challenge starts from the recognition that innovation and industry evolution are highly affected by the interaction of heterogeneous actors with different knowledge, competencies, and specialization, with relationships that may range from competitive to cooperative, from formal to informal, and from market to nonmarket.

B. A Technological Innovation and Diffusion Model

This model developed by Iwai (1984) intends to show that under the Schumpeterian hypothesis on technological diffusion and innovation, an economy's state of technology will be in a perpetual disequilibrium. Franke (2000) has discussed this model in some detail and showed that although the evolutionary force of competition and pressure on the profit-maximizing firms steer the economy toward a neoclassical equilibrium in which all firms use the most efficient production technique available, the function of innovation is precisely to upset this equilibrating tendency. Through a series of simulations of the stochastic version of the general model he showed that the assumption of a stochastic arrival of innovations typically yields long waves of oscillations in the growth rates of average productivity. These long waves can be viewed as originating with the frequency distribution of techniques on a wave train.

The diffusion model developed by Iwai (1984) is based on three exogenous parameters: λ is the rate of technical progress, i.e., the average growth rate of productivity of newly invented techniques; the innovation parameter ν is a measure of the effectiveness with which firms introduce these inventions; and γ represents the speed of technical diffusion. There are systematic cost gaps between the existing production methods and the best practice technique (BPT) currently in use. Assuming production techniques with fixed unit costs c, the cost gaps denoted by z are specified as the logarithmic differences to the BPT unit cost c, i.e., $z = \ln c - \ln C$. While the level of the BPT unit cost decreases over time at the average rate λ, the relative frequencies of techniques with a given distance to the current BPT are assumed to be stable. The distribution of the expected values of the capacity shares in the statistical equilibrium can be described by a density function $\bar{s} = \bar{s}(z)$.

The process of technological diffusion is assumed to be governed by differential cost advantages, which occur gradually. Assuming a speed of adjustment $\gamma > 0$, the changes in capacity can normally be expressed directly as

$$s_{i,t} = [1 - h\gamma(\ln c_i - \ln \bar{c}_i)]\, s_{i,t-h} \qquad \text{for } i \leq N_t, \tag{2.6}$$

where N_t is the index of BPT at time t and t does not belong to $U(N_t)$, where $U(N_t)$ is the setup phase to build BPT and $s_{i,t}$ is the capacity shares of the technique i at time t. Note that the capacity share of the techniques changes inversely in proportion to the percentage deviations of their unit costs from the economy-wide average unit cost $\bar{c}$ where

$$\ln \bar{c}_t = \sum_{i \leq N_t} s_{i,t} \ln c_i . \tag{2.7}$$

Franke (2000) has discussed three important implications of the Iwai model, which extended the Schumpeterian dynamics of interaction between technological innovation and diffusion. The first implication deals with the speed of diffusion γ. The Iwai model showed that this parameter γ can be approximately expressed as

$$\gamma \sim \beta_s \rho w / k,$$

where β_s is the constant propensity to save out of profits, w is the share of wages in national income, k is the capital–output ratio, and ρ is a constant speed of adjustment. Thus the speed of diffusion depends on the firm's responsiveness to the profitability of alternative technologies, i.e., higher capital–output ratios would tend to lower the speed of diffusion, while higher profitability induces greater speed of diffusion.

The second implication is that the differential equations of the mode describe an evolutionary process that tends to steer the economy's state of technology toward an equilibrium in which all firms use the most efficient production function but the function of innovation lies precisely in upsetting this equilibrating tendency. The Iwai model derives an equilibrium trajectory Φ^e where $\Phi = \{s_{i,t} : i \in N, t = 0, h, 2h \ldots\}$ and Φ^e denotes a balanced growth path. This equilibrium Φ^e corresponds to what is known as a traveling wave or a wave train in the literature on partial differential equations. The significance of the equilibrium concept of a wave train depends on its global stability. Finally, Franke has shown by a series of simulations that across a wide range of parameter scenarios the average wave lengths underlying the long oscillation in the growth rates of average productivity are found to be closely related to the lifetime of techniques in the underlying economy. One important extension of this Iwai–Franke model lies in an endogenous transformation of the model, where profitability can be directly related to the diffusion process.

C. A Cournot–Nash Model of Spillover

Innovations in investment and knowledge capital tend to reduce unit costs of firms and industries and thereby build competitive pressure across firms. They also generate significant external economies and spillover effects. These spillover effects occur at several levels. First, we have the new growth theory which introduced several endogenous factors, which challenged the basic assumption of the Solow model that technology alone determines the long-run growth of an economy and that this technology is completely exogenous in the sense that it is unaffected by profits and market opportunities. Endogenous growth theory emphasizes the spillover and externality effects through technology diffusion. One simple form of endogenous growth model is the AK model:

$$Y(t) = A(k)K(t)$$

with real income (Y) as a linear function of $K(t)$ which is a composite measure of the combined stock of human, physical, and knowledge capital. Here $A(k)$ represents endogenous technical change depending on per capita K. Different economies will have different $A(k)$ values depending on their pattern of knowledge creation and technological diffusion and spillover. A basic premise of endogenous growth theory is that technology or innovation in knowledge capital is in part a public good. Private good market incentives and profitability both influence its development, whereas the public good property stresses the point that not all cost economies from knowledge creation and accumulation can be internalized. Diffusion and spillover and interfirm interdependence help spread the innovation. Endogenous growth theory assumes that an economy automatically benefits from its investments in new knowledge (Lucas 1993; Romer 1990) because knowledge has a public good aspect that can be used by an entire economy, leading to innovation and growth. Braunerhjelm et al. (2010) use the knowledge spillover theory of entrepreneurship derived from the basic spillover theory of knowledge to develop a theoretical model in which the transformation of knowledge into economic growth depends on how knowledge diffuses through both incumbent and entrepreneurial activity. The entrepreneur is the missing link in converting knowledge into economically relevant knowledge. Based on OECD data from 1981 to 2002 they show that entrepreneurship Granger-causes economic growth and that this effect increased in the 1990s and later as the knowledge economy began to grow.

Endogenous growth theory suggests that active government policies can definitely affect the long-run rate of economic growth by impacting the accumulation of composite capital K in the AK model.

The second aspect of knowledge spillover theory arises through the effort and investment allocated to R&D and the diffusion knowledge through software development and other linkages provided by the new information technology. Lucas has stressed the concept of learning spillover technology as an important feature of endogenous technology. This spillover is the source of rapid productivity growth and cost economies due to increasing returns to scale. To the question why does net capital flow from rich to poor countries on a large scale, the answer provided by the Lucas model is that the spillover effect is very small in poor countries. Lucas introduced several new dimensions of endogenous technology as innovations. He pointed out that the Asian growth miracles, e.g., high sustained growth in five Asian countries, Japan, South Korea, Hong Kong, Singapore, and Taiwan, over 1965–2005, cannot simply be explained by physical capital accumulation alone. One has to introduce the dynamic role of human and knowledge capital.

A third aspect of knowledge spillover theory is its impact on the globalization of markets in high-tech goods and services. Competitive pressures have increased and the pressure of significant increasing returns to scale in new high-tech industries disrupted the guiding principles of Walrasian competitive equilibria. The new market structure that has evolved in these new industries such as telecommunications, computers, microelectronics, and bioengineering is dominated by large firms which enjoy large economies of scale due to innovation-based investment. This type of market structure has been called by D'Aveni (1994) "hypercompetition," which diverges from a competitive market structure in several ways. First of all, it is driven by knowledge capital and innovative investments. Second, it augments the various strategies of nonprice competition. Mergers and acquisitions, cooperative ventures in R&D networks have led to decline in unit costs and prices, resulting in Cournot–Nash-type equilibrium solutions.

Unlike Walrasian adjustment, the Cournot–Nash framework emphasizes the game-theoretic interdependence of duopoly or oligopoly firms. Their mutual reaction functions describe the dynamic process of adjustment and several types of equilibria are possible. Three types of equilibria are most important. One is the dominant firm model often discussed in limit pricing theory. There is one dominate firm but it cannot set monopoly price because of the potential threat by firms on the competitive fringe. This may also lead to a leader–follower model, where the dominant firm is the leader and the rest are followers. Secondly, firms may compete in an oligopoly framework, where innovations through R&D investments generate spillover effects that cannot be internalized by individual firms. In this case firms may form a cartel so as to internalize spillover effects or act independently in a Cournot–Nash competition. Thirdly, there is the hypercompetitive market framework, where dynamically efficient firms follow the growth frontier and sustain it, whereas inefficient firms fail to compete and exit the market. We would briefly discuss these noncompetitive selection mechanisms for industry growth.

A dominant firm in the context of a limit pricing model may be a leader with a large market share, where the follower's reaction functions to the leader's strategy are already incorporated in the leader's optimal output and pricing strategies. However a dominant firm cannot adopt a price monopoly strategy due to the possibility of new entry. Cost-reducing innovation strategy therefore offers a long-run optimal strategy for the dominant firm.

To consider this type of cost-reducing innovation strategy we consider a dynamic cost-reducing model of innovation capital k where the objective is to maximize the discounted profit stream:

$$\max_u \pi(k_0) = \int_0^\infty e^{-\rho t}(r(k) - c(u))\mathrm{d}t$$

$$\text{subject to } \dot{k} = u - \delta k,\ k(0) = k_0 > 0,$$

where u is investment. The revenue $r(k)$ and cost function $c(u)$ are assumed to be concave, i.e.,

$$r(k) = ak - bk^2$$

$$c(u) = c_1 u - c_2 u^2,$$

where all parameters a, b, c_1, c_2 are positive. The cost function exhibits economies of scale, i.e., unit cost declines as investment rises.

On using the Hamiltonian function

$$H = ak - bk^2 c_1 u + c_2 u^2 + q(u - \delta k)$$

we derive the adjoint equation

$$\dot{q} = \frac{\mathrm{d}q}{\mathrm{d}t} = \rho q - \frac{\partial H}{\partial k} = (p + \delta)qa + 2bk.$$

This yields

$$\begin{aligned}
\dot{u} &= (p + \delta)u + \frac{(p + \delta)c_1 - a}{2c_2} - \frac{bk}{c_2} \\
\dot{k} &= u - \delta.
\end{aligned}$$

The characteristic equation has two roots:

$$\lambda_1, \lambda_2 = \frac{1}{2}\left[\rho \pm \left\{(\rho + 2\delta)^2 - \frac{4b}{c_2}\right\}^2\right].$$

It follows that λ_1 is negative, while λ_2 is positive. Hence we have to consider only the stable root λ_1 where the growth path of $k(t)$ converges to the steady-state equilibrium values $\bar{k}$ and $\bar{u}$:

$$\begin{aligned}
\bar{k} &= \left(\frac{1}{2}\right)\frac{c_1(\rho + \delta) - a}{b - c_2\delta(\rho + \delta)} \\
\bar{u} &= \delta\bar{k}.
\end{aligned}$$

The equilibrium is a saddle point if and only if

$$\delta c_2(\rho + \delta) < b.$$

The existence of a stable manifold converging to the saddle point equilibrium for the dominant firm shows a viable strategy for the innovation investment.

The strategic interaction between the dominant firm and the competitive fringe can be recast as a dynamic limit pricing model where the dominant firm sets the price and the fringe enjoys lower production costs due to newer technology.

Recently Cellini and Lambertini (2009) have formulated a dynamic oligopoly model, where the firms may undertake independent research ventures or form a cartel for cost-reducing R&D investments. We consider here a duopoly version, where $q_i(t)$ are the outputs ($i = 1, 2$) and the market demand and unit cost functions are

$$p(t) = A - q_1(t) - q_2(t)$$
$$\frac{\dot{c}_i(t)}{c_i(t)} = -k_i(t) - \beta k_j(t) + \delta, i \neq j,$$

where dot is time derivative, $k_i(t)$ is the R&D effort of firm i, and δ is the constant rate of depreciation. The parameter β with $0 < \beta < 1$ denotes the positive technological spillover that firm i receives from firm j. When each firm behaves independently, the cost of setting up a single R&D laboratory is assumed to be of the form

$$G_i(k_i(t)) = b(k_i(t))^2, b > 0.$$

On applying Pontryagin's maximum principle and assuming the case of independent R&D ventures, each firm maximizes a discounted profit function:

$$\max_{q_1, q_2} \pi_i(t) = \int_0^\infty e^{\rho t} \left[(A - q_i(t) - q_j(t) - c_i)q_i(t) - b(k_i(t))^2\right] \mathrm{d}t$$
$$\text{subject to } \frac{\dot{c}_i(t)}{c_i(t)} = k_i(t) - \beta k_j(t) + \delta; i \neq j; i = 1, 2.$$

On using the present value Hamiltonian, one can derive the optimal conditions denoted by asterisks:

$$q_i^* = \left(\frac{1}{2}\right)(A - q_i(t) - c_i(t))$$
$$k_i^* = \frac{-\lambda_{ij}(t)c_(t) - \beta\lambda_{ij}(t)c_j(t)}{2b},$$

where $\lambda_{ij}(t) = \mu_{ij}(t)e^{-\rho t}$ is the present value costate variable for the control variable $c_i(t)$. These two equations describe the standard Cournot–Nash reaction functions. If we satisfy the condition $\delta\rho \leq \frac{A^2(1+\beta)}{24b}$, then there is a saddle point equilibrium with steady-state values

$$\bar{c} = \frac{A(1+\beta) - \left\{(1+\beta)\left[A^2(1+\beta) - 24b\beta\delta\right]\right\}^{1/2}}{2(1+\beta)}$$
$$\bar{k} = \delta(1+\beta)^{-1},$$

where $c_1(t) = c_2(t) = c(t)$ (case of symmetry assumed) clearly $\partial k/\partial\beta < 0$, i.e., an increase in the spillover effect β leads to a decrease in the steady-state equilibrium level of k. This suggest the need for remedial public sector policies.

In case the firms form a cartel in the R&D style the firms choose output levels noncooperatively while maximizing joint profits. In this case the steady-state levels of c and k are

$$\bar{c} = [2(1+\beta)]^{-1}[A^2(1+\beta)^2 - 24b\rho\delta]^{1/2}$$
$$\bar{k} = \delta(1+\beta)^{-1}.$$

The steady-state levels of R&D effort $\bar{k}$ are the same in this case, but the level of unit cost in the case of Cartelization is lower. The extent of consumer surplus (CS) in the steady state however is much lower for the case of cartel compared to the case of independent ventures, since we have

$$\begin{aligned}\text{CS(cartel)} &= [18(1+\beta)^2]^{-1}\left[A(1+\beta) + \left\{A^2(1+\beta)^2\right.\right.\\ &\qquad \left.\left. + 24b\delta\rho\right\}^{1/2}\right]\\ \text{CS(independent ventures)} &= [18(1+\beta)]^{-1}\left[A(1+\beta)^{1/2}\right.\\ &\qquad \left. + A^2(1+\beta)^2 24b\delta\rho^{1/2}\right]^2.\end{aligned}$$

Note also that the steady-state unit cost is much higher for the case of independent ventures and hence the cooperative R&D in case of cartelization would help increase R&D investment more than the case of independent ventures.

Modern firms in the information technology sector today have several economic incentives to cooperate and combine R&D efforts. First of all, the technology of the new innovation process is becoming increasingly complex and the initial cost of development, a fixed cost, is becoming very large. Second, there is increasingly the possibility that the competitors may copy the new technology, e.g., software technology. Third, collusion and cooperation in the R&D phase may help the innovating firms to internalize a large portion of the spillover effects and thereby reduce unit costs and gain larger market shares. By now the governments in most industrial countries have recognized this need. For example, the European Commission allowed in March 1985 a 13-year block exemption under Article 85(3) of the Treaty of Rome to all firms forming joint ventures or cartel in R&D.

d'Aspremont and Jacquemin (1988) analyzed the collaborative R&D situations and compared them in some detail with noncooperative R&D levels. The model of Cellini and Lambertini is only a dynamic extension of the A&J model. Their major conclusion is that optimal cooperative R&D levels exceed those of noncooperative R&D, whenever technological spillover is relatively large (i.e., above 50 %) while the opposite holds for small spillover below 50 %. These results imply that the antitrust authorities should encourage the formation of joint ventures in R&D with a sharing of all information but without allowing collusion in the product market.

D. Demand-Induced Model of Innovation

Modern innovations have two major endogenous impacts. One is in terms of significant market expansion both locally and globally. Secondly, there have occurred significant economies of scale in demand fostered by economies of scale in supply. The competitive advantage (CA) principle emphasized by Baumol (2002); Porter (1990), and others has discussed this cumulative process of demand-induced growth of endogenous innovation.

Modern economies have undergone a fundamental transformation today due to the widespread use of computers and communication technology. The shift from traditional large-scale material manufacturing to the use of new technology and software networks has introduced three profound changes in industrial structure all over the world. Gone are the days of diminishing returns industries. The increasing returns and scale economies have dominated the new technology increasingly using knowledge and innovations in software and networking methods. This has resulted in decreasing unit production costs and increasing productivity. Modern technology involves high fixed cost for the initial innovation but very low or negligible marginal cost, e.g., iPod and iPhone. Secondly, this technology generates high network effects which involve increasing value of products as more and more users use or adopt the product or the process, e.g., Windows 7. This is sometimes called scale economies in demand. Finally, new technology frequently involves high switching costs, so that the users once locked in find it difficult to switch to alternative products. All these characteristics of modern technology involve two major impacts on the industrial structure. One is that the competitive paradigm of the market structure no longer holds. Hence various types of noncompetitive structures have to be analyzed. The dynamic model formulated by Spence (1984) and others like the dynamic limit pricing model have to be analyzed in the new paradigm. These models discuss the welfare implications of declining cost industries subject to noncompetitive structures. A second type of model considers industry growth through the entry dynamics. Sengupta (2007) has discussed several types of dynamic entry models and market evolution. Most of these models view entry either as entering into an existing market or as an increase in market share of an existing industry through unit cost reduction due to new technology or innovation.

The Spence model considers markets where firms compete over time by investing resources for reducing unit costs. In many instances their strategies take the form of developing new products at cheaper costs. Cost-reducing expenditures like R&D investments (e.g., research for new drugs) are largely fixed costs with very little marginal costs. As a result the market structures are likely to be concentrated and imperfectly competitive. Cournot–Nash-type equilibria are more appropriate in this environment. The scale economies and product differentiation are two important characteristics of this environment. Two important economic issues arise here. One is the spillover or externality effect of R&D investment and dynamic innovation. These spillover benefits are internally appropriable. Hence firms have to devise alternative methods like cooperative ventures in R&D to share the benefits. Secondly, while spillovers reduce the incentives for cost reduction through innovation, they can also reduce the costs at the industry level of achieving a given level of cost reduction. However, the incentives can be restored through subsidies. Many high growth countries in Southeast Asia like China, Taiwan, and Singapore have adopted these strategies through direct state subsidies to R&D innovations.

In the dynamic entry model the efficient firms tend to increase their market share through cost-reducing strategies. A typical model here takes the form

$$\frac{\dot{y}_j}{y_j} = a(\bar{c} - c_j), a > 0 \tag{2.8}$$

$$c_j = f(I_j), \frac{\partial c_j}{\partial I_j} < 0,$$

where dot denotes time derivative. Here c_j and y_j are unit cost and output of the efficient firm j which invests I_j to reduce unit costs and $\bar{c}$ denotes average costs of other firms in the industry. When c_j falls or $\bar{c}$ rises, the efficient firm increases its output resulting in an increase in market share. When investment I_j follows its optimal expansion path, $\dot{c}_j$ falls and therefore $\frac{\dot{y}_j}{y_j}$ increases. On replacing y_j by the market share of the efficient firm, this relation (2.8) can be directly used for empirical testing.

An alternative framework for analyzing the cost-reducing aspect of R&D investment is through a Pareto efficiency model applied to n firms in an industry. This may be done through a sequence of linear programming (LP) models also known as DEA. Two types of formulations may considered here. One emphasizes the cost-reducing impact of R&D inputs. This may be related to the learning-by-doing implications of knowledge capital. Secondly, the impact on output growth through R&D investment may be formulated as a growth efficiency model. Here a distinction is drawn between the level and growth efficiency, where the former specifies a static production frontier, while the latter a dynamic frontier. Denote unit (or average) cost of any firm j by $\frac{c_j}{y_j}$ where total cost c_j excludes R&D costs denoted here by r_j instead of I_j. Then we set up the Pareto efficiency model (DEA) with radial efficiency scores θ:

$$\min \theta, \text{ subject to}$$

$$\sum_{j=1} n c_j \lambda_j \leq \theta c_h \qquad \sum_{j=1} n r_j \lambda_j \leq r_h$$

$$\sum_{j=1} n r_j^2 \lambda_j = r_h^2 \qquad \sum_{j=1} n y_j \lambda_j \geq y_h$$

$$\sum_{j=1} n \lambda_j = 1; \lambda_j \geq 0; j, h \in I_n = \{1, 2, \ldots, n\}.$$

On using the dual variables $\beta_0, \beta_1, \beta_2, \beta_3$, and α and solving the LP model above for a firm j which is Pareto efficient, we obtain the optimal values $\theta^* = 1.0$ and zero for all slack variables with the following average cost frontier:

$$c_j^* = \beta_0^* - \beta_2^* r_j + \beta_3^* r_j^2 + \alpha^* y_j,$$

where asterisk denotes optimal values and $\beta_0^* = 1.0$ if $\theta^* = 0$. Thus if R&D spending r_j rises, average cost c_j falls for the efficient firm if $2\beta_3^* r_j < \beta_2^*$. If we replace r_j by cumulative R&D R_j as in learning-by-doing models where R_j is cumulative experience, then the AC frontier becomes

$$c_j^* = \beta_0^* - \beta_2^* R_j + \beta_3^* R_j^2 + \alpha^* y_j.$$

So long as the coefficient β_3^* is positive, r_j may also be optimally chosen as r_j^*, if we extend the objective function in the LP model as min $(\theta + r)$ and replace r_h by r. In this case the optimal value of R&D spending r^* is

$$r^* = (2\beta_3^*)^{-1}(1 + \beta_2^*).$$

A similar result follows when we use the cumulative R&D spending R_j or R here. This framework can be easily extended to the case of multiple inputs and outputs.

Now consider a Pareto model of growth efficiency frontier. Consider a firm j producing a single (composite) output y_j with m inputs x_{ij} by means of a log-linear production function:

$$y_j = \beta_0 \prod_{i=1}^{m} e^{B_i} x_{ij}^{\beta_i}, \; j = 1, 2, \ldots, n,$$

where the e^{B_i} denotes the industry effect as a proxy for the share of total industry R&D. On taking logs and time derivatives of both sides we can easily derive the production frontier:

$$Y_j \leq \sum_{i=0}^{m} b_j X_{ij} + \sum_{i=1}^{m} \phi_i \hat{X}_i$$

$$\text{when } b_i = \beta_i, b_0 = \frac{\dot{\beta}_0}{\beta_0 X_{0j}}, \; j = 1, 2, \ldots, n$$

$$e^{B_i} = \phi_i \hat{X}_i, \; X_{ij} = \frac{\dot{x}_{ij}}{x_{ij}}, \; Y_j = \frac{\dot{y}_j}{y_j}$$

$$\text{and } \hat{X}_i = \frac{\sum_{j=1}^{n} \dot{x}_{ij}}{\sum_{j=1}^{n} x_{ij}}$$

and dot denotes time derivative. Note that b_0 here denotes technical progress in the sense of Solow residual and ϕ_i denotes the input specific industry efficiency parameter. In the Pareto efficiency or DEA model we test the relative growth efficiency of each firm k in an industry of n firms by the LP model

$$\min C_k = \sum_{i=0}^{m} (b_i X_{ik} + \phi_i \hat{X}_i)$$

$$\text{subject to } \sum_{i=0}^{m} (b_i X_{ij} + \phi_i \hat{X}_i) \geq Y_j,\ j = 1, 2, \ldots, n$$

$$b_0 \text{ free in sign; } b_1, b_2, \ldots, b_n \geq 0;\ \phi_i \geq 0.$$

Denoting the optimal solutions by asterisks one can derive as before the following results: a firm k is growth efficient if

$$Y_k = b_0^* + \sum_{i=0}^{m} (b_i^* X_{ik} + \phi_i^* \hat{X}_i).$$

In case the equality sign changes to the "greater than" sign >, then the kth firm is not growth efficient, since the observed output growth Y_k is less than that of the optimal output. This growth efficiency model can be used to compute two subsets of firms: one growth efficient, the other not so. Clearly the industry growth would be dominated by the growth-efficient firms. Technology and innovations would play a catalytic role here. Also we can compare the level efficiency here with the growth efficiency.

Innovations have two dynamic characteristics. One is their impact on production costs and economic efficiency. This occurs through upward shifts in the production frontier. Frequently this involves a race in R&D investments among competing firms. It also leads to quality improvements of existing goods and services. For example, a pharmaceutical firm develops an improved drug through R&D investment over several years. It then becomes the new leader, the winner of the R&D race. It raises the price exactly to the extent of the quality improvement. At this price the leading firm becomes a monopoly producer, because infinitesimal price reductions allow it to take over the market. Economic efficiency increases for the industry as a whole due to what Schumpeter called "creative destruction," i.e., old processes or products cannot survive the new competition and die out. A second dynamic aspect of innovation is the process of routinization of innovations in oligopolistic competition and the spread of incremental innovations. The latter involves industry-wide transmission of new technology and cumulative multiplier effects. Baumol (2002) has considered this process as the dynamic engine of unprecedented capitalist growth in modern times. We would discuss in this section two important models developed by Baumol. One is the technology consortium model, where he characterizes the cost of nonmembership. The second model develops optimal rules for recouping innovation outlays that involve large fixed costs. Technology knowledge by innovation is itself a kind of capital good that can be accumulated through R&D and other knowledge-creation activities. It goes far beyond the Schumpeterian notion of creative destruction.

The R&D race model considers an industry consisting of more or less homogeneous firms engaged in R&D competition. The instantaneous net profit of a representative incumbent firm is a function of the number of firms n in the industry and of an R&D parameter u so that $\pi = \pi(n, u)$. The R&D parameter u is the effort made by the firm in product innovation at time t. Given n, the incumbent firm maximizes current profits to obtain optimal R&D effort:

$$u(n) = \max_u \pi(n, u)$$

assuming the profit function to be concave in u. For the long run each incumbent firm chooses the time path of R&D that maximizes the present value of staying in the industry indefinitely, i.e.,

$$\nu_0 = \int_0^\infty e^{-rt} \pi(n, u) \mathrm{d}t,$$

where r is the real discount rate assumed to be a positive constant. If one firm innovates successfully, it will be a leader during the subsequent time period until another firm wins the R&D race. Any winner earns monopoly profits. The expected monopoly profits for the successful winner depend on the expected monopoly surplus due to higher price equaling quality improvement and the probability that the firm innovates successfully.

The winner of the R&D race may reap another important benefit, i.e., through innovative R&D it may augment its productivity significantly. In that case the exploitation of scale economies may generate a higher market share for the leading firm. In this case the leading firm may play the role of a dominant firm; the other firms in the fringe are then the followers in a Bertrand game. The dominant firm may attempt to maintain its dominance in market share through innovations based on up-to-date R&D and also prevent potential entry.

Baumol (2002) has stressed the distinction between routinized vs. nonroutinized innovations, implying that the latter affects industry growth in a cumulative fashion. Also it intensifies the impact of the competitive advantage principle in a global fashion. Independent nonroutinized innovations can be viewed as dynamic shocks to the static equilibria of the Walrasian competitive paradigm. They may involve new processes, new products, or new markets. Baumol (2002) has discussed in some detail three growth creating properties of nonroutinized innovations as follows:

1. The cumulative character of many independent innovations, which not only replace old technology but also create new technical knowledge. The spillover effect is thus enhanced and other firms can utilize such spillover to reduce their unit costs and prices. Many successful NICs in Taiwan, China, and Korea

have used deliberate state policies to intensify the transmission of this spillover process.

2. The public good property of such innovations, which imply economies of scope in the generation of this new technological knowledge. This generates the adverse effect of reducing the optimal levels of innovation investment. Appropriate public policy is therefore needed here to correct the imbalance.
3. This type of innovation generates accelerator effects of induced investment, where the innovating sector's output and investment growth help other sectors grow through forward and backward linkage. There is considerable scope of state action in this framework. In many successful NICs of Southeast Asia, industrial parks, hubs, export zones, and technology consortia have been deliberately sponsored by the state as a sharing center of new knowledge about the latest technology and software.

We may now add a few comments on the CA theory in global trade and its diffusion, which emphasize industry growth due to the innovation process reducing unit costs and prices of new technology-intensive products.

Competitive advantage (CA) principle has two basic features. One is that the firm with CA earns a higher rate of economic profits than the average rate of economic profit earned by other firms in the market. Thus to assess if the technology firm Sun has a CA in its core business of designing and selling high-technology company servers, we would compare Sun's profitability in this business to the profitability of such firms as IBM and HP that also sell enterprise servers. The second feature of CA is higher competitiveness of firms with CA. In international trade this is revealed through relative cost advantage of successful firms dominating the international market. Growth in modern technology and knowledge diffusion through the information and communication technology have expanded the market structure to global levels and CA can be measured in this framework through (1) technological competitiveness T/T_w, (2) price competitiveness P/P_w, and (3) capacity utilization C. Here T and P denote technology development index and price per domestic good. The subscript w in T and P denotes the world levels. Fagenberg (1988) has measured the economic effect of CA in international trade through increase in export share through a multiplicative functional form as

$$S = AC^v \left(\frac{T}{T_w}\right)^e \left(\frac{P}{P_w}\right)^{-a},$$

where A, v, e, a are positive constants. On differentiating with respect to time (denoted by a dot over the variable) we obtain

$$\frac{\dot{S}}{S} = v\left(\frac{\dot{C}}{C}\right) + e\left(\frac{\dot{T}}{T} - \frac{\dot{T}_w}{T_w}\right) - a\left(\frac{\dot{P}}{P} - \frac{\dot{P}_w}{P_w}\right).$$

He further measured capacity advantage in terms of the ability to deliver at cheaper price. This improved ability is assumed to depend on three factors: (a) the growth in technological capability and knowledge diffusion of technology along the world innovation frontier $\dot{Q}/Q$, (b) the growth in physical capital and infrastructure $\dot{K}/K$, and (c) the growth in demand $\dot{D}/D$.

$$\frac{\dot{C}}{C} = \alpha_1\left(\frac{\dot{Q}}{Q}\right) + \alpha_2\left(\frac{\dot{K}}{K}\right) - \alpha_3\left(\frac{\dot{D}}{D}\right),$$

where α_1, α_2, α_3 are positive constants. He assumed knowledge diffusion to follow a logistic curve:

$$\frac{\dot{Q}}{Q} = \beta - \beta\left(\frac{Q}{Q^*}\right),$$

where β is a positive constant and Q/Q^* is the ratio between the country's (or firm's) own technological development and that of the countries on the world innovation frontier. On combining the equations above we obtain the final equation for CA of firms in international trade.

$$\frac{\dot{S}}{S} = v\alpha_1\beta - v\alpha_1\beta\left(\frac{Q}{Q^*}\right) + v\alpha_2\left(\frac{\dot{K}}{K}\right) - v\alpha_3\left(\frac{\dot{D}}{D}\right) + e\left(\frac{\dot{T}}{T} - \frac{\dot{T}_w}{T_w}\right) - a\left(\frac{\dot{P}}{P} - \frac{\dot{P}_w}{P_w}\right).$$

This model was empirically tested on pooled cross country and time series data for the period 1960–1983 covering 15 industrial countries (mostly OECD countries) and the results show that the main factors influencing differences in international competitiveness and growth across countries measured by export shares are technological competitiveness and the dynamic ability to compete in satisfying world demand measured by efficiency of capacity utilization. Recent experiences of rapidly growing economies of Southeast Asia have exhibited the dynamic role of technological and cost competitiveness in achieving high export performance in world markets.

Recently Porter (1990) made a comparative study of the sources of growth of rapidly growing countries of the world and found that the only meaningful concept of competitiveness through CA at the national level is national productivity which is measured by the firms moving along the innovation frontier. Three basic points are central to competitive advantage, e.g., (1) scale economies, (2) technological change, and (3) quality improvements and new product innovations.

In global competition firms from any nation can gain scale economies by selling worldwide. Comparative advantage theory in trade helps explain in part the specialization in specific commodities for the advanced industrial countries. Thus the Italian firms reaped the economies of scale in appliances, German firms in chemicals, Swedish firms in mining equipment, and the Swiss firms in textile machinery. The second point in competitive advantage model is recently stressed in the "technology gap" theories in which nations will export in industries in which their firms gain a lead in technology. Exports will then fall as technology diffuses over time and the spillover effect spreads and the gap closes. Finally, the spear-heading of new products and quality improvements has been intensified in world competition through the spread of multinational corporations. Their prominence in world trade means that trade is no longer the only important form of international competition. Recent empirical suggests that a significant portion of world trade is between subsidiaries of multinationals. National success in an industry increasingly implies that the nation is the home base for leading multinationals in the industry, not just for domestic firms that export.

Porter's theory of competitive advantage (CA) of nations comprises several new features, e.g., (1) it moves beyond the comparative advantage theory of international trade which is restricted to limited types of factor-based advantages, (2) it extends the Schumpeterian model of innovation by asking why do some firms, based in some nations, innovate more than others, (3) it explains how firms gain CA from changing the constraints, i.e., by improving the equality of factors, raising productivity, and creating new products, and (4) it emphasizes the managerial perspective in creating competitive advantage.

To investigate why countries gain competitive advantage in particular industries, Porter studied ten countries, Denmark, Germany, Italy, Japan, South Korea, Singapore, Sweden, Switzerland, the UK, and the USA, over a 4-year (1985–1988) study. One has to note that this list of countries includes four Southeast Asian countries, which are very important among the NICs in Asia which have achieved rapid growth rates in the last three decades. It is instructive to analyze the sources of rapid growth in these countries which have successfully excelled in world competition in modern technology-intensive products.

In global markets today competitive efficiency holds the key to economic success. Porter's study of ten industrially successful countries reached four important conclusions. First, sustained productivity growth at the industry level requires that an economy continually upgrade itself. A country's growing firms must also develop the capability to compete in more new and more sophisticated industry segments. At the same time an upgrading economy is one that develops the capability of competitive success in entirely new and modern industries.

Secondly, firms gain competitive advantage from conceiving new ways to conduct activities, employing new technologies or different inputs. Thus Makita in Japan emerged as a leading competitor in power tools because it was the first to employ new and less expensive materials from making tool parts. Gaining competitive advantage requires that a firm's value chain is managed as a system rather than as a collection of separate parts. A good example is in appliances, where Italian firms transformed the channels of distribution to become world leaders in the 1970s. Likewise Japan in cameras. Firms generate competitive advantage by discovering new and better ways to compete in an industry. Porter identified five sources of innovations that shift CA as follows:

1. New technologies
2. New buyer needs
3. Emergence of a new industry segment

4. Shifting input costs such as labor and knowledge capital
5. Liberalization of government regulations

The last source has played a most dynamic role in the wave of economic reforms introduced in China, Taiwan, and South Korea, which has achieved a very high growth rates and then sustained it over the last three decades.

Thirdly, the CA principle is basically dynamic and hence it thrives under competitive international trade. Trade allows a country to raise its productivity by specializing in those industries in which its firms are relatively more efficient. This allows exports to grow with multiplier effects in the domestic sectors through linkages. For new technology transfer the countries specializing in the efficient sectors may gain early mover advantages such as being the first to reap economies of scale, reducing costs through cumulative learning and R&D knowledge spillover.

Finally, one must note the dynamic role of sustainability. CA is sustained by constant improvement and upgrading. This is precisely what Japanese automakers have done. They initially penetrated foreign markets with inexpensive compact cars of adequate quality and competed on the basis of lower labor costs. Then they became innovations in process technology. Sustaining competitive advantage requires change and innovation. It demands that a company exploit rather than ignore industry trends. In many situations an innovation firm has to destroy old advantages to create new higher-order ones. This is what Schumpeter called "creative destruction." For example, South Korea's shipbuilding firms did not become international leaders until they aggressively expanded the scale and scope of new changes in technology.

Two Asian economies, Taiwan and South Korea, have to be mentioned as special examples of success in rapid growth, where the competitive advantage principle has been applied to a significant degree. The scale and scope of application of this principle has been widespread across the new industries competing intensely in international trade.

Korean Case

Three basic features about Korean growth have been emphasized by Porter in his empirical study. First, Korea has made major investments in factor creation, well beyond those of most other successful Asian NICs. This is a major reason why it has been able to upgrade its economy and compete in international markets. It has a high level of literacy and a high average level of education with universal education into the high school level. A survey performed by the Economic Planning Board in 1987 found that 84.5 % of Korean parents wanted to provide their children with a college level education. The university system is extensive and particularly aggressive investments have been made in engineering. Korean companies above a certain size are required by law to provide training for their employees. It is typical for a large Korean group of companies to invest $25 to 30 million in training facilities alone. Major Korean companies also invest heavily to upgrade their technical capability compared to companies from other developing countries. High rates of R&D to sales ratio are typical for most modern companies. Korean firms are unique among firms from other NICs in their commitment to developing their own product models and to investing in the up-to-date process technology.

Porter has stressed several important features of Korean companies, which utilize the CA principle in remarkable ways. First, the most unique feature of almost all modern Korean companies is their utmost willingness to take risk. Companies rush into industries and make huge investments in plant and equipment in advance of any substantial orders. In shipbuilding, for example, Hyundai and Daewoo built huge shipyards before the orders arrived to fill them. In videotape industry all four of their leading firms (e.g., Sachan, SKC, Lucky–Goldstar, and Kolon) have more than doubled installed capacity in 1987–1990, despite having already achieved about 25 % of the world market.

Second, Korean companies in high-tech fields face fierce competition in domestic fields, e.g., in automobiles, computer semiconductors, shipbuilding, steel, fabrics, TV sets, and memory chips. This domestic competition creates continued pressure to invest, improve productivity, and introduce new products. The Korean government has played a dynamic productive role in this competitive process. One of the unique historical strengths of Korean government policy has been its capacity to adjust and evolve and thereby help the process of industry growth.

Another unique feature of the Korean industry is the importance of the large groups called the *chaebol*. Companies such as Hyundai, Samsung, and Lucky–Goldstar contribute close to 40 % of world exports by some estimates. The *chaebol* have been favored and heavily supported by government. That is why they are able to take larger risks than in other Asian NICs.

Finally, the Korean economy is largely innovation driven. Three aspects of this innovation drive have to be made. One is that the more advanced firms in this economy develop increasingly sophisticated service needs in engineering, testing, and marketing. Secondly, the companies not only import advanced technology from other nations but create them. Learning by doing is actively followed by the heavy emphasis on human resources, skills, and R&D by both government and private firms. Thirdly, a new form of Schumpeterian "creative destruction" strategy has been consistently adopted by the progressive Korean firms. Thus selective cost disadvantages in design and technology have helped stimulate new innovations that advance product and process technology. Industry clusters and research centers augmented the industry capacity to innovate more new industries and their ancillaries.

Taiwan Model

Taiwan's rapid industry growth has two important differences from the Korean model. First, it has emphasized small and medium industries much more than the large ones. As a result, the resulting income distribution has been more equitable. The so-called Kuznets hypothesis which asserts a close positive correlation of economic growth with inequality of income distribution has been found not to hold for Taiwan. Secondly, much of rapid growth in China and Hong Kong over the last three decades has been contributed by Taiwan and its investment in new processes and innovations.

Three aspects of the Taiwan model of growth deserve special mention: (1) impressive record of the IT (information technology) sector, (2) emphasis on decentralized industry development, and (3) sound macroeconomic policy emphasizing economic efficiency in governance.

Taiwan's contemporary knowledge-based economy has revealed more remarkable growth of the IT sector than China and other Asian NICs. From 1995 to 1999, Taiwan's IT industry ranked third in the world after the USA and Japan. Taiwan's strong leadership in R&D and other investment in the IT sector started in 1982, when the value of exports of IT products was only $106 million in US dollars, but by 1985 these exports climbed to $1.22 billion, representing about 1 % of world market share. The overall R&D intensity rose from 1.78 in 1995 to more than 2.90 in 2008. The World Economic Forum (2004) has computed a growth competitiveness index (GCI) based on three components: infrastructure development, efficiency of public institutions, and the use of best practice technology. Here Taiwan's record of performance in the IT sector is most impressive. In terms of average number of annual US patents per million people, the top rankings in the world in 2004 were 1 for the USA, 2 for Japan, and 3 for Taiwan. The numbers of patents were 301.48 (USA), 273.40 (Japan), and 241.38 (Taiwan). Singapore ranks 10 and South Korea 14.

Traditional technology is usually subject to diminishing returns. Modern technology however is different. It involves improvement in the productivity of knowledge and R&D investment viewed as "knowledge capital." This capital input is complementary to all other inputs associated with the production function. An economy characterized by this new technology is often called "the new knowledge economy" and it has four fundamental characteristics: accumulating knowledge capital through R&D, improving competitive efficiency, expanding export markets through global trade, and increased collaboration utilizing the external benefits of new technology. Knowledge capital may take several forms, e.g., (1) software development, (2) new designs and blueprints, (3) R&D investments for new products involving "creative destruction" of old process, and (4) skill development through learning by doing. The successful NICs in Asia have developed this new knowledge capital and Taiwan has evidenced a remarkable record performance over the last three decades.

Both China and Taiwan have made consistent attempts to follow the paradigm of competitive market capitalism, where private industries compete for efficiency and growth. An important element of China's and also Taiwan's growth experience is its spread across regions and sectors. Decentralization of growth, the hallmark of competitive capitalism, was much less in China than Taiwan but it was still very significant. The estimates of TFP (total factor productivity) growth over the period 1979–1997 showed significant gains as follows:

China	1979	1997
Hong Kong	1.022	1.016
Guangdong	0.999	1.060
Fujian	1.014	1.053
Taiwan	1.030	1.027

2.3 New Ideas on Innovation Models

We discuss in this section several new ideas on innovation models as follows:

1. Stochastic models
2. Innovation matrix and diffusion
3. Aspects of disequilibrium.

Stochastic Models

Market selection process and how the firms innovate determine the survival of firms in an industry and the growth or decline of an industry. The theory of stochastic selection of industries for growth provides an important framework for analysis. It emphasizes that stochastic forces are vital in this process and it takes several forms. First of all, the decisions to invest for capacity expansion involve uncertainty about future demand and the possibility of future entry and technology competition. When investments are irreversible, the possibility of large sunk costs arises and this involves significant risks when the future demand fluctuations are expected to be high.

Schumpeterian theory emphasizes the innovation process in the market selection process. Technological innovations produce both substitution-cum-diffusion and evolution and these effects are generally nonlinear over time, path dependent involving multiple equilibria. This innovation stream has been frequently viewed as a stochastic process evolving over time. The transition of plants from one technology to another may be viewed as a birth and death process, i.e., a Markov process where birth may involve new plants or technology entering the system and death implying the plants close down due to obsolescence or competition.

We consider in this section two basic sources of stochasticity in industry growth. One is the stochastic birth and death process model, where innovation output (or efficiency) follows a creative destruction process as in the Schumpeterian framework. Secondly, the process of knowledge diffusion and learning affects the inter-sectoral growth process in a stochastic manner.

The stochasticity of the birth and death process depends on two parameters: the birth rate λ and death rate μ. The former represents new technology or new innovations, while the latter indicates the destruction or obsolescence of the old. If λ exceeds μ, then the innovation grows for the industry, leading to productivity growth and consequent price decline. This expands the market and globalization occurs. Stochasticity has two other effects. One is that the competition increases in intensity in the technology race and the firms struggle for survival of the fittest. For major and drastic innovations, the successful innovator may capture a more dominant position, and the others remain on the competitive fringe. This framework is most suitable for the leader–follower model. Alternatively, the framework may lead to rivalrous innovation, where the Cournot–Nash framework is more suitable.

Stochasticity has another important effect. It involves what is sometimes called the "churning process effect." This is like the creative destruction process which occurs when new entrants to the industry challenge the incumbents often with new innovations and as a result the exit rate rises. It has been empirically found that the higher the heterogeneity of the industry measured by output variance, the higher the exit rate. This results in higher concentration of large firms in the industry.

The stochastic birth and death process model may be simply modeled in terms of innovation effort $u(t)$ (e.g., R&D investments) by an innovative firm, where profit $\pi(n, u)$ depends on the number of firms n and $u = u(t)$. Sengupta (2011) has discussed the implications of this type of model for industry evolution. In this type of model the transition probability $p_u(t)$ of $u(t)$ taking a value u at time t satisfies the Chapman–Kolmogorov equation:

$$\frac{\mathrm{d}p_u}{\mathrm{d}t} = \lambda_{u-1} p_{u-1}(t) + \mu_{u+1} p_{u+1}(t) - (\lambda_u + \mu_u) p_u(t),$$

where the birth and death rule parameters depend on the level of u. Birth rate parameter leads to positive growth (i.e., positive feedback) and the latter to decay (i.e., creative destruction) due to the introduction of new technology. If λ_u, μ_u are positive constants (i.e., linear birth and death process), then the mean value function $m(t) = \mathbb{E}u(t)$ and the variance $v(t) = \mathrm{Var}u(t)$ of the process can be written as

$$m(t) = u_0 e^{(\lambda-\mu)t},\ u_0 = u(0)$$
$$v(t) = u_0 e^{(\lambda-\mu)t} \left[u_0 e^{(\lambda-\mu)t} - 1\right].$$

Note that as the mean level of innovation rises, its variance increases over time more than the mean. An interesting case arises when the birth rate parameter λ_u declines with increasing u (e.g., the R&D field in new innovation is saturated) but the death rate is proportional to u^2 (i.e., due to the churning effect), i.e.,

$$\lambda_u = u a_1 (1 - u),\ \mu = a_2 u^2.$$

Then the mean value function follows the trajectory

$$\frac{\mathrm{d}m(t)}{\mathrm{d}t} = (a_1 + a_2) \left[\frac{a_1}{a_1 + a_2} m(t) - m^2(t) - v(t)\right].$$

This shows that the variance function has a large negative impact on the rate of change of $m(t)$. This is what is predicted by the churning process effect.

An interesting interpretation of the birth and death process has been given by Agliardi (1998) where the firms have a choice problem: which technological standard to chose, when there are two substitutable standards (e.g., two softwares) in the field, denoted by zero and one. There are N firms in the industry, and let $n(t)$ have standard 1 and $(N - n)$ have standard 0. Let $y = n/N$ be the proportion of N firms with standard 1. It is assumed that there are benefits from compatibility, i.e., firms are able to exploit economies of scale in using a common supplier of a complementary good. Following Agliardi assume that $n(t)$ is a birth and death process with transition intensities $\lambda(y)$ and $\mu(y)$ for the transition $0 \to 1$ and $1 \to 0$, respectively. Then he has proved an important theorem that under very general conditions $z(t) = \lim_{N\to\infty} \mathbb{E}y(t)$ exists and satisfies the differential

$$\frac{\mathrm{d}z}{\mathrm{d}t} = (1 - z)\lambda(z) - z\mu(z), z(0) = y(0);$$

the fixed points of this equation (i.e., when $(\mathrm{d}z/\mathrm{d}t) = 0$) are the stationary solution $\bar{z}$ of

$$\bar{z} = \frac{\lambda(\bar{z})}{\lambda(\bar{z}) + \mu(\bar{z})}.$$

Under the assumption that $(\partial\mu(z)/\partial z) < 0 < (\partial\lambda(z)/\partial z)$ which involves growth, there exist two solutions: one asymptotically stable, other unstable. The stable solution indicates that the system converges to one of the two standards. However, volatility also remains.

We have so far discussed the implications of positive feedback for the industry evolution. But firms vary in industry evolution in terms of both size and distribution. If some firms have positive feedback and others negative due to diminishing returns, then the interaction between these two groups leads to a dominance of the positive feedback firms. Consider for instance two groups of firms with outputs y_i $(i = 1, 2)$ growing exponentially.

$$y_i(t) = y_{i0}\exp(\lambda_i t), i = 1, 2,$$

where λ may represent the difference of birth rate and death rate intensities. If $\lambda_1 > \lambda_2 > 0$ due to Schumpeterian innovation, then the growth rate of the mixture $y(t) = y_1(t) + y_2(t)$ follows the dynamic process:

$$\frac{\mathrm{d}\ln\dot{y}(t)}{\mathrm{d}t} = \left(\frac{\mathrm{d}\ln y(t)}{\mathrm{d}t}\right)\left[\lambda_1 - \frac{\mathrm{d}\ln y(t)}{\mathrm{d}t}\right];$$

clearly as $t \to \infty$, the total output tends to grow at λ_1 which is the relative growth rate of the more efficient group. The average gain in efficiency for the industry defined as $E(t) = (\mathrm{d}\ln\dot{y}(t)/\mathrm{d}t)\lambda_2$ follows then the time path

$$E(t) = s(\theta e^{-st} + 1)^{-1},$$

where $\theta = y_{20}/y_{10}$ and $s = \lambda_1 - \lambda_2 > 0$. Then $E(t) \to s$ at $t \to 0$. There the parameter s may be interpreted as the efficiency advantage of the higher efficiency type over the lower.

An important area of stochasticity arises due to the diffusion process of the innovation stream and the learning phenomena. Unlike the Marshallian diffusion process, Schumpeter's diffusion process assumes that output growth $(\dot{x}/x)$ of an innovation industry is proportional to the profitability of the new technology, subject to the constraint that unit cost depends on the scale of production of the new technology.

$$\frac{\dot{x}}{x} \geq \frac{\dot{x}_d}{x_d} \quad \text{and} \quad \frac{\dot{x}_d}{x_d} = b(D(p) - x).$$

Here b is a constant indicating adoption coefficient, dot is time derivative, and $D(p)$ the long-run demand curve for the new community introduced by innovation. If growth of capacity agrees with the growth in demand $\frac{\dot{x}_d}{x_d}$ and price $p = kc(x)$ is proportional to marginal cost, we obtain a balanced diffusion path as a logistic model:

$$\frac{\dot{x}}{x} = \alpha - \beta x,$$

where

$$\begin{aligned} \alpha &= b(d_0 - c_0 d_1 k) \\ \beta &= 1 - c_1 d_1 k \\ c(x) &= c_0 - c_1 x \\ D(p) &= d_0 - d_1 p. \end{aligned}$$

Clearly there exist here several sources of equilibrium output growth. First is the diffusion parameter. The higher the diffusion rate of new technology, the greater the output growth. Stochastic forces play an important role here. Second, if demand (x_d) rises over time and the innovator has a forward looking view of market growth, it stimulates capacity growth. The rational expectation model highlights the importance of forward looking view in stimulating industry growth. Thirdly, the learning curve effect enables innovating firms learn about the scale economies in demand and market growth and implies the adoption of new innovations which imply declining unit costs and prices. Such a decline stimulates the innovation and growth process further through cumulative causation. Finally, the marginal cost also tends to decline for new technology firms due to knowledge spillover across different firms and industries. Recently Thompson (1996) developed a Schumpeterian model of endogenous growth, which relates the market value of a firm to its current profits and to its R&D expenditures, where the firm's relative knowledge follows a stochastic differential equation. This differential equation shows that the mean and variance of the output process of the firm is negatively correlated. This implies that the stochasticity is an important source of instability in the innovation framework, when the innovative firm's output augments industry growth.

Modern innovations occur in many forms. Besides Schumpeter's analysis of six types of innovations two of the most important ones are rivalrous innovation and endogenous innovation. In each case two types of new technologies have dominated the modern industrial field, e.g., specific purpose technology (SPT) and general purpose technology (GPT). SPT are incremental processes rather than drastic changes. Software innovations belong to this category. GPT has significant scale effects. Recent improvement in iPhone and other communication technology has dramatically changed the world market for information technology.

In nonrivalrous innovation the firms cooperate to take advantage of economies of scale. The spillover effects of different firms' R&D are jointly utilized, and the overall impact may be welfare increasing. In rivalrous competition however the race for winning the innovation for new process or new product continues. Successful innovations arise as a result of a Poisson process with an intensity u. The probability that a firm innovates successfully during the period $\mathrm{d}t$ is $u\mathrm{d}t$. Since firms are assumed to have equal chances at the beginning of the time period $(t, t+\mathrm{d}t)$ the probability that any particular firm becomes a winner in the race is $(u/n)\mathrm{d}t$, where n is the number of firms. The expected monopoly surplus from winning R&D races in the time interval $(t, t+\mathrm{d}t)$ is $(su/n)\mathrm{d}t$, where s is the monopoly surplus due to quality improvement through innovation and the consequential price rises. Denoting variable costs by $v(u)$ and fixed costs of R&D by c_f, the firms' instantaneous expected profit may now be written as

$$\pi(n, u) = \frac{si}{n} - v(u) - c_f.$$

At each instant the innovating firm chooses the R&D intensity $u(n)$ maximizing the instantaneous profit function $\pi(n, u)$ yielding $u(n) = (s/n)l^{1/(\sigma-1)}$; we assume $v(u) = u^{\sigma}/\sigma$. The optimal profit function may then be written as

$$\pi(n) = a^{-1}\left(\frac{s}{n}\right)^{a} - c_f.$$

This shows that the optimal profit function is monotonically decreasing for increasing $n > 0$.

In rivalrous innovation the firms are likely to be either Cournot–Nash competitors or Stackelberg competitors (i.e., leader–follower). In the former case a firm's payoff from innovation depends on the number of other firms that innovate successfully. In the latter case the leading firm acts as a dominant player and the market dominance model may be more appropriate.

Innovation Matrix and Diffusion

Computable general equilibrium (CGE) models are widely applied in different countries to study the sectoral interdependence. Coupled with a standard input–output (IO) model this framework evaluates the quantitative impact of external shocks including changes in technology. DeBresson and Andersen (1996) and his associates have developed and used empirically an innovative-interaction matrix between sectors which are suppliers of innovative activity and the sectors which are users. The supplier industries make up the rows and the user industries make up the columns. Innovative activity is measured either by investment or by output.

As investment innovation in sector i is explained in terms of investment by destination, i.e.,

$$I_i = \sum_{j=1}^{n} u_{ij} I_j, \; \sum_j u_{ij} = 1, u_{ij} \geq 0,$$

the growth of output of sector i is then related to innovative investment I_i. When measured in terms of output, two types of hypothesis have been put forward about the innovative activity affecting different sectors of the economy. One is by Schumpeter who postulated that the innovations tend to concentrate in certain sectors due to agglomeration effects of economies of scale rather than evenly distributed over the entire economic space. DeBresson finds substantial evidence of such innovation clusters in the UK, Italy, and Greece. Recently the most successful NICs in Asia like China, South Korea, Taiwan, and Japan have displayed this concentration most significantly. A second trend is the close interdependence between the innovative activity and the sectoral linkages. DeBresson estimated a linear regression equation for Italy over the period 1980–1984 with innovative output (I) as the dependent variable and the following three independent variables: economic linkages both forward and backward (L), and index (T) of linkages with the world technology and the R&D expenditure (R):

$$I = -136.9 + 8.92L + 29.6T + 0.02R$$
$$\bar{R}^2 = 0.69.$$

Clearly this shows that the impact of foreign technical know-how and its diffusion is very important. For the successful NICs in Asia like South Korea, Japan, Taiwan, and Singapore this type of international diffusion of innovative knowledge has played a most significant catalytic role in their rapid growth episodes.

Aspects of Disequilibrium

Based on the neoclassical optimization model the Solow model analyzed long-run economic growth of per capita output through a steady-state model of equilibrium. Technology and innovations were exogenous in this formulation and convergence to the steady-state equilibrium was guaranteed by the assumption of diminishing returns to capital. Modern theory of endogenous growth assumes endogenous technology, where knowledge capital and innovation have increasing returns to scale. The spillover of information technology and innovation linkages across countries have been emphasized by Romer, Lucas, and other growth as critical in explaining the rapid growth episodes in the successful NICs in Asia. The case of Taiwan provides a notable example. It shows the intensity of knowledge diffusion and software development to a significant degree. Also Taiwan's record of performance in the IT sector is most impressive. In terms of the average number of annual US patents per million people, the top rankings in the world in 2004 are 1 for the USA, 2 for Japan, and 3 for Taiwan. The numbers of patents are 301.4 (USA), 273.4 (Japan), and 241.4 (Taiwan).

Unlike the steady-state formulation of growth in the Solow model, the Iwai model of diffusion emphasizes the non-steady-state and disequilibrium properties due to innovation. In Schumpeterian dynamics innovations not only tend to be concentrated in certain sectors, e.g., the IT sector in modern times, but they tend to disrupt the system and create disequilibrium. Entrepreneurs who carry out the innovation move the whole industrial system away from the neighborhood of equilibrium to the upside. Economic evolution is characterized by upward-moving neighborhoods of equilibrium that are separated from one another by two distinct phases. In the first the system draws away from equilibrium under the impulse of innovations and during the second it moves to another equilibrium.

The analysis of non-steady-state growth has striking similarity with the genetic theory of evolution. This theory emphasizes the fitness principle underlying evolution. Evolutionary economic theory has used the replicator dynamics principle of genetic evolution model to explain the variety of pattern of industry growth. The central hypothesis of this model is that the frequency of a species (e.g., technologies or firms) grows differentially according to whether it is below or above the average fitness. If genetic fitness is replaced by economic efficiency or core competence, the replicator dynamics in firm growth can explain the industry evolution and growth. Metcaffe (1994) and Mazzucato (2000) have used this type of replicator dynamics to explain the non-steady-state pattern of industry evolution following a Schumpeterian innovation framework. This innovation process may be viewed as affecting the entry and exit behavior of a dynamic market and its growth. Thus if $N(t)$ be adoption of new innovations (e.g., new combinations, new products, or new processes). One may then formulate innovation as a diffusion process:

$$\frac{\mathrm{d}N(t)}{\mathrm{d}t} = \left(p + \frac{qN(t)}{m}\right)(m - N(T)).$$

Here m is the ceiling of $N(t)$, p the coefficient of innovation, and q is the coefficient of imitation. Assuming $F(t) = N(t)/m$ the fraction of potential adopters who adopt the technology or the innovation at time t, one type of diffusion model is of the form

$$\frac{\mathrm{d}F(t)}{\mathrm{d}t} = (p + qF(t))\,(1 - F(T));$$

if $p = 0$ then we consider the imitation effect alone, where firms tend to imitate the invention process of others as in the leader–follower model. If $\theta = 0$ and $F_0 = 0$, then $F(t)$ and hence $N(t)$ follow a logistic path that has been empirically observed for many technological innovations. Note that the ceiling m itself may increase in the long run and the growth process may be explosive.

Schumpeter's innovation approach to evolutionary economics which emphasizes non-steady-state and disequilibrating aspects of industry growth contains five elements as follows:

1. The rate of growth of innovations depends on two factors: the gap of the advanced technology from the existing one.
2. Unit cost declines due to new investment in innovation. This results in excess quasi-monopoly profits for the successful innovators who adopt the advanced technology.
3. Profits from innovative investment lead to further innovations, which generate diffusion of new knowledge. This diffusion and spillover linkages provide incentives for other firms and industries to innovate further.
4. Birth rate of new innovations through R&D investments provides the positive side of industry evolution, where the death rate provides the negative side. The contagion effect of birth rates influences other firms to invest in more R&D.
5. Long-term profit maximization and faster rates of growth provide the basic incentives for firms to innovate.

The relations above can be used to develop a dynamic model of industry growth with non-steady-state characteristics, where the trajectories would indicate the paths of endogenous evolution. Scale economics and profit incentives are the two key forces in this growth paradigm. Unbounded growth and oscillations may occur in this path-dependent growth trajectories.

http://www.springer.com/978-3-319-02182-9

Theory of Innovation
A New Paradigm of Growth
Sengupta, J.
2014, X, 154 p., Hardcover
ISBN: 978-3-319-02182-9