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Schumpeterian Growth Theory: An Overview

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Since the early 1990s, several studies have provided an elegant formalization of economic growth through creative destruction. The Schumpeterian features of the new theory are presented, and a basic formal model is developed to highlight its analytical structure. The implications of Schumpeterian growth theory are briefly discussed.

Introduction

The traditional theory of growth, pioneered by Solow (1956), which focused on economic expansion caused by exogenous population growth, has come under increasing scrutiny. Its main implication that policy cannot affect long-run growth rates was at odds with recent country experiences. Under the heading of endogenous growth, new approaches to growth theory have emerged. These approaches have brought technological progress to the center of growth theory and have demonstrated how economic policies can affect long-run growth. The impact of the new theories has been profound. The concept of growth, as well as the theory of growth, have undergone a permanent transformation. *Economic expansion* might be a better term for the type of growth that neoclassical theory has analyzed for the last 35 years. *Economic progress* can characterize the component of growth that is based on endogenous technological change.[1] The present chapter is concerned with Schumpeterian growth theory, which has formalized Schumpeter's (1942) insights into endogenous technological change that in turn leads to economic progress.

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1. Schumpeter (1928) has used this terminology and emphasized the distinction between economic expansion caused by accumulation of factors of production and economic progress, which is based on endogenous technological change.

If, in fact, Schumpeterian growth theory formalizes Schumpeter's description of technological progress, why did it take so long to develop? One answer to this question is that the analytical tools that were necessary for the development of the new theory only became available in the mid-1980s. It was not until the 1970s that dynamic game theory and industrial organization developed analytical tools for the study of dynamic imperfect competition.[2] In the early 1980s, trade theorists pioneered in the development of general equilibrium models with imperfect competition that examined issues related to patterns of trade.[3] The next important step was taken by Romer (1986, 1990), who constructed models based on dynamic imperfect competition and focused on technological externalities as a mechanism of economic growth. Other studies quickly followed and identified a variety of endogenous growth patterns. Lucas (1988) developed a model where human capital accumulation and external economies provide the engine of growth. Young (1991) analyzed learning-by-doing mechanisms of endogenous growth. Grossman and Helpman (1991), Feenstra (1996), and Rivera-Batiz and Romer (1991), among others, analyzed endogenous growth through the accumulation of new varieties of goods.

The development of Schumpeterian growth theory started with two studies. Segerstrom, Anant, and Dinopoulos 1990 was the first study to model the process of Schumpeterian growth in a dynamic general equilibrium model of North-South trade. This study modeled sequential innovation races that resulted in growth through product quality improvements. New products replaced old ones and were imitated after an exogenous imitation lag. Aghion and Howitt (1990) developed a closed-economy model of Schumpeterian growth based on stochastic R&D races that resulted in process innovation. New and better intermediate products endogenously replaced old ones. These two studies have been extended and generalized in several important dimensions.[4]

The next section of this chapter makes an attempt to identify the Schumpeterian characteristics of what Cheng and Dinopoulos (1992) and Romer (1994) have called the neo-Schumpeterian approach to growth. The third section develops a simple model of Schumpeterian growth. The fourth section presents an overview of the implications of the new theory for international

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2. Reinganum (1989) provides an excellent survey of the industrial organization literature on innovation.

3. Krugman (1979a, 1979b) developed general equilibrium models of the product cycle and of monopolistic competition and intraindustry trade. Eithier (1982) analyzed issues of external scale economies and international trade.

4. The fourth section of this chapter presents the contributions of other Schumpeterian growth studies. For a recent survey of Schumpeterian growth models, see Aghion and Howitt 1993.

economics, macroeconomics, and empirical research. The final section presents my conclusions.

Growth through the Process of Creative Destruction

Schumpeter described the mechanics of economic progress (i.e., growth) in detail in two studies: "The Instability of Capitalism" (1928) and *Capitalism, Socialism and Democracy* (1942). Instead of stating the basic features of creative destruction, let me present Schumpeter's thoughts through his own words

> Economic progress, in capitalist society, means turmoil. And, . . . in this turmoil competition works in a manner completely different from the way it would work in a stationary process, however perfectly competitive. Possibilities of gains to be reaped by producing old things more cheaply are constantly materializing and calling for new investments. These new products and new methods compete with the old methods not on equal terms but at a decisive advantage that may mean death to the latter. This is how "progress" comes about in capitalist society. (Schumpeter 1942, p. 32)

> The introduction of new methods of production and the new commodities is hardly conceivable with perfect competition from the start. And this means that the bulk of what we call economic progress is incompatible with it. As a matter of fact, perfect competition is and always has been temporarily suspended whenever anything new is being introduced. (Schumpeter 1942, p. 105)

> What we, unscientifically, call economic progress means essentially putting productive resources to uses hitherto untried in practice, and withdrawing them from the uses they have served so far. This is what we call "innovation." (Schumpeter 1928, p. 64)

> Successful innovation is, as said before, a task suis generis. It is a feat not of intellect, but of will. Its difficulty consisting in the resistances and uncertainties incident to doing what has not been done before, it is accessible for, and appeals to, only a distinct type which is rare. . . . It is this entrepreneur's profit which is the primary source of industrial fortunes, the history of every one of which consists of, or leads back to, successful acts of innovation. And as the rise and decay of industrial fortunes is the essential fact about the social structure of capitalist society, both the emergence of what is, in any single instance, as essentially temporary gain, and the elimination of it by the working of the competi-

> tive mechanism, obviously are more than "frictional" phenomena, as is that process of underselling by which industrial progress comes about in capitalist society and by which its achievements result in higher incomes all around. (Schumpeter 1928, pp. 66–67)

Segerstrom, Anant, and Dinopoulos (1990) and Aghion and Howitt (1990) developed the first two models of Schumpeterian growth, which captured three main features of the process of creative destruction. First, both studies built models using a dynamic general-equilibrium framework. Second, product obsolescence based on quality improvements, coupled with imperfect competition, formalized Schumpeter's notion of temporary market power. Third, R&D races were used to capture the entrepreneurial risk and uncertainty that are inherent in the process of innovation. These three features constituted the skeleton of all subsequent Schumpeterian growth studies.

I would like to emphasize that the new theory does not claim exclusive rights to all of Schumpeter's thoughts. Indeed, several normative implications of the new theory do not always coincide with views advocated by Schumpeter. However, this theory is closer to Schumpeter's notion of creative destruction than any other existing approach to economic growth.

A Simple Model of Schumpeterian Growth

This section develops a simple closed-economy model of Schumpeterian growth by combining the taste structure of Segerstrom, Anant, and Dinopoulos (1990) with the R&D structure of Aghion and Howitt (1990). The analysis in this section follows the spirit of Grossman and Helpman (1991, chap. 4), who integrated the two original studies.[5] There is only one final good, whose quality can be improved through the introduction of better products. Labor is the only factor of production; it is supplied inelastically and the aggregate endowment of labor is fixed over time. In other words, unlike the neoclassical growth model, there is no population growth in this model. Labor can be allocated between two economic activities, manufacturing of the high-quality goods and R&D services that are used to discover new products of higher quality. There is instantaneous free mobility of labor between manufacturing and R&D services, which ensures that the wage rate is equalized across the two activities. For simplicity of exposition and notation, I assume that one unit of labor can produce either one unit of manufacturing output or one unit

5. The basic model differs from the "quality ladders" model developed by Grossman and Helpman in at least two important aspects. First, it abstracts from the continuum of industries framework. Second, it introduces instantaneous diminishing returns to R&D. The first feature enhances the intuitive understanding of the theory and allows me to focus on how financial markets deal with aggregate uncertainty. The second feature has implications for the welfare properties of the model that differ from the original "quality ladders" model.

of R&D services. Using labor as the numeraire, I can normalize the wage rate to unity.

The process of endogenous innovation is modeled through stochastic and sequential R&D races. Individual firms hire labor that performs R&D services. By devoting more resources to R&D, each firm participating in a race increases the probability of discovering the next higher-quality product. The sole winner of each R&D race enjoys temporary market power until it is replaced by the firm that wins the next R&D race. The arrival of innovations follows a Poisson process whose intensity depends on resources devoted to R&D. The random time intervals between innovations, which follow the exponential distribution, serve as market-determined "patents" for the winners of R&D races. This formalization of Schumpeterian innovation has two desirable features: It captures the risk associated with discovering new goods and it formalizes the notion that increasing resources devoted to R&D shortens the expected time between innovations, which results in higher Schumpeterian growth.

R&D investment is financed through consumer savings. Consumers allocate their income between consumption and savings by maximizing their discounted lifetime utility. There is a stock market that channels consumer savings to firms engaged in R&D activities. The instantaneous interest rate clears the stock market at each instant in time.

The preference structure of the model is captured by the following standard intertemporal utility function of the representative consumer

$$U = \int_0^{\infty} e^{-\rho t} \ln [z(\cdot)] dt \tag{1}$$

where $\rho > 0$ is the consumer's subjective discount rate and $z(\cdot)$ is a subutility function that takes the following form:

$$z(x_0, x_1, x_2, \ldots) = \sum_{q=0}^{\infty} \alpha^q x_q, \quad \alpha > 1. \tag{2}$$

The subutility function (2) introduces product obsolescence, which is essential for Schumpeterian growth. In this economy, there is a countably infinite set of products $\{x_0, x_1, x_2, \ldots\}$. The parameter $\alpha > 1$ captures the degree of quality improvement of a product relative to its immediate predecessor. The functional form of $z(\cdot)$ implies that products are perfect substitutes.

To illustrate the product replacement mechanism embodied in (2), assume for the time being that each product is priced at marginal costs. At time zero, the economy starts with good x_0, because the rest have not yet been discovered. The consumer maximizes $z(x_0, 0, 0, \ldots) = x_0$. When good x_1 is discovered, the consumer maximizes $z(x_0, x_1, 0, \ldots) = x_0 + \alpha x_1$. If both goods command the price of unity, then no consumer buys good x_0: one unit of good x_1 gives $\alpha > 1$ units of utility, whereas one unit of good x_0 gives only one unit of utility. The endogenous substitution of higher quality products for lower quality ones allows the economy to shift resources from old uses to new ones. Unless the new products are better than the old ones, growth cannot be sustained in the long run.[6]

The above reasoning can be readily applied to the case of goods x_q and x_{q-1}. Because goods are perfect substitutes, consumers allocate their consumption expenditure E on a single good. Thus $x_q = E/p_q$ and $x_{q-1} = E_{q-1}/p_{q-1}$, where p_q and p_{q-1} are prices of goods x_q and x_{q-1}, respectively. Consumers switch to good x_q from x_{q-1} if $z(0, \ldots, x_q, 0 \ldots) > z(0, \ldots, x_{q-1}, 0, \ldots)$. Substituting x_q and x_{q-1} into (2) we obtain the following product replacement condition:

$$\alpha p_{q-1} > p_q. \tag{3}$$

Thus, the price of the state-of-the-art quality product cannot exceed the price of its immediate predecessor times the quality increment α. I will assume that even if (3) holds as an equality, each consumer switches her expenditure to the higher quality product, although formally she is indifferent.

Innovation, which results in higher-quality products, is modeled through sequential R&D races. Denote with L the aggregate amount of labor devoted to an arbitrary R&D race. Then $\mu(L)dt = L^{\gamma}dt$ is the probability that if the next higher-quality product has not been discovered at time t, it will be discovered at time $(t + dt)$, where dt is an infinitesimal increment of time. The returns to R&D races are assumed to be independently distributed over time. The parameter $0 < \gamma \leq 1$ captures the degree of instantaneous diminishing returns to R&D.[7] In the balanced-growth equilibrium, the duration of each innovation race is exponentially distributed. This implies that the expected

6. Stokey (1988) has an excellent discussion of the importance of obsolescence in models of growth through the introduction of new goods.

7. The standard argument for constant returns of scale, which is based on replication of plants, does not apply to R&D. Replicating an R&D plant creates the possibility of duplicating the effort of the existing plant. Strong diminishing returns to R&D investment are required for sensible comparative steady-state analysis in Schumpeterian growth models with a continuum of industries and linear manufacturing technology. Over time, each R&D race is characterized by a common pool problem that arises from the "winner takes all" assumption. This property implies diminishing returns to R&D investment because when a firm increases its R&D investment, the aggregate hazard rate increases and every firm in the race faces a shorter expected duration. When γ is strictly less than unity, there is also a similar common pool property across rivals at each instant in time, which captures possible interdependencies of R&D strategies. Instantaneous diminishing returns to R&D can be generated by industry-specific factors. Houser (1994) and Segerstrom (1995) provide more details on issues related to diminishing returns to R&D.

time of innovation arrival becomes shorter with the more resources devoted to R&D.[8]

The preceding paragraphs described the structure of tastes and technology of the model. I will concentrate on the balanced-growth equilibrium, defined as the equilibrium path in which the allocation of resources remains constant over time. Consider the product market first. The winner of an R&D race becomes the only firm that knows how to produce the state-of-the-art quality product. The demand for that product is

$$x_q = \begin{cases} \dfrac{E}{p_q} & \text{if } p_q \leq \alpha \\ 0 & \text{if } p_q > \alpha \end{cases} \tag{4}$$

where E is consumer expenditure and p_q is the price of good x_q. Because product x_q is competing with product x_{q-1}, condition (3) implies that the producer of x_q can charge at most a price that is α times the marginal costs (equal to unity by assumption) of its closest competitor.

The maximum instantaneous profit for the winner of an R&D race is

$$\pi = (p_q - 1)\frac{E}{p_q} = \frac{(\alpha - 1)}{\alpha}E, \tag{5}$$

where $p_q = \alpha$ is the maximum price that drives the immediate predecessor out of business.

Let $\mu_j dt$ be firm j's instantaneous probability of discovering the next higher quality product. Then $\mu(L)dt = (\Sigma_j \mu_j)dt = L^\gamma dt$ is the aggregate probability of success. Let L_j be the amount of labor firm j devotes to an R&D race. Then $L = \Sigma_j L_j$ is the aggregate amount of labor in R&D. Assume that each firm participating in a race behaves competitively and treats the aggregate labor in R&D as given when it chooses its own R&D labor level. Assume also that $\mu_j/\mu = L_j/L$, which states that firm j's relative instantaneous probability of success equals its share of R&D resources. These assumptions imply that firm j's instantaneous probability of success is $\mu_j dt$, where $\mu_j = L_j\mu/L = L_j L^{\gamma-1}$.

Denote with $V(t)$ the expected discounted profits of a *successful* innovator, which serves as a reward to R&D investment. The expected discounted profits of a typical firm j in an R&D race are

$$VL_jL^{\gamma-1}dt - L_j dt. \tag{6}$$

8. The arrival of innovations is governed by a Poisson process with parameter $\mu(L)$. The interarrival time of innovations is exponentially distributed with mean $1/\mu(L)$ and variance $1/[\mu(L)]^2$. The expected number of innovations from time zero to time t equals $\mu(L)t$, which equals the variance of the number of innovations as well. Taylor and Karlin (1984, chap. 5) provide an exposition of the Poisson process.

Firm j earns V with instantaneous probability $L_j L^{\gamma-1} dt$ and incurs L_j costs (the wage of labor serves as the numeraire) for a time interval dt. Each firm in the race is infinitesimally small, and chooses L_j to maximize equation (6), taking L as given. Thus there are constant returns to scale in L_j for each individual firm, but decreasing returns to scale for the industry as a whole. Following the Schumpeterian growth literature, assume that there is free entry into each R&D race, which implies that equation (6) becomes zero

$$V(t) = L^{1-\gamma}. \tag{7}$$

The free-entry condition renders the size of each firm L_j indeterminate, but establishes a positive relationship between the reward to innovation, $V(t)$, and the aggregate amount of resources devoted to innovation, L.[9]

The next step is to establish a relationship between $V(t)$ and π. Following Segerstrom, Anant, and Dinopoulos 1990, let me introduce the stock market, which plays a pivotal role in financing the R&D investment. Each firm participating in an R&D race does not earn any revenues for the duration of the race, and each needs to borrow in order to pay its R&D workers. At each instant in time, each firm issues a risky Arrow-Debreu security that pays the flow of monopoly profits if the firm wins the race instantaneously and pays zero otherwise. Although from the point of view of each firm there is uncertainty, from the point of view of the economy, firm-level risk remains idiosyncratic. The representative consumer knows that there is a single firm that earns profits, π, and that there are many firms engaged in R&D to discover a better product. If a new product is discovered, only the *identity* of the firm earning profits changes, and nothing else.[10] Because the utility function is logarithmic and the uncertainty is industry-specific, there exists monetary separation in portfolio allocation.[11] Thus, it is possible to construct many mutual funds, each of which yields the same return, $r(t)$, in every state of nature, with $r(t)$ remaining constant over time.

For simplicity of exposition, let me construct an economy-wide (industry-specific) mutual fund with a riskless rate of return. At each instant in time, the mutual fund manager lends L amount of dollars, which cover the R&D

9. Consider the case of $\gamma = 1$, which corresponds to constant returns of scale in R&D in the presence of linear R&D costs. Condition (6) becomes $(V - 1)L_j dt$, and implies that each firm has an incentive to engage in infinite R&D if $V > 1$ and in zero R&D if $V < 1$. Segerstrom (1995) has shown that in the case of $\gamma = 1$ and in a continuum of industries framework, the unique symmetric steady-state equilibrium with $L > 0$ is unstable, and all stable equilibria result in a no-growth trap. Diminishing returns to R&D resolve this type of instability problem.

10. Cheng and Dinopoulos (1993) have analyzed a similar model using stochastic optimal control techniques to deal with aggregate uncertainty. In the case of equal quality increments, the instantaneous interest rate $r(t)$ remains constant in the balanced growth equilibrium.

11. For more details on separation theorems, see Cass and Stiglitz 1970.

costs of *all* firms in the race. Because in the steady-state equilibrium one of these firms will discover the new good, the net income flow of this portfolio is $\pi - L$, which equals $r(t)\bar{N}A$, where A is per capita wealth. If and when an R&D race ends, the mutual fund manager finances the next R&D race. At the steady-state equilibrium, the net income flow, $\pi - L$, can be obtained with certainty and does not vary over time. The riskless rate of return, $r(t) = (\pi - L)/A\bar{N}$, is independent of which firm wins the race. Any mutual fund that invests in all firms engaged in R&D obtains the same rate of return as the economy-wide mutual fund.[12]

At each instant in time, there are two types of firms in the economy. The existing dominant firm and firms engaged in R&D to discover the next higher-quality product. Portfolio efficiency requires that the expected return to the security of the existing monopolist be equal to the riskless rate of return, which equals the instantaneous interest rate. Consider the stock market valuation of the firm that produces the state-of-the-art quality product. Over the time interval dt, the shareholder receives a dividend equal to $\pi(t)dt$ and the value of the firm appreciates by $\dot{V}(t)dt = (\partial V(t)/\partial t)dt$. Because the firm is targeted by other firms engaged in R&D to discover the next higher-quality product, this shareholder suffers a total capital loss of $V(t)$ if further innovation occurs. The latter event occurs with probability $\mu(L)dt = L^{\gamma}dt$, whereas the former event occurs with probability $1 - L^{\gamma}dt$. The shareholder could have earned the riskless rate of return $r(t)dt$, and it must be that

$$\frac{\pi(t)}{V(t)}dt + \frac{\dot{V}(t)}{V(t)}(1 - L^{\gamma}dt)dt - \left[\frac{V(t) - 0}{V(t)}\right]L^{\gamma}dt = r(t)dt\,. \tag{8}$$

Taking the limit as dt goes to zero we obtain

$$\frac{\dot{V}(t)}{V(t)} + \frac{\pi(t)}{V(t)} = r(t) + L^{\gamma}. \tag{9}$$

Equation (9) states that, in the steady-state equilibrium where $\dot{V}(t) = 0$, the rate of return of a dollar invested in the existing monopolist exceeds the instantaneous interest rate by a risk factor that equals the probability that the monopolist will be replaced by the next innovator.

The next equilibrium condition is derived from the requirement that, at each instant in time, the amount of labor demanded by firms engaged in R&D

12. One can check the consistency of the above analysis by considering the GNP identity $E \equiv r(t)A\bar{N} + \bar{N}$, which states that aggregate consumption expenditure equals income from assets plus wages at the steady-state equilibrium. Substitute $r(t) = (\pi - L)/A\bar{N}$ to obtain $E \equiv \pi + (\bar{N} - L)$, which states that GNP equals aggregate profits plus manufacturing costs, which is the goods-market definition of GNP.

and the firm manufacturing the final good must equal the aggregate endowment of labor,

$$L + \frac{E}{\alpha} = \bar{N}, \tag{10}$$

where (E/α) is the quantity of a typical product produced and equals the number of workers engaged in manufacturing. $\bar{N}$ is the aggregate endowment of labor. Equation (10) is the resource constraint of the economy and defines a trade-off between consumption, E, and investment, L, at each instant in time.

The solution to the consumer intertemporal maximization problem determines the supply of savings. Denote with $C(t) = E(t)/\bar{N}$ the per capita consumption expenditure. Substituting $z(\cdot) = [\alpha^q C(t)/\alpha]$ into equation (1), I can express the consumer problem as

$$\max_{C(t)} \left\{ \int_0^\infty e^{-\rho t} \ln C(t) dt + \text{Exp} \int_0^\infty e^{-\rho t}(q-1) \ln \alpha \, dt \right\},$$

subject to $\dot{A}(t) = r(t)A(t) + 1 - C(t)$. The term Exp denotes the expectation operator, $A(t)$ stands for consumer assets, and $r(t)$ is the instantaneous interest rate. Because the second integral does not depend on consumption expenditure or assets, the consumer problem is equivalent to maximizing the first integral, subject to a differential equation describing the evolution of assets.

Since there is no aggregate risk, I can use standard optimal control techniques to solve the consumer problem. Define the current value Hamiltonian

$$H = \ln C(t) + \lambda(t)[r(t)A(t) + 1 - C(t)], \tag{11}$$

where $\lambda(t)$ is the multiplier. The necessary conditions for a maximum are

$$\frac{\partial H}{\partial C} = \frac{1}{C} - \lambda = 0, \tag{12a}$$

and

$$\dot{\lambda} = \rho\lambda - \frac{\partial H}{\partial A} = \rho\lambda - r(t)\lambda; \tag{12b}$$

equations (12a) and (12b) imply

$$\frac{\dot{C}}{C} = \frac{\dot{E}}{E} = r(t) - \rho. \tag{13}$$

In the balanced-growth equilibrium, consumption expenditure is constant over time and equation (13) implies that $r(t) = \rho$. In other words, the instantaneous interest rate equals the subjective discount rate.

Substituting $r(t) = \rho$, π from equation (5) and $V(t)$ from equation (7) into equation (9) with $\dot{V}(t) = 0$ we obtain the R&D equilibrium condition[13]

$$(\alpha - 1)E = \rho\alpha L^{1-\gamma} + \alpha L, \tag{14}$$

which defines a positive relationship between R&D investment L and consumption expenditure E. The resource constraint (10) and the R&D equilibrium condition (14) determine the market equilibrium values of L and E. Figure 1 illustrates the balanced-growth equilibrium in the R&D investment and consumption expenditure space. The full employment of labor condition (10) defines a negatively sloped line, NN, and equation (14) defines the positively sloped locus, OR, which starts at the origin. The intersection of the two curves at point A defines the unique market equilibrium values $\bar{E}$ and $\bar{L}$.

What are the properties of the balanced-growth equilibrium? The incumbent monopolist does not have any incentive to engage in R&D investment to discover the next higher-quality product. This result depends on the free-entry condition for each R&D race and on the absence of differences in the technology and costs of R&D between the incumbent and the challengers.[14] The values of R&D investment, consumption expenditure, and assets are all constant when measured in units of labor. New products are discovered through

13. Equation (14) can be derived by calculating the net expected benefits of winning an arbitrary race discounted to the beginning of the race, and setting the expression equal to zero because of free entry. See Cheng and Dinopoulos (1993) for this alternative methodology.

14. The argument for the absence of incentives for the incumbent to engage in further R&D can be summarized as follows: Suppose the incumbent were to win the next R&D race. This firm would be two quality levels above its immediate competitor and could have charged a price equal to α^2, earning an instantaneous flow of profits equal to $\pi' = [1 - 1/\alpha^2]E$, which is higher than $\pi = [1 - 1/\alpha]E$. However, a fraction of π' equal to π has to be paid as a dividend to investors who have financed the first of the two R&D races the incumbent won. Thus, the additional R&D investment by the incumbent has to be justified by the difference in profits, $\pi' - \pi = [1 - 1/\alpha](E/\alpha)$, this firm would make if it won the next R&D race. Each challenger, on the other hand, obtains profits π if it wins the next race and zero otherwise, and consequently the difference in profits is $\pi = [1 - 1/\alpha]E$, which exceeds $\pi' - \pi$. Thus, each challenger has an incentive to invest more in R&D than the incumbent firm, given symmetry in R&D technology and costs between challengers and the incumbent. Reinganum (1985, proposition 5) has shown this result under more general market-structure conditions than those of the present chapter. The free-entry condition in each R&D race implies that a challenger makes zero discounted expected profits. Consequently, an incumbent makes negative discounted expected profits if it engages in the next R&D race.

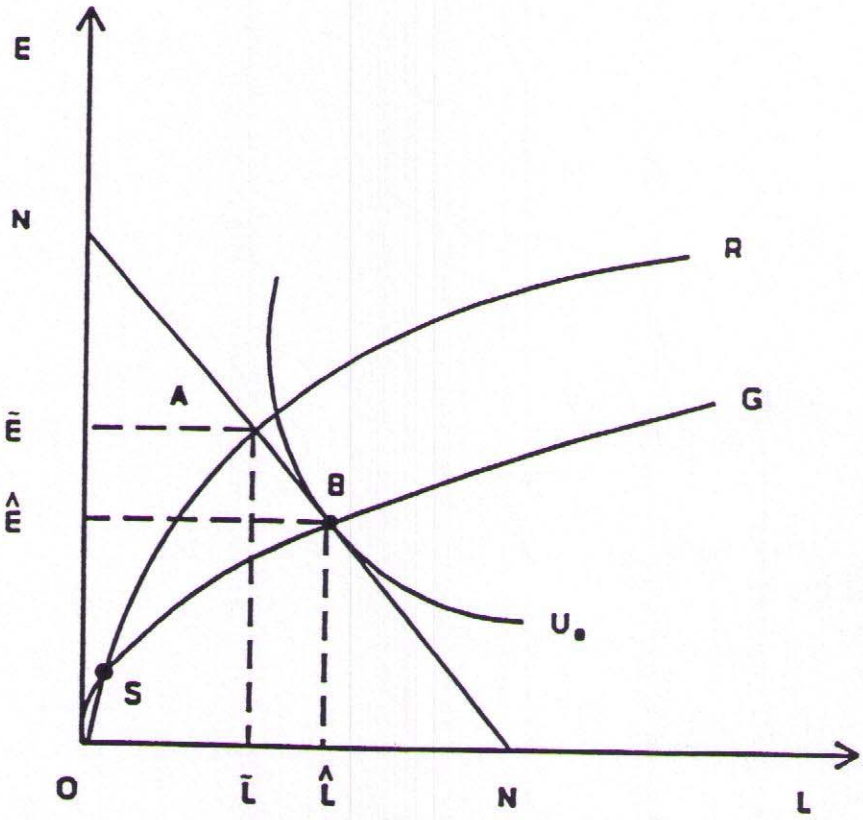

Fig. 1. Social optimum and market equilibrium

R&D races, old products are replaced by higher-quality ones, and firms are born and die. Temporary monopoly profits fuel innovation and technological progress. The arrival of new products is governed by a Poisson process whose intensity depends positively on R&D investment. The random time intervals between innovations are exponentially distributed.

There are no transitional dynamics in this simple model of Schumpeterian growth. At time zero the economy jumps immediately to point A in figure 1 because consumers choose E and firms choose L instantaneously. Thus, point A is the unique perfect foresight steady-state equilibrium consistent with optimizing behavior of consumers and firms. Dinopoulos (1994, appendix) provides a formal analysis of perfect foresight dynamics. This simple model captures all basic features of Schumpeterian growth through creative destruction: Firms chase temporary economic profits and face considerable uncertainty. In the meantime, every time a new product is discovered the utility of the representative consumer jumps by an increment equal to ln α.

I can obtain simple expressions of Schumpeterian growth and welfare by concentrating on the steady-state behavior of the economy. The indirect subutility at time t is given by $z(\cdot) = \alpha^q E/\alpha$, where $q(t)$ denotes the number of innovations between time zero (when the economy jumps to the steady-state equilibrium) and time t. Taking logarithms and denoting with $F(t,E) =$ Exp[ln (z)] the expected aggregate instantaneous utility at time t, I obtain $F(t,E) = \ln E - \ln \alpha + \ln \alpha[\text{Exp}(q)]$ because aggregate expenditure is constant over time. The number of innovations is governed by a Poisson process with intensity L^{γ}, and therefore $\text{Exp}(q) = tL^{\gamma}$, and

$$F(t,E) = \ln E - \ln \alpha + tL^{\gamma} \ln \alpha. \tag{15}$$

The long-run Schumpeterian growth is defined as

$$g = \frac{dF(t,\, E)}{dt} = L^{\gamma} \ln \alpha\,, \tag{16}$$

which equals the expected growth rate of the quality weighted index of consumption. In other words, g is the expected growth rate of subutility $z(\cdot)$ defined in equation (2).

The expected growth rate of the economy increases in the quality increment, α, and in the amount of R&D investment, L, and decreases in the degree of instantaneous diminishing returns to R&D, which is related to γ. The dependence of the expected growth rate on R&D investment generates the endogenous growth feature of the model. A variety of policies (trade, investment, or consumption taxes) can alter the equilibrium level of R&D investment and long-run growth. Because the population in the economy is fixed, g represents the per capita expected long-run growth. Finally, notice that L^{γ} is the intensity of the Poisson process that governs the arrival of innovations. The higher the R&D investment, the higher the "frequency" of innovations per unit of time, and the lower the expected lifespan of each new product.

Comparative statics results can be obtained easily by totally differentiating equations (10) and (14), or by utilizing figure 1. An increase in $\bar{N}$ shifts the NN curve to the right, resulting in higher $\bar{E}$ and $\bar{L}$. An increase in $\bar{N}$ should be interpreted as an increase in market size and not as population growth. Larger economies experience higher growth rates and higher consumption per capita. More complicated versions of the simple model can demonstrate that international trade has a similar potential effect on long-run growth. Trade results in larger market size, which increases profits and R&D investment. An increase in α rotates both curves OR and NN clockwise and results in higher $\bar{E}$ and $\bar{L}$. Economies facing larger technological opportunities experience higher long-run growth. An increase in ρ rotates the OR curve counterclockwise without affecting curve NN. Economies that value the future less invest less and consume more. Finally, an increase in γ rotates the OR curve clockwise, resulting in higher investment and long-run growth and in lower consumption expenditure. The lower the degree of diminishing returns to R&D, the higher the level of Schumpeterian growth.

The above-mentioned comparative statics results are remarkably intuitive. However, the policy implications of the present model are more complicated. How does the market solution compare to the socially optimal one? Aghion and Howitt (1990) provide an excellent analysis and discussion of the nature of the distortions inherent in Schumpeterian growth models. The following discussion follows the spirit of their analysis.

Substituting equation (15) into equation (1), I obtain a simple expression for the expected welfare discounted to time zero

$$U = \int_0^\infty e^{-\rho t} F(t, E)\, dt = \frac{1}{\rho}\left(\ln E - \ln \alpha + \frac{L^\gamma \ln \alpha}{\rho}\right). \tag{17}$$

Expression (17) was obtained under the assumption that each manufacturing firm charges a price equal to α. In principle, there are two ways of viewing the government's problem: The government can maximize equation (17) subject to the resource constraint (10). This approach confines the government to the use of instruments that alter the market incentives faced by firms. Following the analysis of existing Schumpeterian growth models, I will present the case of private R&D. Alternatively, the government can engage in R&D and finance it through lump-sum taxes. The present model allows the analysis of public R&D as well. Because in this case the government engages in marginal-cost pricing, the second term inside the parentheses in equation (17) becomes zero, and the resource constraint (10) becomes $\bar{N} = L + E$.

Because U is an increasing and concave function of consumption E and investment L, the solution to the government's problem can be obtained and illustrated with the use of welfare indifference curves. Totally differentiating equation (17) and setting $dU = 0$, I obtain $dE/dL = -(\gamma E \ln \alpha)/(\rho L^{1-\gamma}) < 0$, which states that welfare indifference curves are downward sloping and convex to the origin in the consumption-investment space. At the social optimum, the slope of an indifference curve equals the slope of the market resource constraint (10), which is $dE/dL = -\alpha$, and therefore I have

$$\frac{(\gamma \ln \alpha)\hat{E}}{\rho \hat{L}^{1-\gamma}} = \alpha. \tag{18}$$

Equations (18) and (10) determine the optimal consumption $\hat{E}$ and R&D investment $\hat{L}$. The right-hand side of equation (18) can be thought of as the market rate of technical transformation, and it is equal to the monopoly price, α. In the case of public R&D, the right-hand side of equation (18) equals unity. The left-hand side of equation (18) is the marginal rate of substitution between consumption and investment.

To compare the socially optimal solution to the market equilibrium for the case of private R&D, note that the resource constraint (10) is identical for both problems. The market R&D equilibrium condition (14) can be written as

$$\frac{(\alpha - 1)\bar{E}}{(\rho + \bar{L}^{\gamma})\bar{L}^{(1-\gamma)}} = \alpha. \tag{19}$$

The right-hand side of equation (18) is identical to the right-hand side of equation (19). The social planner allows each firm to charge a monopoly price in order to allow product replacement to take place. However, there are three differences between equations (19) and (18).

First, the parameter $\gamma < 1$, which captures the degree of diminishing returns to R&D, appears in the numerator of equation (18) but not in equation (19). The social planner takes into account the fact that, at the margin, the social value of R&D diminishes as more resources are devoted to R&D. In the market equilibrium, each firm in an R&D race is small, so this effect is ignored by the firms. Thus, the higher the degree of diminishing returns to R&D (i.e., the lower the value of γ), the higher the bias of the private sector toward R&D investment.

Second, the numerator of equation (19) has the term $(\alpha - 1)$, whereas the numerator of equation (18) has the term $\ln \alpha$ instead. This is the monopoly distortion effect. The winner of each R&D race is concerned about the profit margin, $\alpha - 1$, associated with each new product, whereas the social planner is concerned with the change in consumer surplus due to an innovation that equals $\ln \alpha < \alpha - 1$ for $\alpha > 1$. This effect tends to create a private sector bias toward R&D investment.

Finally, there is the intertemporal spillover effect, which is reflected in the denominators of equations (18) and (19). The social planner discounts each innovation by using ρ instead of $\rho + L^{\gamma}$, which is the private discount rate. The social planner takes into account the fact that the benefits of an innovation continue forever, whereas private firms discount future profits by taking into account the probability that these profits will disappear. This effect tends to increase the level of R&D investment of the planner relative to the market solution at each level of expenditure.

The above discussion and analysis are illustrated in figure 1. The downward-sloping line NN is the resource constraint (10), and the upward-sloping concave curve OSAR is the market R&D equilibrium condition, with point A being the market equilibrium. The positively sloped concave curve OSBG is the graph of equation (18), and its intersection with NN at point B determines the optimal consumption and investment levels. Point B corresponds to the tangency of a welfare indifference curve U_0 and the resource constraint, NN. It is easy to see that the graph of equation (18) lies above the graph of equation (19) for low values of R&D investment, and below the graph of equation (19) for high values of R&D investment.[15] Point S corresponds to the intersection point of the two curves. If the resource constraint NN just happens to pass through point S, then the market and social solutions coincide. There is no scope for government intervention. Thus, point S is loosely associated with Schumpeter's view of no government intervention in the absence of various macroeconomic frictions. At point S, however, it is simply the case that the various externalities and distortions exactly offset each other. Small economies should move resources toward more consumption and avoid risky R&D investments. Economies with lots of resources should encourage even more R&D investment than the market is willing to undertake.

One lesson from this simple Schumpeterian growth model is that, depending on the parameters of the model, either R&D taxes or subsidies are optimal. This insight has been robust in more general versions of the model, and it is similar in spirit to that of static models with imperfect competition.

Accomplishments and Implications

Many studies have constructed more sophisticated versions of the basic Schumpeterian growth model to address a variety of issues. These studies have increased the number of analytical techniques and have provided valuable insights into the mechanics of Schumpeterian progress. Because the Schumpeterian growth literature is still evolving, it is premature to provide a complete survey. I will confine my attention to several representative studies that highlight the accomplishments and implications of the new theory.

A popular version of Schumpeterian growth theory is the "quality ladders" model of economic growth developed by Grossman and Helpman (1991, chap. 4) and refined by Segerstrom (1991, 1995) and Houser (1994). Instead of one sector, the quality ladders model has a continuum of industries

15. Dividing equation (18) by equation (19), I obtain $\hat{E}/\bar{E} = [(\alpha - 1)/\gamma \ln \alpha][\rho/(\rho + L\gamma)]$. The first bracket is always greater than one. For L close to zero, $\hat{E} > \bar{E}$. As L increases, $\hat{E}/\bar{E}$ declines monotonically, and approaches zero as L approaches infinity.

and no aggregate uncertainty. Thompson and Waldo (1994) formalized another version of Schumpeterian growth based on Schumpeter's notion of "trustified capitalism," where innovating firms are infinitely lived and compete in market shares through the introduction of better products.

Several studies constructed multisectoral dynamic general equilibrium models to analyze the implications of Schumpeterian growth theory for patterns of trade, gains from trade, and trade restrictions. Segerstrom, Anant, and Dinopoulos (1990), Grossman and Helpman (1991), Dinopoulos, Oehmke, and Segerstrom (1993), and Taylor (1993), among others, have analyzed dynamic patterns of trade and investment through the perspective of Schumpeterian growth models. These studies emphasized the sectoral composition of aggregate growth and the relevance of comparative advantage to dynamic trade patterns. Segerstrom, Anant, and Dinopoulos (1990), Grossman and Helpman (1991), Taylor (1994), and Dinopoulos and Syropoulos (1995) analyzed the effects of trade liberalization and tariffs on Schumpeterian growth and/or welfare. These studies revealed the complex general-equilibrium interactions between trade restrictions and growth based on intersectoral shifts of resources caused by trade intervention. Romer (1994) and Dinopoulos and Syropoulos (1994) highlighted the risks of trade intervention by recalculating the costs of protection using neo-Schumpeterian models of growth.

The area of macroeconomics has also benefited from developments in Schumpeterian growth theory. Aghion and Howitt (1990) and Cheng and Dinopoulos (1992, 1993, 1996) have applied the insights of the new theory to issues of economic fluctuations. These models managed to provide a unified framework to study the interactions between long-run Schumpeterian growth and economic fluctuations. The latter are generated as a result of multiple perfect foresight equilibria, or can emerge in the presence of asymmetric technological opportunities in the form of technological breakthroughs and improvements. Aghion and Howitt (1994) introduced frictions in the labor market and analyzed the interactions between long-run Schumpeterian growth and involuntary unemployment.

Finally, several empirical studies have tested implications of the theory. Phillips (1993) reported a positive correlation between R&D investment and technological change measured by Solow residuals. Thompson (1995) has utilized U.S. firm-level data to estimate a Schumpeterian growth model of trustified capitalism. Arroyo, Dinopoulos, and Donald (1994) introduced population growth and neoclassical physical capital accumulation in the model of the previous section and estimated it using U.S. macroeconomic data. These studies provided very encouraging signals for the empirical relevance of Schumpeterian growth theory.

Conclusions

In the preface to Japanese edition of "Theorie der wirtschaftlichen Entwicklung," Schumpeter (1937) was searching for a theory of endogenous technological change

> There must be a purely economic theory of economic change which does not merely rely on external factors propelling the economic system from one equilibrium to another. It is such a theory . . . that I have tried to build . . . [and that] explains a number of phenomena, in particular the business cycle, more satisfactorily than it is possible to explain them by means of either the Walrasian or the Marshallian apparatus.

Fifty years later, Schumpeter's description of endogenous growth through creative destruction was formalized using state-of-the-art modeling techniques.

The goal of the present chapter was to describe the basic features, developments, and implications of Schumpeterian growth theory. The autonomy of the new theory is based on the distinct features of creative destruction. Schumpeterian growth models utilize a dynamic general-equilibrium framework, model temporary market power through dynamic imperfect competition, and focus on the risks associated with endogenous introduction of better products and processes. Although the spirit and basic assumptions of Schumpeterian growth models are definitely Schumpeterian, as the extensive quotations in the second section establish, several normative implications of the new theory do not always coincide with Schumpeter's views. The new theory has provided one of many possible formalizations of the process of creative destruction, and it is more Schumpeterian in spirit and implications than other existing models of economic growth.

The Schumpeterian growth theory is still evolving, following the general law of creative destruction. Better new models replace old ones, empirical testing modifies the original assumptions of some models, and more powerful analytical techniques push the boundaries of the new theory. More research is needed on the stability properties of Schumpeterian growth models with state variables such as physical or human capital accumulation. In addition, international transfer of technology, unemployment caused by business fluctuations, personal income distribution, multiproduct firms, and empirical testing of Schumpeterian growth models are unexplored important issues that await further research.

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