

WHAT IS ENDOGENOUS IN ENDOGENOUS GROWTH MODEL?

İÇSEL BÜYÜME MODELİNDE İÇSEL OLAN NEDİR?

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Abstract

The neoclassical growth model predicts that as soon as technologic improvements and innovations are not provided the growth in per capita income would stop in long term. However, the long-run data for many countries indicate that positive rates of per capita income growth can persist over the long term. Growth theorists of the 1950s and 1960s recognized this modeling deficiency and usually patched it up by assuming that technological progress occurs in an exogenous manner. The endogenous growth theory has sought to supply the missing explanation of long-run growth. The endogenous growth approach provides a theory of technical progress, one of the central missing elements of the neoclassical model. Therefore, from the perspective of economic growth modeling this new approach is the theory of integrating technologic progress into endogenous growth models what is endogenous in endogenous growth models is the theory of technical progress incorporated into the models.

Keywords: Economic Growth, Endogenous Growth, Neoclassical Growth, Technological Progress

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Öz

Neoklasik büyüme modelinin temel öngörüsü, teknolojide sürekli gelişmenin sağlanamaması durumunda kişi başına gelirdeki büyümenin uzun dönemde sıfır olacağıdır. Ancak, birçok ülkeye ilişkin veriler pozitif kişi başına gelir büyümesinin uzun dönemler boyunca gözlemlenebildiğini göstermektedir. 1950'lerin ve 1960'ların büyüme teorisyenleri bu modelleme defosunun farkına vardılar ve bu defoyu teknolojik gelişmenin dışsal bir biçimde ortaya çıktığını varsayarak gidermeye çalıştılar. Buna karşın, içsel büyüme teorisi uzun dönemli büyümenin açıklanmasını sunmayı amaçladı. Bu çerçevede içsel büyüme yaklaşımı neoklasik modelin temel eksik yanlarından biri olan teknolojik gelişme teorisini ortaya koymaktadır. Ekonomik büyüme modeli perspektifinden bu yeni yaklaşımda içsel olan büyüme modellerine entegre edilen teknolojik gelişme teorisidir.

Anahtar Kelimeler: Ekonomik Büyüme, İçsel Büyüme, Neoklasik Büyüme, Teknolojik Gelişme

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1. Introduction

One of the predictions of the neoclassical growth model, when the concept of capital in the model is broadened from physical goods to include human capital, is that in the absence of continuing improvements in technology, per capita income growth is meant to disappear eventually. This prediction, which resembles those of Malthus and Ricardo, comes from the assumption of diminishing returns to a broad concept of capital. The long-run data for many countries indicate, however, that positive rates of per capita income growth can persist over a century or more and that these growth rates have no clear tendency to decline.

Growth theorists of the 1950s and 1960s recognized this modeling deficiency and usually patched it up by assuming that technological progress occurred in an unexplained (exogenous) manner. This device can reconcile the theory with a positive, possibly constant per capita income growth rate in the long run. The obvious shortcoming, however, is that the long-run per capita income growth rate is determined entirely by an element-the rate of technological progress-that comes from outside the model.

Recent studies on endogenous growth theory have sought to supply the missing explanation of long-run growth. The endogenous growth approach provides a theory of technical progress, one of the central missing elements of the neoclassical model. Therefore, from the perspective of economic growth modeling, what is endogenous in endogenous growth models is the theory of technical progress incorporated into the models. The reason for the name 'endogenous growth' is the determination of long-run growth within the model rather than by an exogenously growing variable, such as unexplained technological progress. The inclusion of a theory of technical change into the neoclassical framework is difficult, however, because the standard competitive assumptions cannot be maintained. This is because technological advance involves the creation of new ideas that are partially nonrival and therefore have aspects of public goods. For a given technology-that is, a given state of knowledge-it is reasonable to assume constant returns to scale in the standard model with rival factors of production, such as labor, broad capital, and land. But, then, the returns to scale tend to be increasing if the nonrival ideas are included as factors of production. These increasing returns conflict with perfect competition. Moreover, the compensation of nonrival old ideas in accordance with their current marginal cost of production will not provide the appropriate reward for the research effort that underlies the creation of new ideas.

2. Endogenous Growth Theory: A Brief History

The determinants of the wealth of nations and its evaluation over time have mystified economists ever since the beginning of our discipline. Why do some countries grow faster than others? Complete answer to this question cannot possibly be provided within the narrow limits of a single branch of economics. Nevertheless, macroeconomic theories of economic growth have much to offer, as exemplified by the seminal contributions of Ramsey (1928), Harrod (1939), Domar (1946), and Solow (1956).

Most recently, new endogenous growth models have gone beyond Solow's neoclassical growth model that exhibited diminishing returns to capital and labor separately and constant returns to both factors jointly, and that left technological progress as a residual. However, at various times in the history of thought, economists have stressed increasing returns as an endogenous explanation for economic growth. Adam Smith did so in emphasizing that growth in productivity was due to the division of labor, which depends on the extent of the market. Alfred Marshall also emphasized that the role of 'nature' in production may be subject to diminishing returns, but the role of 'man' is subject to increasing returns. Young (1928) also related economic progress to increasing returns that were external to the firm as a result of the progressive division and specialization among industries and the

use of round about methods of production.

On the other hand, nobel laureate Kenneth Arrow (1962) gave a dynamic interpretation to increasing returns by emphasizing 'Learning by Doing'. This was an early attempt to render technological progress endogenous in growth models by making the productivity of a given firm an increasing function of cumulative aggregate investment for the industry. But that theory suffers from the limitation that it assumes that productivity improvements occur serendipitously as a by-product of capital accumulation, although deliberate efforts to develop new products and technologies have been very prominent. One can recall the dramatic developments in consumer electronics, computers, and pharmaceuticals in order to see the important role of deliberate research and development (R&D) in raising our standards of living. R&D has grown in importance in all industrial nations.

The new wave of research on economic growth was stimulated by Romer (1986) and Lucas (1988). Their work relies on Arrow's mechanism of learning-by-doing, but following Uzawa (1965), they have redirected its application to the accumulation of knowledge and human capital rather than the accumulation of plant and equipment. Moreover, they have changed the focus toward explanations of sustained long-run growth and cross country variations in growth rates. Following Arrow (1962), they have taken the view that aggregate production exhibits increasing returns to scale. But returns to scale are external to single economic agents and internal to a sector or larger parts of the economy. Consequently competition can prevail. However, this approach avoids complications of market conduct and structure that arise when economies of scale are internal to firms. Such complications are unavoidable when we wish to deal explicitly with profit-seeking investment in innovation, as we should, given the rising importance of commercial R&D in the industrial world.

The integration of imperfect competition with innovation based growth was first achieved by Judd (1985). His main interest was in the issue of industrial organization. Therefore, he did not explore the implications for growth. Romer (1990) combined Judd's approach with learning-by-doing in innovation and thereby developed a model that sustains long-run growth at an endogenous rate. Consequently, from the perspective of economic growth modeling, what is endogenous in endogenous growth models is the theory of technical progress incorporated into the models. This one was an important achievement, because it opened the door to a new research line with realistic features.

3. Endogenous Growth Models

If technical change (A) affects output by shifting the production function, then we call it as 'exogenous' technical change. However, it could shift the production function by affecting capital (K) or labor (L). So, we may have technical change that might affect the capital stock;

$$1) Y = F(A(t)K, L)$$

That is, even with the same amount of machine as before we can produce more because of capital augmenting technical progress.

Technical progress may also affect labor;

$$2) Y = F(K, A(t)L)$$

That is, labor rather than capital becomes more efficient. This is called labor saving or Harrod neutral technical progress.

On the other hand, we could have technical progress that affects both factors, i.e.,

$$3) Y = A(t)(K, L)$$

This is called Hicksian neutral technical progress.

If technical progress, on the other hand, is not just a function of time, but also it is a function of output itself, then it is called 'endogenous technical progress'. It can be expressed as

$$4) Y = A(Y)F(K, L)$$

That technical progress is due to learning-by-doing, the more you do, the more and better you produce.

How these kinds of technical changes affect the economic growth can be summarized as follows: In terms of exogenous technical change, Harrod neutral would be the easiest one to consider. In fact, if we use a Cobb-Douglas production function, due to the special form of this function, it can be viewed as capital augmenting or labor saving (Harrod Neutral), or Hicksian neutral. That is, by assuming that technical progress occurs at a constant rate (g), we have:

$$5) Y = e^{gt}(K^\alpha L^\beta), \text{ i.e., Hicksian neutral,}$$

$$6) Y = (e^{\left(\frac{g}{\alpha}\right)t} K)^\alpha L^\beta, \text{ i.e., capital augmenting, or}$$

$$7) Y = K^\alpha (e^{\left(\frac{g}{\beta}\right)t} L)^\beta, \text{ i.e., labor saving (Harrod neutral).}$$

However, in a general case, we may not be able to express all these three forms by the same function. Therefore, we will look at the general case with Harrod neutral technical progress:

If we define $(e^{\left(\frac{g}{\beta}\right)t} L)$ as efficient labor force, then output per efficient labor can be written as $(Y/(e^{\left(\frac{g}{\beta}\right)t} L) = F(K/(e^{\left(\frac{g}{\beta}\right)t} L), 1)$ where $K/(e^{\left(\frac{g}{\beta}\right)t} L)$ is the capital/labor ratio in efficiency unit.

If we define $y = Y/(e^{\left(\frac{g}{\beta}\right)t} L)$ and $k = K/(e^{\left(\frac{g}{\beta}\right)t} L)$, then output per efficient labor then can be expressed as

$$9) y = f(k), \text{ where } k \text{ is the capital/labor ratio in efficiency unit.}$$

Since $k = K/(e^{\left(\frac{g}{\beta}\right)t} L)$, it follows that change in capital per efficient labor over time $\left(\frac{dk}{dt}\right)$ can be written as

$$10) \left(\frac{dk}{dt}\right) = \left(\frac{K'}{e^{\left(\frac{g}{\beta}\right)t} L}\right) - k\left(\left(\frac{g}{\beta}\right) + n\right), \text{ where } K' \text{ is the change in capital stock over time, } \left(\frac{g}{\beta}\right) \text{ is Harrod neutral technical progress, and } n \text{ is the growth rate of labor force.}$$

If the accumulation of capital is assumed to be a fix proportion of output, then the change in capital stock per efficient labor can be written as

$$11) \left(\frac{K'}{e^{\left(\frac{g}{\beta}\right)t} L}\right) = sy = sf(k), \text{ where } s \text{ is the savings/output ratio.}$$

If we substitute this into the equation (10), for $\left(\frac{dk}{dt}\right)$ above, we have

$$12) \left(\frac{dk}{dt}\right) = k' = sf(k) - \left(\left(\frac{g}{\beta}\right) + n\right)k.$$

From this equation it follows that

$$13) \lim_{t \rightarrow \infty} k = k^* \text{ (a constant), and therefore,}$$

$$14) \lim_{t \rightarrow \infty} y = f(k^*) = y^* \text{ (a constant).}$$

However, note that the fact that per capita output in efficiency unit becomes a constant does not mean that output grows at the same rate as the labor force, but it grows at the same rate as the efficient labor supply. That is, if technical progress occurs at 3 % per annum and population grows at 2 % per annum, then output (Y) in the long-run will be growing at 5 % per annum. Therefore per capita income in the long run is not a constant, but it grows at a constant rate. Formally, growth rate of output (φ) will be $\varphi = \left(\frac{g}{\beta}\right) + n$, and therefore, rate of growth of per capita income will be $\varphi - n = \left(\frac{g}{\beta}\right)$. This means that per capita output grows as fast as the rate of technical progress if it is Harrod neutral. In other words, if technical progress is exogenous and if it is Harrod neutral, then income will be growing faster than population growth and therefore, per capita income will be growing at a constant rate, and this constant rate is a Harrod neutral technical progress rate. The implication is that if you have two countries both having same population growth rates, in the absence of technical progress, they would end up with the same growth rate. In the absence of technical progress, it also implies that the per capita income in the long run would be growing at zero rate in both countries.

Here we can distinguish between Harrod neutral technical progress and population growth. That is, population growth rate has no effect on per capita income, whereas technical progress, if it occurs, affects the per capita income. On the other hand, if we look at the various countries in the world, there are two major observations to make; they are growing at different rates and they have different income levels. If one country grows faster than the other, then presumably it will be able to catch up. However, in the case of large per capita income differential and a small difference in technical progress rates, the catch up will take a long time.

The endogenous growth theory seeks to explain changes in technology by analyzing the role of investment in research, training, and education by firms as well as by government, and the role of government policies in changing incentives to promote physical and human capital. Thus, the new theory also examines how changes in government policies may have a permanent effect on the output. On the other hand, if we take orthodox neoclassical growth theory's assumption that technical progress is exogenous, then given the fact that knowledge is a relatively inexpensive input, all countries should attain same A in the long-run in their production function. Thus, the orthodox growth theory predicts a convergence, or catching up process where countries acquire techniques and learn how to use them efficiently. Eventually, a system of convergence should produce the same per capita GDP across all countries. However, available cross-country data do not provide evidence for this prediction. The endogenous growth theory has tried to explain such lack of convergence by introducing the role of human capital as a complementary input to physical capital in the production function.

In what follows we will discuss the three presentations of endogenous growth model by Barro and Salai-Martin, Lucas, and Romer.

Barro and Salai-Martin (1995) present a constant saving rate version of the simplest endogenous growth model, the AK model. Although this model is rudimentary, it is rich

enough to show how the elimination of diminishing returns can lead to endogenous growth.

The key property of endogenous growth model is the absence of diminishing returns to capital. The simplest version of a production function without diminishing returns is the AK function:

$$15) Y = AK, \text{ where } A \text{ is a positive constant that reflects the level of technology.}$$

The global absence of diminishing returns may seem unrealistic, but the idea becomes more plausible if we think of K in a broad sense to include human capital. Output per capita is:

$$16) y = Ak, \text{ where } y = Y/L \text{ and } k = K/L, \text{ and average and marginal products of capital are constant at levels for } A > 0.$$

Recall that in neoclassical growth model the growth rate of per capita capital is given by

$$17) \frac{k'}{k} = \left\{ \frac{sf(k)}{k} \right\} - (n + \tau), \text{ where } \tau \text{ is the depreciation rate of capital stock.}$$

Recall also the expression for y ; $y = f(k)$ $y=f(k)$. Then it follows that

$$18) f(k) = Ak, \text{ which implies } f(k)/k = A.$$

If we substitute this into equation (17) for the growth rate of capital per capita, we have

$$19) \frac{k'}{k} = sA - (n + \tau), \text{ where we assume that there is no exogenous technological change.}$$

The difference between neoclassical and endogenous growth models can be shown easily. Assume that initially $\left\{ \frac{sf(k)}{k} \right\} > (n + \tau)$, which implies that $\frac{k'}{k} > 0$. Due to the diminishing return to capital, $f(k)/k$ term will become smaller and smaller, and therefore, $\frac{k'}{k}$ will become zero. However, in the endogenous growth model case, if initially $sA > (n + \tau)$, since all the terms here are constants, $\frac{k'}{k}$ will be greater than zero indefinitely.

Now we turn to Lucas's presentation. Lucas(1988) suggested that technical progress is not exogenous, but endogenous. In addition, Lucas emphasized the role of human capital as a factor of economic growth. That is, he emphasized the importance of education (schooling) and training (learning-by-doing). He compares the exogenous growth model, a model emphasizing physical capital accumulation and technological change, with the endogenous growth model, a model emphasizing human capital accumulation through schooling and specialized human capital accumulation through learning-by-doing.

Lucas's model can briefly be presented as follows. Lucas emphasized that if we want to look at macroeconomics, we have to have microfoundation. Therefore, we have to look at preferences and the technology. Lucas assumed the following utility function;

$$20) u(c) = \left(\frac{1}{1-\sigma} \right) (c^{1-\sigma} - 1), \text{ where } c \text{ is the consumption per capita.}$$

Then at the aggregate level utility maximization problem can be expressed as follows:

$$21) \text{Max } \int_0^{\infty} e^{-\sigma t} \left(\frac{1}{1-\sigma} \right) (c^{1-\sigma} - 1) N dt \text{ subject to } K' + cN = AcK^{\alpha}L^{1-\alpha} \text{ where } N \text{ is the number of the people.}$$

The solution to that problem yields that per capita consumption and per capita capital grow at the common rate μ ,

$$22) \mu = \frac{g}{1-\alpha}, \text{ where } g = A'/A^\alpha, \text{ technical progress.}$$

That is, to say with exogenous technical progress we can have a none-zero consumption per capita growth rate over time as long as we have technical progress.

According to Lucas, however, by assigning so great a role to technology as a source of growth, neoclassic growth theory is obliged to assign correspondingly minor roles to everything else, and therefore it has a very little ability to account for the wide diversity in growth rates of various countries.

In explaining his endogenous growth model, Lucas (1988) assumed the following production function:

$$23) Y = AK^\alpha(huN)^{1-\alpha}h^\kappa, \text{ where } h: \text{ labor skill, } u: \text{ fraction of time to improve the skill,}$$

h^κ : the external effects of human capital, and A : technology level (assumed constant).

So the technology of goods production can be written as follows:

$$24) K' + cN = AK^\alpha(huN)^{1-\alpha}h^\kappa$$

With the new constrained to the maximum problem above, solution now will yield that

$$25) \mu = \left(\frac{1-\alpha+\kappa}{1-\alpha} \right) v, \text{ where } v \text{ is the growth rate of the labor skill.}$$

That is, with the labor skill growing at a fixed rate (v), $\left(\frac{1-\alpha+\kappa}{1-\alpha} \right) v$ plays the role of the exogenous technological change in the exogenous growth model. That is to say, the labor skill accumulation through schooling is an important factor for economic growth.

Romer (1986) did something very similar by arguing that the technological progress is endogenous. While Lucas (1988) based his theory mainly on the decisions made by households, Romer (1986) emphasized the decisions made by firms. In his 1986 article, Romer presented a fully specified model of long run growth in which knowledge is assumed to be an input in production that has increasing marginal productivity. Romer's model can be viewed as an equilibrium model of endogenous technical change in which long run growth is driven primarily by the accumulation of knowledge by forward- looking profit-maximizing agents.

Romer argued that investment in knowledge has a natural externality, the creation of new knowledge by one firm is assumed to have a positive external effect on the production possibilities of other firms because knowledge cannot be perfectly patented or kept secret. According to Romer, the three elements- externalities, increasing return in the production of output, and decreasing return in production of new knowledge - combine to produce a well specified equilibrium model of growth.

4. Conclusion

According to endogenous growth theorists, technological change lies at the hearth of economic growth. This is because technological change provides the incentives for continued capital accumulation, and together, capital accumulation and technological change account for much of the increase in output per hour worked.

Technological change arises in large part because of intentional actions taken by

people who respond to market incentives. That is, it is not a 'magna from haven' as it is in the case of neoclassical growth models. Specifically, in Romer (1986)'s analysis, knowledge through investment in research leads to increasing marginal productivity so that per capita income can continue to grow and return to capital may continue to increase. However, in neoclassical growth models, diminishing return to capital is assumed. This assumption leads to a constant per capita capital which in turn leads to a constant per capita income level. In Lucas (1986)'s analysis, endogenous technological change driven by increase in labor skill through schooling or on the job training has a growth effect beyond simply the level effect (upward shifting of production function) suggested by earlier learning-by-doing models.

References

- Arrow, Kenneth J. 1962.** "The Economic Implications of Learning by Doing". Review of Economic Studies, Vol.29, No.3, pp.155-173.
- Barro, Robert and Xavier Salai Martin (1995).** Economic Growth. McGraw-Hill, Inc. New York.
- Domar Evsey D. (1946).** "Capital Expansion, Rate of Growth, and Employment". Econometrica, Vol.14, No.2, pp.137-147.
- Harrod, Roy F. (1939).** "An essay in Dynamic Theory". The Economic Journal, Vol.49, No.193, pp.14-33.
- Judd, Kenneth L. (1985).** "On the Performance of Patents". Econometrica, Vol. 53, No.2, pp.567-585.
- Lucas, Robert E., Jr. 1988.** "On the Mechanics of Economic Development". Journal of Monetary Economics, Vol. 22, No.4, pp.3-42.
- Ramsey, Frank P. (1928).** "A Mathematical Theory of Saving". The Economic Journal, Vol. 38, No.152, pp.543-559.
- Romer, Paul M. 1986.** "Increasing Returns and Long Run Growth". Journal of Political Economy, Vol. 94, No.5, pp.1002-1037.
- Romer, Paul M. 1990.** "Endogenous Technological Change". Journal of Political Economy, Vol. 98, No.5, pp.S71-S102.
- Solow, Robert M. 1956.** "A Contribution to the Theory of Economic Growth". Quarterly Journal of Economics, Vol. 70, No.1, pp.65-94.
- Uzawa, Hirofumi (1965).** "Optimal Technical Change in an Aggregative Model of Economic Growth". International Economic Review, Vol.6, No.1, pp.18-31.
- Young Allyn A. (1928).** "Increasing Returns and Economic Progress". The Economic Journal, Vol.38, No. 152, pp.527-542.