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**Teacher-Dr. Ramesh Chandra Das**

**ENDOGENOUS TECHNOLOGY AND GROWTH THEORY**

Endogenous growth theory attempts to make the steady state growth rate endogenous, in place of the neoclassical proposed exogenous growth rates that we have already discussed. That is the rate which is determined from within the theory. There are two basic ways of endogenizing the steady state growth rate. First, if there are constant returns to factors of production that can be accumulated then the steady state growth rate will be affected by the rate at which the factors are accumulated. The working of diminishing returns then will be vanished and the growth rate of per capita variables will not be fixed, rather will be changeable. This can be explained by a simplest production function of Y = AK, where A stands for the marginal productivity of capital which is not diminishing, rather constant. Second, the rate of technological progress can be made endogenous. The proponents of the endogenous growth theory pronounce that the investment in generating human capital, the learning by doing, expenditure in R&D activities, government’s intervention into the economic activities, etc. can facilitate the working of increasing returns to scale in the overall production system that will ultimately enable both the level as well as per capita variables to grow and there should be no end to the growth process, and hence the neoclassical prediction of cross country convergence will not appear. There will be a significant difference between the countries with high levels of endogenous growth factors, which is the developed ones, compared to the developing ones and there should be conditional convergence in place of absolute convergence across the economies.

**The Model under AK Technology**

The production function of Y = AK is a very simple function which provides proportional relation between output and capital at level values with labour force assumed to be fixed. The production function follows CRS and the marginal product of capital is constant which prohibits the working of diminishing marginal returns to the factors. The MPK = APK = A > 0 and dMPK/dK = 0, not ≤ 0. Since, L is fixed, hence, per capita growth of income, y (y = Ak), will be equal to growth of level income, Y. Note the production function does not allow technological progress. The equilibrium growth rate in the long run can be determined by some basic relations that we had considered under the neoclassical framework. They are as follows-

S = sY

dK= I – (n + δ)K

S = I at equilibrium in a simple economic system without public sector and international flow of goods and services.

Making necessary substitutions we get the following-

dK = sY - (n + δ)K

or, dK = sAK - (n + δ)K

or, dK/K = sA - (n + δ)……….

On the other hand, in per capita terms, the growth equation becomes

dk/k = sA - (n + δ) …………..

Hence there is no difference in considering the steady state growth rates of level variable and per capita variable. It is also to note that dK/k = dY/Y = sA - (n + δ). Hence, as long as sA> (n + δ) then there will be perpetual growth of all the variables, either in level or per capita terms, in the long run which is a strong claim of the endogenous growth theoreticians against the neoclassical growth model. Figure discusses the AK model and its growth phenomenon.

Figure . The AK model



The figure shows that the positive difference between sA and (n + δ) can be maintained even there is no technological progress. Hence, the AK type production function allows the growth to be endogenous in place of exogenous.

We can analyze the parametric effects of savings rate, level of technological progress, population growth rate and depreciation. Unlike the Solow-Swan model, an increase in the savings rate in the AK type production function have permanent growth effect upon per capita growth rate and the over savings in this model is not inefficient. Similarly, improvement of technology can make positive growth rates of per capita income. On the other hand, increase in population growth rate and depreciation make permanent decrease in the growth rates of per capita income and the reverse happens for decrease in population growth supported by effective population policy and maintenance of capital to avoid depreciation.

As the effects of parameters are permanent and the working of diminishing returns to capital is absent in AK type production function, the prediction of the neoclassical model with regard to absolute convergence across the economies does not make sense, rather there may be convergence in conditional sense.

**Growth under Endogenous Technological Progress**

This is the second possibility, as we have already mentioned in the preceding section, of making the growth rates endogenous. Given the diminishing returns to the factors, an economy can grow in the long run uninterruptedly if the technological progress is continuously done in endogenous way. There has been a wide literature on various possibilities of making technological progress endogenous. They are of Arrow’s (1962) *learning by doing* or *experience* factor, in taking investment or production decisions. Later Romer (1986) used this concept and reoriented the effect into knowledge capital which has a spillover effect across the firms and economies and allows the working of increasing returns to factor (i.e. external economies of scale) that guards the diminishing returns and allows permanent growth of per capita capital and output. Lucas (1988) introduced the concept of human capital into the production function and there is no end to improving quality of human, there is the possibility of endless growth rates in the long run.Barro (1990) on the other development of the growth theory, captured the effect of government as institution in assisting the rest of the economy to grow in an indefinite term. In the following discussion we will highlight the basic structures of two models of endogenous growth one by one as of Romer and Barro.

**Romer model**

Important assumptions under the Arrow and Romer model of growth are as following.

1. There are many firms in a market.

2. Knowledge or technological advance is a non-rival good.

3. There are increasing returns to scale to all factors taken together and constant returns to a single factor, at least for one.

4. Technological advance comes from things people do. This means that technological advance is based on the creation of new ideas.

5. Many individuals and firms have market power and earn profits from their discoveries. This assumption arises from increasing returns to scale in production that leads to imperfect competition.

Romer in his seminal work on endogenous growth in 1986 presented a variant on Arrow’s model which is known as learning by investment. He assumes creation of knowledge as a side product of investment.Romer took three key elements in his model, namely externalities, increasing returns in the production of output and diminishing returns in the production of new knowledge. According to Romer, it is spillovers from research efforts by a firm that leads to the creation of new knowledge by other firms. In other words, new research technology by a firm spills-over instantly across the entire economy or knowledge has the public property with non excludability and non rivalry.In his model, new knowledge is the ultimate determinant of long-run growth which is determined by investment in research technology. Research technology exhibits diminishing returns which means that investments in research technology will not double knowledge.

Let us discuss the formal model of Romer in line with Arrow’s learning by doing factor.

Suppose the production function of the ith firm is

Yi = AKiαLi1-α

where A is the level of technology which determines the total factor productivity (TFP) which depends on stock of capital. The higher the capital stock the more the economy is able to use new technologies. Thus the progress of technology under Romer model is determined by the accumulation of capital. The capital to technology transformation may be given by the following relation-

A = BK1-*α*

where K is the aggregate level of capital stock and B is the learning by doing factor which generates the positive externality effect to others. That means, dA/dK = B. (1-α)/Kα> 0 for 0< α <1. Assuming symmetry across firms and substituting this relation into the production function, we get the aggregate production function as follows-

Y = BKL1-α

Further assuming that labour force, L, equivalent to population is constant and normalized into 1, we get the aggregate production function as,

Y = BK

This production function is characterized by constant return to scale and looks like the AK type production function. This means marginal productivity of capital is constant and equal to the average productivity of capital and is equal to B (dY/dK = Y/K = B).

The basic rule of capital accumulation is recalled as

dK = s.Y – δK

or, dK = s. BK - δK

where δ is the rate of depreciation of capital. The growth of population is zero as L = 1. Hence the growth rate of capital can be written as

dK/K = s.B – δ

This is the basic growth equation in Romer model. Rate of growth of capital (dK/K) will be positive in the long run as long as s.B> δ. Hence, dK/K = dY/Y = B. That means, given the value of s and δ, positive growth of capital and output is possible under a positive accumulation of knowledge driven by learning by doing.

Now the rate of growth of technology under the Romer model is given by (follows from the equation, A = BK1-*α*)

dA/A = (1-α). dK/K = (1 – α). (s.B. – δ)

The expression gives that the rate of growth of technology depends on the rate of growth of capital. At the same time technology affects capital. This means, growth is an endogenous process without any transitional dynamics. This further establishes that an increase in savings leads to increase the growth rate of per capita capital and income permanently. This is a strong departure from the neoclassical model’s conclusion of temporary growth of per capita income because of exogenous technological progress and savings rate. The effect of diminishing returns to the factors under the Solow-Swan model gets replaced by constant returns to the variable factor in a system of increasing returns to scale in a total production system.

**Barro Growth Model**

Like the learning by doing approach or knowledge spill over model, Barro (1990) developed the increasing returns to scale in the overall production system by introducing the public sector that is capable of endogenizing the technological progress and thereby explaining the increasing growth of capital and output per capita in the long run. In the Barro model public spending goes for public investment (infrastructures, schools, sanitation, institutional facilities, good governance, etc.). Public investments, which are financed through income taxes, complement private investments so that there are crowding-in effects of this public investment and thereby promoting growth of output. Since public investments raise the productivity of private investments, higher taxes can be associated with an increase or a decrease in overall growth. If government expenditure is kept fixed and there are constant returns to scale in L and K, then the working of diminishing returns to the factors cannot be barred. If we allow government expenditure as variable in accumulation of capital, then the working of diminishing returns will no longer be there and the economy is capable of producing endogenous growth like the simple AK type model.

The model of Barro adds public spending to the AK model. Suppose the production function is like the following-

Y = AL1-α. Kα. G1-α

where G stands for the public expenditure on goods and services. The production function exhibits increasing returns to scale (IRS). Suppose increase all the factors by λ proportion then new output is

A.(λL)1-α. (λK)α. (λG)1-α = λ2-α. AL1-α. Kα. G1-α =λ2-α. Y

Since 0<α<1, 2-α >1 and hence new output after introduction of government sector is greater than the scale effect. Hence, IRS is working and there is possibility of making increasing growth rates of income over time.

Suppose the production function in the Barro model is

Y = BK1-αGα

where BK1-α is technological progress, A, determined by the accumulation of capital. Public expenditure, G, depends on the amount of revenue generated through income tax, υ.Y, where ‘υ’ represents rate of income tax with 0 <υ< 1. Hence, public expenditure function is

G = υ.Y

To determine the long run growth rate of capital and income, we first determine the value of B. To get this let us substitute the government expenditure function into the production function which gives the following:

Y = BK1-α (υ.Y) α

Or, Y 1-α = B υ α. K1-α

Or, Y = B 1/1-α .υ α/1-α. K

Or, Y = D.K

where D = B 1/1-α .υ α/1-α

The marginal productivity of capital with given government expenditure and population is dY/dK = D = constant, not diminishing. Hence, there is the possibility of scale effect and getting output growth to be positive.

Now recall the rule of capital which is as follows-

dK = I – δK

or, dK = s .(1-υ).Y – δK

After substitution of the expression of Y from above we get

dK = s. (1-υ). D.K - δK

or, dK = s. (1-υ). B 1/1-α .υ α/1-α. K – δK

or, dK/K = s. (1-υ). B 1/1-α .υ α/1-α – δ

or, dK/K = s. (1-υ). D – δ

Now the rate of growth will be positive as long as s. (1-υ). D > δ. Therefore, introduction of public expenditure in developmental projects makes the positive growth of income and consumption in place of zero growth results under the neoclassical growth model. Hence, public sector makes the technological progress to be endogenous.











