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endogenous growth

Endogenous growth theory explains long-run growth as emanating from economic activities that create new technological knowledge. This article sketches the outlines of the theory, especially the 'Schumpeterian' variety, and briefly describes how the theory has evolved in response to empirical discoveries.

Endogenous growth is long-run economic growth at a rate determined by forces that are internal to the economic system, particularly those forces governing the opportunities and incentives to create technological knowledge.

In the long run the rate of economic growth, as measured by the growth rate of output per person, depends on the growth rate of total factor productivity (TFP), which is determined in turn by the rate of technological progress. The neoclassical growth theory of Solow (1956) and Swan (1956) assumes the rate of technological progress to be determined by a scientific process that is separate from, and independent of, economic forces. Neoclassical theory thus implies that economists can take the long-run growth rate as given exogenously from outside the economic system.

Endogenous growth theory challenges this neoclassical view by proposing channels through which the rate of technological progress, and hence the long-run rate of economic growth, can be influenced by economic factors. It starts from the observation that technological progress takes place through innovations, in the form of new products, processes and markets, many of which are the result of economic activities. For example, because firms learn from experience how to produce more efficiently, a higher pace of economic activity can raise the pace of process innovation by giving firms more production experience. Also, because many innovations result from R&D expenditures undertaken by profit-seeking firms, economic policies with respect to trade, competition, education, taxes and intellectual property can influence the rate of innovation by affecting the private costs and benefits of doing R&D.

AK theory

The first version of endogenous growth theory was AK theory, which did not make an explicit distinction between capital accumulation and technological progress. In effect it lumped together the physical and human capital whose accumulation is studied by neoclassical theory with the intellectual capital that is accumulated when innovations occur. An early version of AK theory was produced by Frankel (1962), who argued that the aggregate production function can exhibit a constant or even increasing marginal product of capital. This is because, when firms accumulate more capital, some of that increased capital will be the intellectual capital that creates technological progress, and this technological progress will offset the tendency for the marginal product of capital to diminish.

In the special case where the marginal product of capital is exactly constant, aggregate output Y is proportional to the aggregate stock of capital K:

$$Y = AK \tag{1}$$

where A is a positive constant. Hence the term 'AK theory'.

According to AK theory, an economy's long-run growth rate depends on its saving rate. For example, if a fixed fraction s of output is saved and there is a fixed rate of depreciation δ, the rate of aggregate net investment is:

$$\frac{dK}{dt} = sY - \delta K$$

which along with (1) implies that the growth rate is given by:

$$g \equiv \frac{1}{Y}\frac{dY}{dt} = \frac{1}{K}\frac{dK}{dt} = sA - \delta.$$

Hence an increase in the saving rate s will lead to a permanently higher growth rate.

Romer (1986) produced a similar analysis with a more general production structure, under the assumption that saving is generated by intertemporal utility maximization instead of the fixed saving rate of Frankel. Lucas (1988) also produced a similar analysis focusing on human capital rather than physical capital; following Uzawa (1965) he explicitly assumed that human capital and technological knowledge were one and the same.

Innovation-based theory

AK theory was followed by a second wave of endogenous growth theory, generally known as 'innovation-based' growth theory, which recognizes that intellectual capital, the source of technological progress, is distinct from physical and human capital. Physical and human capital are accumulated through saving and schooling, but intellectual capital grows through innovation.

One version of innovation-based theory was initiated by Romer (1990), who assumed that aggregate productivity is an increasing function of the degree of product variety. In this theory, innovation causes productivity growth by creating new, but not necessarily improved, varieties of products. It makes use of the Dixit–Stiglitz–Ethier production function, in which final output is produced by labour and a continuum of intermediate products:

$$Y = L^{1-\alpha} \int_0^A x(i)^\alpha \; di, \quad 0 < \alpha < 1 \tag{2}$$

where L is the aggregate supply of labour (assumed to be constant), $x(i)$ is the flow input of intermediate product i, and A is the measure of different intermediate products that are available for use. Intuitively, an increase in product variety, as measured by A, raises productivity by allowing society to spread its intermediate production more thinly across a larger number of activities, each of which is subject to diminishing returns and hence exhibits a higher average product when operated at a lower intensity.

The other version of innovation-based growth theory is the 'Schumpeterian' theory developed by Aghion and Howitt (1992) and Grossman and Helpman (1991). (Early models were produced by Segerstrom, Anant and Dinopoulos, 1990, and Corriveau, 1991). Schumpeterian theory focuses on quality-improving innovations that render old products obsolete, through the process that Schumpeter (1942) called 'creative destruction.'

In Schumpeterian theory aggregate output is again produced by a continuum of intermediate products, this time according to:

$$Y = L^{1-\alpha} \int_0^1 A(i)^{1-\alpha}\, x(i)^{\alpha} di, \tag{3}$$

where now there is a fixed measure of product variety, normalized to unity, and each intermediate product i has a separate productivity parameter $A(i)$. Each sector is monopolized and produces its intermediate product with a constant marginal cost of unity. The monopolist in sector i faces a demand curve given by the marginal product: $\alpha \cdot (A(i)L/x(i))^{1-\alpha}$ of that intermediate input in the final sector. Equating marginal revenue (α time this marginal product) to the marginal cost of unity yields the monopolist's profit-maximizing intermediate output:

$$x(i) = \xi L A(i)$$

where $\xi = \alpha^{2/(1-\alpha)}$. Using this to substitute for each $x(i)$ in the production function (3) yields the aggregate production function:

$$Y = \theta A L \tag{4}$$

where $\theta = \xi^{\alpha}$, and where A is the average productivity parameter:

$$A \equiv \int_0^1 A(i)\ di.$$

Innovations in Schumpeterian theory create improved versions of old products. An innovation in sector i consists of a new version whose productivity parameter $A(i)$ exceeds that of the previous version by the fixed factor $\gamma > 1$. Suppose that the probability of an innovation arriving in sector i over any short interval of length dt is $\mu \cdot dt$. Then the growth rate of $A(i)$ is

$$\frac{dA(i)}{A(i)} \cdot \frac{1}{dt} = \left\{ \begin{matrix} (\gamma - 1) \cdot \frac{1}{dt} & \text{with probability } \mu \cdot dt \\ 0 & \text{with probability } 1 - \mu \cdot dt \end{matrix} \right\}.$$

Therefore the expected growth rate of $A(i)$ is:

$$E(g) = \mu(\gamma - 1). \tag{5}$$

The flow probability μ of an innovation in any sector is proportional to the current flow of productivity-adjusted R&D expenditures:

$$\mu = \lambda R / A \tag{6}$$

where R is the amount of final output spent on R&D, and where the division by A takes into account the force of increasing complexity. That is, as technology advances it becomes more complex, and hence society must make an ever-increasing expenditure on research and development just to keep innovating at the same rate as before.

It follows from (4) that the growth rate g of aggregate output is the growth rate of the average productivity parameter A. The law of large numbers guarantees that g equals the expected growth rate (5) of each individual productivity parameter. From this and (6) we have:

$$g = (\gamma - 1)\ \lambda R / A.$$

From this and (4) it follows that the growth rate depends on the fraction of GDP spent on research and development, $n = R/Y$, according to:

$$g = (\gamma - 1)\ \lambda \theta L n. \tag{7}$$

Thus, innovation-based theory implies that the way to grow rapidly is not to save a large fraction of output but to devote a large fraction of output to research and development. The theory is explicit about how R&D activities are influenced by various policies, who gains from technological progress, who loses, how the gains and losses depend on social arrangements, and how such arrangements affect society's willingness and ability to create and cope with technological change, the ultimate source of economic growth.

Empirical challenges

Endogenous growth theory has been challenged on empirical grounds, but its proponents have replied with modifications of the theory that make it consistent with the critics' evidence. For example, Mankiw, Romer and Weil (1992), Barro and Sala-i-Martin (1992) and Evans (1996) showed, using data from the second half of the 20th century, that most countries seem to be converging to roughly similar long-run growth rates, whereas endogenous growth theory seems to imply that, because many countries have different policies and institutions, they should have different long-run growth rates. But the Schumpeterian model of Howitt (2000), which incorporates the force of technology transfer, whereby the productivity of R&D in one country is enhanced by innovations in other countries, implies that all countries that perform R&D at a positive level should converge to parallel long-run growth paths.

The key to this convergence result is what Gerschenkron (1952) called the 'advantage of backwardness'; that is, the further a country falls behind the technology frontier, the larger is the average size of innovations, because the larger is the gap between the frontier ideas incorporated in the country's innovations and the ideas incorporated in the old technologies being replaced by innovations. This increase in the size of innovations keeps raising the laggard country's growth rate until the gap separating it from the frontier finally stabilizes.

Likewise, Jones (1995) has argued that the evidence of the United States and other OECD countries since 1950 refutes the 'scale effect' of Schumpeterian endogenous growth theory. That is, according to the growth equation (7) an increase in the size of population should raise long-run growth by increasing the size of the workforce L, thus providing a larger market for a successful innovator and inducing a higher rate of innovation. But in fact productivity growth has remained stationary during a period when population, and in particular the number of people engaged in R&D, has risen dramatically. The models of Dinopoulos and Thompson (1998), Peretto (1998) and Howitt (1999) counter this criticism by incorporating Young's (1998) insight that, as an economy grows, proliferation of product varieties reduces the effectiveness of R&D aimed at quality improvement by causing it to be spread more thinly over a larger number of different sectors. When modified this way the theory is consistent with the observed coexistence of stationary TFP growth and rising population, because in a steady state the growth-enhancing scale effect is just offset by the growth-reducing effect of product proliferation.

As a final example, early versions of innovation-based growth theory implied, counter to much evidence, that growth would be adversely affected by stronger competition laws, which by reducing the profits that imperfectly competitive firms can earn ought to reduce the incentive to innovate. However, Aghion and Howitt (1998, ch. 7) describe a variety of channels through which competition might in fact spur economic growth. One such channel is provided by the work of Aghion et al. (2001), who show that, although an increase in the intensity of competition will tend to reduce the absolute level of profits realized by a successful innovator, it will nevertheless tend to reduce the profits of an unsuccessful innovator by even more. In this variant of Schumpeterian theory, more intense competition can have a positive effect on the rate of innovation because firms will want to escape the competition that they would face if they lost whatever technological advantage they have over their rivals.

Much more work needs to be done before we can claim to have a reliable explanation for why economic growth is faster in some countries and in some time periods than in others. But the fact that much of the cross-country variation in growth rates is attributable to differences in productivity growth rather than differences in rates of capital accumulation suggests that endogenous growth theory, which aims to provide an economic explanation of these differences in productivity growth, will continue to attract economists' attention for years to come.

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See also

<xref=xyyyyyy> growth, models of;
<xref=xyyyyyy> Schumpeterian growth and growth policy design.

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Index terms

aggregate production function
capital accumulation
competition
creative destruction
economic growth
endogenous growth
human capital
innovations
intellectual capital
intermediate products
intertemporal utility maximization
law of large numbers
marginal product of capital
neoclassical growth theory
physical capital
product variety
productivity growth
research and development
saving rate
Schumpeterian growth
steady state
technological progress
technology
technology frontier
total factor productivity
transfer of technology

Index terms not found:

Schumpeterian growth
transfer of technology