M. A. ECONOMICS

COURSE NO. : ECO 302

SEMESTER III

PART II

TECHNICAL PROGRESS AND ARROW'S MODEL OF LEARNING BY DOING

11.1 INTRODUCTION

A growing economy needs an increase in output, income and employment. But when the resources are fully employed, it is difficult to achieve the target of ever growing economy under the given state of art as we know that for a constant technology, diminishing returns to scale are applicable which lead to lower subsequent increments in total output as the units of inputs increase. Consequently, the economy reaches the stationary state. However, the working of diminishing returns can be postponed if not avoided completely, if technology changes. Improvements in technology enhance productivity and therefore, are considered the key to economic growth. Hence, a growing economy not only needs more of capital but also a continuous flow of new knowledge to enhance its productivity, employment, income and hence the standard of living of its citizens.

11.2 OBJECTIVES

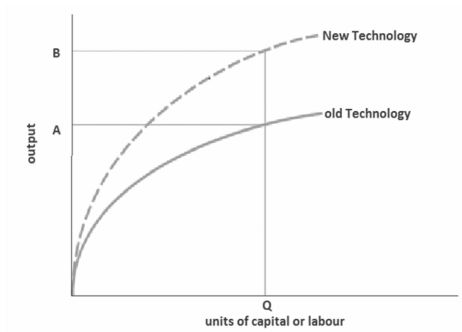
This lesson has the following objectives:

1. To know about the meaning of technical progress
2. To know about the types of technical progress
3. To examine the impact of technical progress
4. To analyse the impact of learning on productivity of factors.
5. To analyse the impact of learning by doing on aggregate production of any economy.

11.3 MEANING OF TECHNICAL PROGRESS

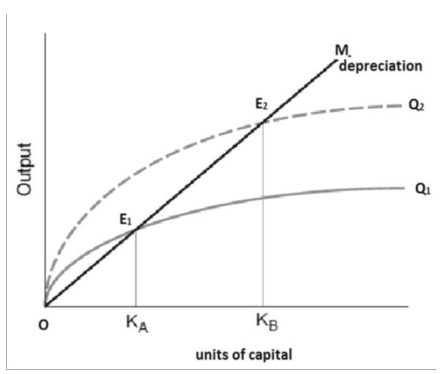
Technology is a complex set of knowledge, ideas and methods and is likely to be the result of various accidental as well as intentional activities aiming at doing things in a better way. A production function shows the functional relationship between the inputs and output. An improvement in technology yields greater output from the same quantity of inputs. Therefore, technical progress is defined as new and better ways of doing things and using the resources more productively. Technical progress, thus, shifts the production function in upward direction. This can be observed from the figure 1.

Figure 1: Technical Progress



The figure shows that for OQ units of capital or labour the old technology gave OA output while the new technology produces OB output with same amount of inputs i.e. OQ. The shift in production curve and consequent rise in output for same level of inputs is termed as technical progress. The shift in production curve also shows that with technical progress now the economy achieves the steady state at a higher level of output. As we have already learnt in the neo classical models of economic growth that a steady state is the level of output and employment and investment from where the economy is not interested in moving in either direction. This is the unvarying state where the economy is in stable equilibrium. But with technical progress the economy moves to a steady state at a higher level of output. This can be understood with help of figure 2.

Figure 2: Steady State Equilibrium with Technical Progress



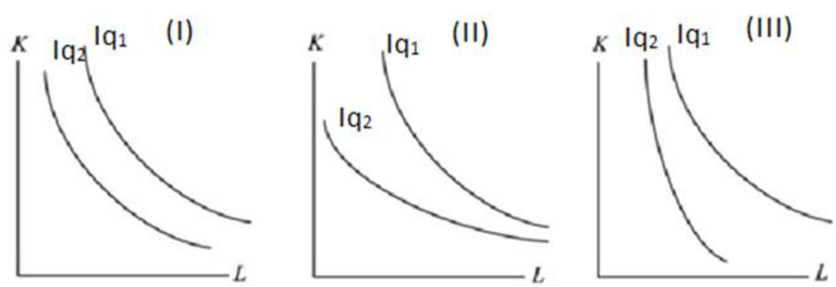
In figure 2, OQ1 is the original output curve and OM is the depreciation curve which is a straight line through the origin showing a constant rate of depreciation. Originally, the steady state equilibrium is achieved at E_1 with output K_AE_1 by using capital K_A but with technical progress, the output curve shifts to OQ_2 and new point of equilibrium is achieved at E_2 at higher level of output i.e. E_2K_B.

11.4 TYPES OF TECHNICAL CHANGE:

In economic theory technical change is classified on basis of its spread or nature and on basis of its presence or embodiment. On basis of former category, economic theory identifies technical change as neutral or non-neutral technical change while the latter categories identifies the technical change as embodied and disembodied technical change. These types are discussed below:

11.4.1 Neutral and Non-Neutral Technical Change: We have observed that technical change means increase in productivity of the factors that lead to an upward shift of the production possibility curve or the output curve for same amount of inputs. This may also lead to a downward shift in the isoquants showing same level of output even at a lower isoquant. But shifts in isoquants may be parallel or non-parallel; the upward shift in the output curve may or may not change the factor proportions after technical progress. The nature of this shift in the output curve or the isoquants defines the nature of the technical progress. The type of technical progress can be observed from figure 3.

Figure 3: The Nature of Technical Progress



In figure 3, we have three different types of shifts in the iso-quants. Part I of the figure shows neutral progress while part II and III seem to be capital saving and labour saving, respectively, and therefore can be termed as non-neutral. Hicks states that a technical change is neutral if if it leaves the ratio of marginal products of capital to that of labour unchanged even after technical change. On the other hand, Solow says that technical progress leads to improvement in productivity of capital and therefore capital augmenting while for Harrod increase in output after technical progress is actually due to increase in output per head and it is therefore labour augmenting. Taking 'Y' as the level of output or income, K and L units of capital and labour and 'A' as the efficiency parameter showing the level of technical progress at a given point of time. We can understand the different versions of neutral technical progress in the following functional forms:

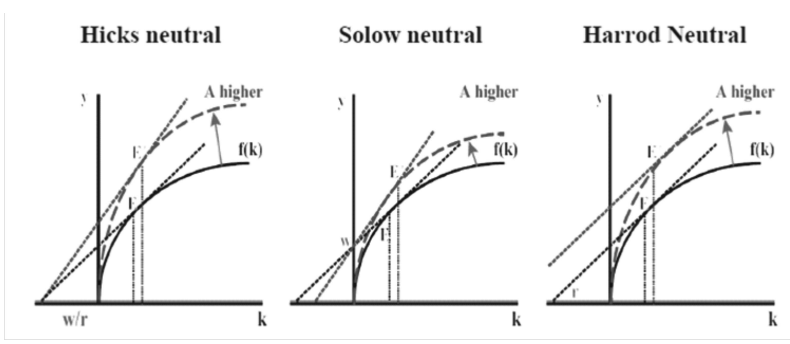
1. The technical progress is Hicks neutral if Y=A.f(K, L) i.e. whole of the output increases by 'A' times after technical progress and therefore, the ratio of marginal productivity of capital to labour remains constant.

2. The technical progress is Solow neutral if after technical progress, the production function takes the form Y= f(A.K, L) showing a capital augmenting technical progress. It also means that the marginal productivity of capital increases while that of labour remains constant leading to an increase in 'r' while 'w' remains constant. Here, 'r' is the rate of return to capital and 'w' is the wage rate which are respectively equal to the marginal product of capital and labour.

3. The technical progress is Harrod neutral if the production function after technical progress takes the form Y= f(K, A.L) showing a labour augmenting technical progress. In this case, 'r' remains constant while 'w' rises.

These different types of neutral technical progress can also be observed from figure 4. In the figure, Y-axis show output per worker while the right side of the X-axis show capital per worker and the left side shows the ratio of wages (w) to the rate of return (r). The ratio w/r is actually measured through the slope of the tangent drawn to the production function which is expressed in terms of capital per worker i.e. f(k). The change in size of the angle shows the change in ratio w/ r. In this figure the dotted line shows production function after technical progress which is shown as a higher value of efficiency parameter i.e. 'A'. In case of Hicks neutrality, we can observe that the slope of the tangent to the output curve f(k) remains the same before and after technical progress while the output increases from point F to point E and since the ratio of marginal productivity of labour and capital, shown here as w/r remains constant, therefore, it is termed as Hicks neutral. In the second part of this figure, we can observe that after technical progress, the shift in slope of the tangent shows that the ratio w/r has declined as the marginal productivity of capital has increased while that of labour remained constant showing Solow neutrality in which technical progress is capital augmenting. Lastly, in case of Harrod neutral technical progress, the production function shifts in such a way that the marginal productivity of capital remains constant while that of labour rises. In the figure the parallel shift of the tangent line shows that at higher level of output, the marginal productivity of capital has remained constant. Thus, the capital output ratio will remain constant for a constant rate of profit in case of Harrod neutrality.

Figure 4: Neutral Technical Progress



11.4.2 Disembodied and Embodied Technical Change : A technical change is considered to be disembodied when it takes the form of new procedures or techniques for producing goods and services. This may also be defined as purely organizational change which permits more output to be produced from unchanged inputs. Thus, the disembodied technical progress shifts the production curve upwards without disturbing the ratio of capital and labour. Therefore, in a production function, this is considered as an exogenous factor which is expressed as below:

$$Q=F(K,\ L;\ t)$$

Here, Q refers to the level of output while K and L stand for units of capital and labour. The disembodied technical progress is strictly Hicks-neutral and therefore, can be written as

$$Q=A(t).f(K,\ L)$$

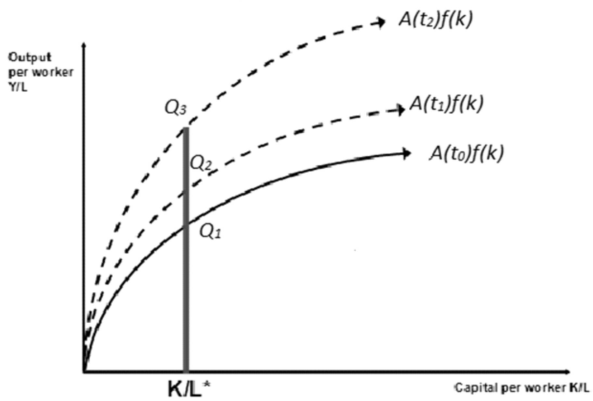
Where, A(t) is the index of technical progress. This equation can also be written in per capita terms.

$$\frac{Q}{L}=A(t).f\left(\frac{K}{L},1\right)$$

$$q\ =\ A(t).f(k)$$

In figure 5, we can observe the change in output due to technical progress with given capital-labour ratio. The figure shows that with technical progress between period 0 to 1, the production function shifts from $A(t_0)f(k)$ to $A(t_1)f(k)$ and in time period '2' it further shifts to $A(t_2)f(k)$. On each level of technical progress, we can observe that the level of output increases from OQ_1 to OQ_2 and further increases to OQ_3 for same capital labour ratio i.e. K/L* in t_0, t_1 and t_2 time periods. Since the capital labour ratio has been constant, therefore whole of the change can be assigned to technical progress and it would be termed as disembodied technical progress just because, it has not altered the factor proportions.

Figure 5: Disembodied Technical Progress



The disembodied technological progress can be taken as a residual function as suggested by Solow. Assuming a Cobb-Douglas type production function which exhibits constant returns to scale, the contribution of technological progress to total output can be measured by deducting the contribution of labour and capital from total change in output. The production function can be written as

$$Q\text{-}AK^{\alpha}K^{1-\alpha}$$

$$\log Q = \log A + \alpha.\log \mathrm{K} + (1\text{-}\alpha) \text{ Log } L$$

Deriving the total derivative of this equation

$$\frac{1}{Q}.\frac{dQ}{dt}=\frac{d}{dt}(\log A)+\alpha\frac{dK}{dt}.\frac{\partial Q}{\partial K}+(1-\alpha)\frac{dL}{dt}.\frac{\partial Q}{\partial L}$$

$$\frac{Q}{Q}=\frac{A}{A}+\alpha.\frac{K}{K}+(1-\alpha)\frac{L}{L}$$

Where, $\dot{Q}, \dot{A}, \dot{K}, \dot{L}$ and are respectively time derivatives of output, technology, capital stock and labour. The change in total output due to technological change can be found as follows:

$$\frac{\dot{A}}{A} = \frac{Q}{Q} - \left[\alpha.\frac{\dot{K}}{K} + (1-\alpha)\frac{\dot{L}}{L}\right]$$

This residual approach, however is criticized on the ground that it ignores the fact that any technical change have an important influence upon the productivity of labour as well as capital and it can not be separated from the other factors. Moreover, the assumption of constant returns to scale in an economy with technical progress is also equally unrealistic. The embodied technical change is therefore, considered more realistic phenomenon in economic theory. It assumes that the technical change is embodied in the form of capital itself. Therefore, technical progress is related with new machinery only and it has no impact on the productivity of the existing or old machinery. The embodied technical progress is recognized as advances in design and quality of new vintages of capital goods and intermediate inputs. The new technologies are embodied in new machines and therefore, the introduction of new technology coincides with the introduction of new machines or equipment. Thus, the machines of different vintage will have different productivity levels and they need to be included as different production functions. Assuming that the technical progress grows at a constant rate and is uniformly spread, new technology will be more productive than the old or existing one and the production function is linearly homogeneous. The production function with embodied technical change is given below:

$$Qv(t) = Be^{\lambda}Lv(t)^{\alpha}Kv(t)^{1-\alpha} \quad \text{----------------(1)}$$

Here, B^{λ}_{e} shows the level of technical progress which grows exponentially at rate 'λ'; Lv(t) shows employment of labour on machines of different vintage while Kv(t) shows the units of capital employed on machines of different vintage available at time 't'. It must be kept in mind that $t \geq v$. Further, α and 1- α show the output elasticities of labour and capital, respectively. Solow has shown the total investment in 't' time period as the I(v). He further states that as the capital depreciates at a constant rate 'δ', therefore the average age of the machinery is 1/ δ. In this respect, total investment in capital stock of different vintages is given below:

$$Kv(t) = I(v)e^{-\delta(t-v)} \text{ ----------------(2)}$$

At each point of time, we have capital of different vintages operating in the production sector of the economy and the life time and productivity at each point of time would depend upon its rate of depreciation. However, the older a machinery is, the lower will be its capacity to employ additional workforce. But, as this model works in the framework of perfect competition, the wages all across the economy would be same and would not be influenced by the vintage of the machinery. However, under embodied technical progress, the productivity of the labour will be different on machinery with different vintages. In each production sector, the employer will employ the workers up to the point where the wages are equal to the marginal productivity of labour i.e.

$$\mathrm{W(t)} = \frac{\partial Qv(t)}{\partial Lv(t)} = \alpha.\beta e^{\lambda v} Lv\ (t)^{\alpha-1}\ Kv(\mathrm{t})^{1-\alpha} \quad \text{-----------(3)}$$

$$Lv\ (t)^{\alpha-1}\ \frac{W(t)}{\alpha.\beta e^{\lambda v} Kv(t)^{1-\alpha}} = \frac{W(t)}{\alpha.\beta e^{\lambda v}[Iv(t)^{-\delta(1-v)}]^{1-\alpha}}$$

This equation can be further simplified as

$$\mathrm{L}v(t) = \mathrm{H}(t).\mathrm{e}^{\sigma \mathrm{v}}\ .\mathrm{I}(v) \quad \text{----------(4)}$$

Where, $\mathrm{H}(t) = \mathrm{W}(t)\dfrac{1}{\alpha-1}(\alpha\beta)\dfrac{1}{1-\alpha}.\mathrm{e}^{-\delta \mathrm{t}}$ and $\sigma = \delta + \dfrac{\lambda}{1-\alpha}$

Putting the value of Lv(t) from equation (4) and Kv(t) from equation (2) in equation (1), we get

$$Qv\ (t) = Be^{\ -\delta(1-\alpha)t} H\ (t)^{\alpha}.e^{\sigma v}.\ I(v)$$

Since, in the national economy as a whole, we have different machines with different vintages across different sectors of the economy, therefore, the output in the country is sum total of output from all the machines with different vintages available at 't' time period. Hence, the output function becomes $Qv\ (t) = Be^{-\delta(1-\alpha)t} H\ (t)^{\alpha}.\ \int_{-\infty}^{t} e^{\sigma v}.I(v),dv$ and if we substitute $\int_{-\infty}^{t} e^{\sigma v}.I(v),dv = J\ (t)$, then the total production in the economy turns out to be

$$Qv\ (t) = Be^{-\delta(1-\alpha)t} H\ (t)^{\alpha}.\ J(t)$$

Solow calls this 'J' as effective capital stock which is weighted total of the machines of different vintages in terms of their productivity in which greater weight is assigned to new machines while a lower weight is assigned to older machines. In his further research, Solow has proved that greater is the speed of technical progress, higher would be the productivity and any increments in investment would lead to increase in income at an increasing rate.

11.5 ARROW'S THEOREM OF LEARNING BY DOING

Learning-by-doing process is also a potential source of economic growth because experience causes per-worker output to rise. Individual firms and industries also learn from their own and competitor's experiences. But whenever, a new process, which is an outcome of the continuous learning, starts, further production of old products diminishes, even though initially costs may be higher when new products are introduced. Eventually, learning by doing reduces cost below those of the previous production run, and across all firms and industries, economy wide learning by doing, combined with continued introduction of new products and process, reduces unit costs over time. Arrow (1962) gave the idea of learning by doing and stated that knowledge is an unintended by-product of production or investment and experience raises labour productivity over time. Arrow's particular assumption is that technological change grows out of experience, and cumulated experience is measured by cumulated gross investment. At any given level of technology there are fixed coefficients in the production of aggregate output from labour and existing capital goods. If $m(Y)$ represents the fixed amount of labour with a unit of capital with a serial number 'Y' and cumulative gross investment is Y. Further, $n(Y)$ is the capacity embodied in a unit of capital with a serial number 'Y', then the fixed coefficient technology implies at each point of time

$$Q_t = \int_{Y'_t}^{Y_t} n(Y).dY$$

$$X_t = \int_{Y'_t}^{Y_t} m(Y).dY$$

Where Y'_t is the serial number of the oldest capacity actually in use at time t. Taking M and N as the indefinite integrals of m and n, which are both positive and strictly increasing, then Q_t and X_t actually show the addition to capital and labour stock during the whole span of time ranging from Y'_t to Yt and therefore can also be rewritten as

$$N(Y) = \int n(Y).dY$$

and,

$$M(Y) = \int m(Y).dY$$

further, $Q_t = N(Y) - N(Y')$

and, $X_t = M(Y) - M(Y')$

Solving for Y' $\quad Y' = M^{-1}[M(Y) - X(t)]$

one can eliminate Y' by putting its value obtained above in Q_t to get

$$Q_t = N(Y) - N\{M^{-1}[M(Y)-X(t)]\}$$

This can serve as a sort of aggregate production function. Arrow calls it as a novel one because its arguments are current labour input and cumulative gross investment, including some capital goods no longer surviving. Arrow further states that under the situation of full employment with constant growth of capital stock, the aggregate production and productivity per factor increases along with increasing productivity of the labour who learns through the long process of using the machinery from time period Y' to Y. Thus, according to Arrow, technical progress is labour augmenting but its augmentation depends upon cumulative gross investment. After solving a number of equations in Arrow's model, he reached to the following equation showing the impact of capital accumulation as well as labour augmenting effect on aggregate production in the following way.

$$Q = nY(1 - e^{-x/m})$$

Above equation has actually been derived with constant learning curve. We can easily observe increasing returns to scale in this equation as X and Y are ever increasing. This is obvious in above equation that an increase in Y even with constant X, leads to proportionate increase in Q and a simultaneous increase in X will increase the aggregate output further. If the learning curve is taken as declining or increasing, above equation will show multiplier times increase in Q for any increases in X and Y and in each subsequent time periods X can be used more efficiently than the earlier ones. Finally, Arrow also clarified that the increasing returns will not lead to any difficulty with distribution theory as both capital and labour will be paid according to their marginal products, yet, the private marginal product of capital would be less than the social marginal productivity as the learning effect is not compensated in the market. Thus, this model has considered the growth of labour force not only in terms of quantitative but also qualitative increase. Further, it also puts forth the idea that learning takes place only as a by-product of ordinary production. In fact any society always create institutions, education and research whose purpose is to enable learning to take place more rapidly.

11.6 SUMMARY AND CONCLUSION

The classical economic thought has been based upon the assumption of full employment of the resources which lead the economy to a stationary state under the given technology. However, the improvements in technology are as good as increase in availability of the resources because technical progress shifts the output curve in upward direction. Further, we have discussed that the technical progress can be neutral or non-neutral, it can also be embodied or disembodied. The embodiment of the technical progress has attracted attention of many modern theorists. We have discussed here the contribution by Arrow who states that as people involve themselves in the production process, they gradually find new ways of doing things in a better ways. The learning process is another form of embodied technical progress and it results in to increasing returns to scale, without disturbing the distribution process of the economy. However, the process of learning and the spillover effects of the technical change largely depends upon the spread and quality of existing institutions that promote education, research and its dissemination and these factors are not given due importance in Arrow's model of 'learning by doing' as it is based upon the assumption of perfect information and mobility which is somewhat an impractical assumption, particularly for the developing economies which generally suffer from structural rigidities. Still, Arrow's theorem was a landmark which provided a strong base for the subsequent developments in economic theory, particularly for endogenous growth models.

11.7 GLOSSARY

(i) Constant, increasing and diminishing returns to scale : The returns to scale are constant, diminishing or increasing if the change in output is respectively, equi-proportional, less than proportional and more than proportional change in inputs.

(ii) Iso-quant : An iso-quant is also termed as the iso-product curve. This is defined as a curve whose each point indicates same level of output of a particular commodity by using different combinations of factor inputs. A higher iso-quant shows a higher level of output.

(iii) Neutral and non-neutral technical change : Technical change is "neutral" when it raises the productivity of all factors inputs in production (e.g., capital and different types of labour) by the same proportion. It is non-neutral when it raises the productivity of some factors more than others.

(iv) Production possibility curve : The production possibility curve is also termed as production possibility frontier. It depicts the maximum capacity of an economy to produce a combination of two commodities with given set of inputs. A downward sloping and concave (towards origin) in shape shows that any point lying on this curve means full capacity utilisation of the given resources while a point lying below the curve shows under utilisation of the full capacity of given inputs while a point above the production possibility curve is unachievable with given inputs and given capacities. However, the technical progress may shift the production possibility frontier in upward direction showing increase in the capacity of the economy to produce with given inputs.

(v) Vintage : In the present lesson, the term vintage is used for the time when a particular machinery was made. Since older machineries are assumed to be less productive than the newer ones, therefore, vintage of a machinery can also be taken as an index of the productivity of different capital stocks.

11.8 SHORT ANSWER TYPE QUESTION

Q 1. What do you mean by technical progress?

Ans. Technical progress is defined as new and better ways of doing things and using the resources more productively. Technical progress, thus, shifts the production function in upward direction.

Q 2. What do mean by steady state?

Ans. A steady state is the level of output and employment and investment from where the economy is not interested in moving in either direction. This is the unvarying state where the economy is in stable equilibrium.

Q 3. Define neutral and non-neutral technical progress.

Ans. In simple terms if technical progress increases the productivity of all the factors of production in the same proportion, the technical progress is assumed to be neutral while a technical progress increasing the productivity of one factor at a higher rate than the other one would be termed as non-neutral technical progress. A non-neutral technical progress can be labour saving or capital saving.

Q 4. Differentiate between disembodied and embodied technical progress.

Ans. A technical change is considered to be disembodied when it takes the form of new procedures or techniques for producing goods and services. This may also be defined as purely organizational change which permits more output to be produced from unchanged inputs. Thus, the disembodied technical progress shifts the production curve upwards without disturbing the ratio of capital and labour. Therefore, in a production function, this is considered as an exogenous factor. On the other hand, the embodied technical progress assumes that technical progress is related with new machinery only and it has no impact on the productivity of the existing or old machinery. The embodied technical progress is recognized as advances in design and quality of new vintages of capital goods and intermediate inputs. The new technologies are embodied in new machines and therefore, the introduction of new technology coincides with the introduction of new machines or equipment. Thus, the machines of different vintage will have different productivity levels and they need to be included as different production functions.

11.9 EXAMINATION ORIENTED QUESTIONS

1. What do you mean by technical progress? Elaborate the neutral and non-neutral technical progress.
2. Discuss the basic models of disembodied and embodied technical change.
3. Critically analyse Arrow's theory of 'Learning by Doing'.

11.10 SUGGESTED READINGS

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11.12 MODEL TEST PAPER

I. Answer the following in brief.

Q 1. What do you mean by technical progress?

Q 2. What do mean by steady state?

Q 3. Define neutral and non-neutral technical progress.

Q 4. Differentiate between disembodied and embodied technical progress.

II. Answer the following in detail

1. What do you mean by technical progress? Elaborate the neutral and non-neutral technical progress.
2. Discuss the basic models of disembodied and embodied technical change.
3. Critically analyse Arrow’s theory of ‘Learning by Doing’.

MODELS OF ENDOGENOUS GROWTH

12.1 INTRODUCTION

In majority of the neo-classical growth models, technical change is considered as an exogenous factor, though it is an important driver to growth. However, Kaldor and Arrow proposed the idea of technology having some endogenous component as well. Further, the Solow Model which is largely based on the idea of residual effect of technical change and that in the long run, the economies move on the stagnant growth path was challenged on several grounds e.g. its unrealistic result for exogenous technical progress accounting for more than 70 per cent of output growth; prediction of convergence among poor and rich economies in the long run; failure to explain widened growth disparities and long run imbalances in factor productivities etc. These shortcomings lead to the birth of endogenous growth theory, which has been formally developed since mid-1980s following the pivotal works by Romer (1986, 1990) and Lucas (1988) and which has soon become the dominant framework for studying economic growth and development. One of the main reasons why economists have grown interested in endogenous growth is because of an empirical puzzle. The neo-classical model predicts that countries with low per-capita incomes grow faster than those with high income, so that over time per-capita incomes converge. But a broader set of data indicated that the rich countries may follow an ever increasing growth path while the poor economies move on at much slower pace leading to divergence among these economies. It is also found that even the same type of technology and rate of investment may not lead to similar results across the economies. This has also been found that even the same level of foreign direct investment may lead to different results in different economies with different human and physical capital. Thus, it is important to find some endogenous factors that determine the rate of growth of the economies.

12.2 OBJECTIVES

This lesson has the following objectives:

1. To understand the weaknesses of neo-classical growth models.
2. To know the meaning of endogenous growth.
3. To understand the impact of technological spillovers on the aggregate production function of the economy.
4. To understand the role of human capital on economic growth of any economy.
5. To examine the limitations of the basic models of endogenous growth.

12.3 ENDOGENOUS GROWTH MODELS: AN INTRODUCTION

The endogenous growth models in contrast to the exogenous growth models believe that the growth of the economy is more influenced by the internal processes and policies, structure etc. than merely the external factors. Endogenous growth is long-run economic growth at a rate determined by forces that are internal to the economic system, that govern 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) assumed 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. The firms may 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. The spread of this knowledge and consequently, the macroeconomic effects of any technical progress depend upon the spillover effects that again depend upon the level of human capital in the society. Here lies the important difference between the endogenous growth theories and the neo-classical growth theories which take technical progress as exogenous factors. In this context, we can discuss here, the basic models of endogenous growth given by Romer and Lucas.

12.3.1 Romer's Model : This model challenges the basic assumption of neo-classical model of growth which refers to applicability of diminishing returns in the long run. This model states that many economies have been able to exhibit increasing returns to scale even in the long run. This long run increase in per capita income has been possible not due to the external factors but due to the endogenous technical changes. Any change in technology leads to positive effects on productivity of the factors whose combined effect may lead to increasing returns. Romer has discussed about the spillover effects of technical change. He states that a technical change, any innovation, new method of doing things do not remain with one individual only. He stresses that the physical part of any new technology may be privately owned but the knowledge part soon becomes a public good. Since, production is a social phenomenon, any new method used in a production unit soon spreads to another units as under perfect markets, the factors are perfectly mobile and they carry their knowledge along with them. A highly productive factor in a production unit not only himself/herself higher level of productivity but also raises the level of productivity of his fellow beings in the production unit. Thus any investment in new knowledge, research and development or human capital may have greater social returns as compared to its private returns. As a result the national output would be increasing at an increasing rate and new unit of human capital investment will yield increasing rate of return. In the simple framework of Romer's model, we take a single sector Cobb-Douglas type production function which has inherent assumptions of homogenous sectors and applicability of constant returns to scale. But in order to include the spillover effects of technology on aggregate production of the economy, it includes a separate variable of human capital. Therefore, the production function in Romer's model can be read as follows:

$$Y=A.K^{\alpha}.L^{1-\alpha}\ .K^{\beta}$$

Here, 'A' is the efficiency parameter of given level of technology, 'L' stands for units of labour, 'K' for units of capital which is presented here both as the physical as well as human capital. 'Y' is the level of output and

α and β are the output elasticies of the respective variables. Above equation can also be written as

$$Y = A.K^{\alpha+\beta}.L^{1-\alpha} \qquad \text{.................(1)}$$

At any point of time, the change in output would be possible only due to change in physical as well as human capital and units of labour along with the changes in factor productivity, therefore,

$$\frac{dy}{dt} = \frac{\partial Y}{\partial K}.\frac{\partial K}{\partial t} + \frac{\partial Y}{\partial L}.\frac{\partial L}{\partial t} \qquad \text{..........(2)}$$

The value of different components of this equation can be found by differentiating equation (1) partially with respect to ‘K’ and ‘L’ and if we further denote $\frac{dy}{dt}$ as ΔY, $\frac{\partial K}{\partial t}$ as ΔK and $\frac{\partial L}{\partial t}$ as ΔL, equation (2) takes the following form:

$$\frac{\Delta Y}{Y} = (\alpha+\beta)\frac{\Delta K}{K} + (1-\alpha)\frac{\Delta L}{L} \qquad \text{......(3)}$$

If both output and capital stock grow at the same and constant rate, then $\frac{\Delta Y}{Y} = \frac{\Delta K}{K} = g$ and since the growth of labour force depends upon the growth of population which grows at a natural rate determined exogenously, $\frac{\Delta L}{L} = n$, where, ‘n’ is natural growth rate of population, equation (3) can be rewritten as

$$g = (\alpha+\beta).g + (1-\alpha).n$$

or,
$$g - n = \frac{\beta.n}{1-(\alpha+\beta)}$$

here, g-n shows the growth of per capita income. In absence of any spillover effects of technological change, the constant returns to scale will be applicable and under such conditions since β=0, this will mean that g-n will also be equal to zero which indicates that in absence of spillover effects, the economy will not experience any growth in its per capital income and hence, the constant returns to scale will be applicable. However, in Romer's model all the factors viz. capital stock, labour and technology are assumed to be working together whose productivities mutually influence each other, the value of β will always be positive. Hence, if $\beta > 0$, the growth of per capita income will also be positive, therefore, g-n > 0. This is possible only due to the spillover effects of the technology within as well as across production units.

Although, this model has provided an important breakthrough, yet its applicability to the developing economies is questionable because many of the assumptions of this model find little validity in the developing economies e.g. the assumption of single sector economy may be unrealistic for the dual economies of the developing countries. Moreover, the developing countries largely face the problem of structural rigidities which are hardly mentioned by Romer. The analysis of these rigidities is very important in the context of the spillover effects of technology, research and development or any any type of knowledge across all production sectors of the economy. Due to these structural bottlenecks many a times the developing economies are found not to be using the full capacity of their available capital even though they fight with the problem of shortage of capital. Romer Model is silent about all such factors in the context of developing economies while these very factors actually lead to slower growth of the per capita income in these economies even though they are using the same technology as has been used by the developed economies. Romer's model is silent about the causes and effects of all such problems of the developing countries. Actually, the developing economies lack sufficient incentives to invest in physical as well as human capital. This has a great effect on supply of savings, capital formation and hence on growth of income. Besides, during the transition phase developing countries also undergo the process of reallocation of resources which are not generally efficient ones, particularly during the initial phase of the transition. This inefficient reallocation of resources at any point of time has medium as well as long term effects upon the growth of income of the ecomnomy. But all these factors have been ignored by Romer's model. Hence, the developing economies find little guidance from this model.

12.3.2 Lucas Model : Lucas' model of growth emphasises the importance of human capital in the growth of the economy. He states that it is difference in attainments of the human capital that has led to world wide economic disparities. Lucas states that the developed countries went through the process of industrial revolution long time back in the history of these economies. The incentive to earn more profits has led to invest in creation of knowledge so that the conditions of normal profits can be converted in to the long run capacity to earn supernormal profits. However, this process was hardly understood by the developing economies. This is their misconceptions or overindulgence in the idea of capital stock being the sole and most important determinant of economic growth that has led to wrong strategies and hence they were not able to experience the same level of growth as experienced by the economies which have experienced the epochs of industrial revolution. These misconceptions or little understanding of the importance of human capital has led to lower investments in human capital for a long time in these economies. Consequently, these economies have lagged much behind the developed economies who are growing at faster rate leading to divergence across the poor and rich economies of the world. Actually, the physical capital and human capital are not substitute to each other, they are rather essential complements of each other. Therefore, a greater investment in human capital also leads to greater productivity of the physical capital. In this framework Lucas model emphasises that the skilled workers and the new technology are inseparable from each other. In order to measure the effect of human capital accumulation on income, we can identify two separate components of total savings in an economy – these savings can be used for increase in physical capital stock and/or these savings can also be used for enhancing the level of human capital in the economy which will lead to an increase in productivity of labour as well as capital in future time period. To further elaborate the growth model given by Lucas, let us first look at the basic equation of this model. in this equation output is considered to be the function of physical as well as the human capital stock.

$$y = k^{\alpha} h^{1-\alpha} \qquad \ldots\ldots\ldots\ldots(1)$$

Here, 'h' stands for human capital and 'k' for physical capital. As discussed above, part of the savings are spent in accumulation of physical capital and its part is spent on accumulation of human capital. These two components of savings can be expressed in the following manner. Firstly, taking 's' as the part of savings being used for accumulation of physical capital i.e.

$$k(t+1) - k(t) = sy(t) \qquad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Secondly, the proportion of savings spent on accumulation of human capital can be expressed as

$$h(t+1) - h(t) = qy(t) \qquad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Thus, $sy(t)$ and $qy(t)$, respectively show the total amount of resources spent on accumulation of physical and human capital. For self-sustained growth of the economy, 'y', 'k' and 'h' should be growing at the same rate. The rate of economic growth actually depends upon the growth of investment in physical as well as human capital. Therefore, it is important to find the ratio of investment in human capital to that of physical capital. For this, we would have to find the growth of these two types of capital in an economy.

a). Growth of Physical Capital : The growth of physical capital can be derived from equation (2) by putting the value of $y(t)$ and also dividing both sides by $k(t)$. The resultant equation can be written as

$$\frac{k(t+1)-k(t)}{k(t)}=\frac{s.[k(t)^{\alpha}\left[h(t)\right]^{1-\alpha}}{k(t)}=S\left[\frac{h(t)}{k(t)}\right]^{1-\alpha}$$

If we take h(t)/k(t)=r, this equation can be written as

$$\frac{k(t+1)-k(t)}{k(t)}=sr^{1-\alpha}$$

Similarly, we can also derive the equation for growth of human capital

b). Growth of Human Capital :

$$\frac{h(t+1)-h(t)}{h(t)}=qr^{-\alpha}$$

Since, in the long period the growth of human capital as well as the physical capital are equal, therefore,

$$sr^{1-\alpha}=qr^{-\alpha} \quad \text{or} \quad r=\frac{q}{s}$$

This '*r*' can be used as long term growth rate and since in the long period, the growth of income, physical capital and human capital are the same, therefore,

$$\frac{y(t+1)-y(t)}{y(t)}=sr^{1-\alpha}=qr^{-\alpha}$$

$$=s^{\alpha}q^{1-\alpha}$$

Thus, the long term growth of the economy depends upon the rate of physical capital formation as well as human capital formation. It is the human capital which compensates the fall in growth of output due to applicability of diminishing returns on physical capital. The human capital investment, rather ensures increasing returns by its internal as well as external positive and output stimulating effects. The internal and external effects of human capital formation in any economy can be discussed as below.

(i) Internal Effects of Human Capital : According to Lucas, the total time of a human being, particularly a worker, can be divided in to two components – the time spent in production and the time spent in accumulation of human capital. If we denote the proportion of time spent in production as $\mu(h)$, then the time spent in accumulation of human capital will be 1- $\mu(h)$. In any economy, the size of the labour force as well as its productivity per hour significantly influences the level of output. Therefore, instead of having merely the size of the work force, Lucas has put forth the idea of 'effective labour force' which is shown as the product of size of the labour force and the time spent on producing goods and services for a given level of human capital.

$$N_e = \int_0^{\infty} \mu(h).N(h).dh$$

Here, $N(h)$ is the size of labour force and N_e is the effective labour force. Thus, we can express production as function of physical capital stock and effective labour force.

$$Y=f(K, N_e)$$

The level of human capital would not only have a macro economic impact upon the aggregate output of the economy but will also have accrue certain private benefits to the holders of the human capital as in a competitive market economy, wages are paid according to the marginal product of workers. Since, the workers with higher level of human capital are more productive, they would have higher earnings. Total wages in an economy for a given level of human capital can be calculated as follows:

Total wages = $f^{'}(K, N_e).h.\mu(h)$

Where, $f^{'}(K, N_e)$ shows the marginal productivity of labour.

(ii) **External Effects of Human Capital :** Increase in level of human capital formation in any economy, undoubtedly increase the level of productivity of a single worker but also have an overall effect upon the average productivity of the economy as a whole. Even a single worker with higher human capital in a production unit has huge ripple effects in the production unit. Same is true for the economy as a whole. But in a perfectly competitive economy, it is generally assumed that human capital of an individual would not affect the average level of human capital, yet its opposite is not true as average level of human capital in any economy determines the minimum target to be achieved by average workers to ensure their employability. Hence human capital investments and its attainments by the private individuals are largely determined by the average level of human capital for the country as a whole. This is termed as external effect of human capital. In order to know about the external effect of human capital, it is important to know about the average level of human capital which can be calculated as below.

$$h_a = \frac{\int_0^\infty h.N(h).dh}{\int_0^\infty N(h).dh}$$

Here, h_a is average level of human capital in a country. Now, we can easily adjust our production function by incorporating internal as well as external effect of human capital. First of all let us have production as function of capital and effective labour force.

$$Q = A.K^\beta(t)N_e^{1-\beta}(t)$$

Putting the value of N_e, we get

$$Q = A.K^\beta(t)[\mu(t).h(t).N(t)]^{1-\beta}$$

Incorporating the external effects of human capital or the average level of human capital for the society as a whole

$$Q = A.K^{\beta}(t)[\mu(t).h(t).N(t)]^{1-\beta}[h_a(t)]^{\tau}$$

Any increase in time for accumulation of human capital i.e. 1-$\mu(t)$ will raise the individual as well as the average level of human capital of the society which will have positive effects upon the level of output at an increasing rate. Thus, the economy would grow at a faster rate due to applicability of increasing returns to scale in the production sector. The change in human capital, which is the main force behind the faster growth of the economy, can be measured as

$$\hat{h}(t) = [h_a(t)]^{\tau}.G[1-\mu(t)]$$

here, G is the growth of human capital and it is always positive i.e. G > 0 but the existing level of human capital or say the knowledge, which the society has attained so far, will have diminishing returns to output, therefore, $\tau < 0$. In order to simplify the analysis if we simply assume τ =1, then the equation showing the change in human capital at any point of time can be shown as

$$\hat{h}(t) = [h_a(t)].G[1-\mu(t)]$$

We can discuss here two extreme cases, one is when whole of the time is spent in accumulation of human capital i.e. μ (t) = 0, and the second when whole of the time is spent in production only i.e. 1– μ (t) = 0 . In the first case, the change in human capital will be

$$\frac{\hat{h}(t)}{[h(t)]^{\tau}} = G$$

i.e. the economy can achieve the highest growth of human capital equal to G while in second case there will be no change in growth of human capital and it would be zero. In absence of any change in human capital, since diminishing returns to scale are applicable to the existing level of human capital, the economy will also grow at diminishing rate for any change in its inputs. But in real life, the value of $\mu(t)$ or that of 1-$\mu(t)$ varies between 0 and 1 which shows that the economy moves on a continuous growth path and the rate of growth of the economy will be higher for higher growth of human capital. This fact points towards the fact that the applicability of diminishing returns can be postponed by increasing investment in human capital. Thus, the economies with higher rate of growth of human capital experience a higher growth of income and the economies with lower investment in human capital will experience the lower growth of income, leading to divergence between the two types of the countries. Through this fact, Lucas pointed out that the the gap between growth of rich and poor economies can be explained by the gap in investments in human capital in these economies.

Finally, Lucas also differentiated between the optimum growth path and the equilibrium growth path. By optimal path he means that the society wants to maximise its utility function by achieving the optimal level of per capita income with an optimal combination of $K(t)$, $N(t)$, $c(t)$, $h(t)$ and $h_a(t)$. On the other hand, equilibrium path means that there is simultaneous equilibrium in all firms and households as well the economy as a whole. Assuming that $h_a(t)$ is exogenously determined and it is expected that each individual will follow the same path so that the actual behaviour coincides with the expected behaviour and there is no gap between demand and supply (i.e. AD = AS), for given physical and human capital stock. The solution will be achieved in both the cases if $h(t) = h_a(t)$. Any divergence between the two will mean the divergence from the equilibrium as well as the optimal growth path.

Like Romer's Model, Lucas' Model also gave little attention to the structural rigidities of the developing economies. There is no doubt that these economies have low level of productivity due to low level of human capital but at the same time these economies are also suffering from the problem of misallocation and misutilisation of the available resources. These economies not only face the problem of skilled workers but also underutilisation of existing human capital. Due to lack of opportunities and low returns to human capital, there is little incentive to invest in human capital by private individuals. On the other hand, the skilled workers have a greater tendency to migrate to other countries in search of better opportunities. These are the workers which the economy needs the most and their emigrations means the drain of most essential and productive resources. This loss of intellectual capital has a huge and long run adverse effect upon the economic growth of the poor countries. These aspects are ignored by Lucas' model of endogenous growth, yet there is no doubt that the developing economies can learn a lot from this model that it is the higher level of human capital that can ensure higher productivity of other resources. So, it must be attained as well as retained.

12.4 SUMMARY AND CONCLUSION

The neo-classical growth theories, though recognised the importance of technology but they took it as exogenous factor and therefore they failed to explain why even in the long run the richer economies are growing at a rate higher than the poor economies and why same level of investment and technology do not produce similar results across the economies. Moreover, there is little evidence of convergence between the two types of the economies as suggested by Solow's framework. The answers to many of these questions can be found in the endogenous growth models which state that the returns to capital and a given technology mainly depend upon the inherent characteristics of the economy and therefore, the factors to growth are endogenous rather than being exogenous. This is the spillover effect of the technology and the spread of human capital that leads to increasing returns to scale even in the long run. Higher is the speed of these spillovres, higher will be the rate of growth of the economy. Similarly, the economies which invest more in human capital are also able to grow at a higher rate than the economies which spend less on the same. Yet, these models have proposed one sector economy which finds little applicability in the developing economies which are dual in character and face the problem of structural rigidities. In the developing economies, misallocation of the resources is as big an issue as the availability of the same. Though the endogenous growth models are the important breakthrough in the existing knowledge of growth economics but they hardly deal with the important issues of the developing economies which hinder the process of growth even with increase in investment in human capital as well as creation of technology.

12.5 GLOSSARY

(i) Convergence and Divergence : The convergence or 'catch up' is the situation when the poor as well as the richer economies come closer to each other in terms of per capita income. On the other hand, if the gap between the per capita income of the rich and poor economies widens over period of time, then this phenomenon will be termed as divergence.

(ii) Empirical Evidence : Empirical evidence means to support a given set or inference of theory with real life observation or data. Any evidence based on verifiable observations or experience rather than pure logic or theory can be termed as empirical evidence.

(iii) Endogenous and Exogenous Variables : An endogenous variable is a dependent variable generated within a model whose value is changed by one of the given functional relationships within the model. On the other hand, the independent variable that affect the dependent variable without being affected by it and whose variation is not determined by any of the factors given within the model. This type of variable is used for given external conditions not controlled by the economy or the economic model itself.

(iv) Human Capital : Human capital refers to the skills, knowledge and experience possessed by an individual, labour force or population in general. The level of human capital largely determines the level of productivity in the economy.

(v) Spillover Effects : By spillover, we mean to say a process of overflowing or spreading the effects of something in one area into another area. Here, in this lesson, we have taken the spillover effects of technology in the sense that the benefits of technology used or created in one sector of the economy are soon spread to other sectors of the economy leading to multiplier effects on productivity.

12.6 SHORT ANSWER TYPE QUESTION

Q 1. Give the basic idea of endogenous growth models

Ans. The endogenous growth models in contrast to the exogenous growth models believe that the growth of the economy is more influenced by the internal processes and policies, structure etc. than merely the external factors. Endogenous growth is long-run economic growth at a rate determined by forces that are internal to the economic system, that govern 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.

Q 2. What did Lucas mean by 'effective labour force'?

Ans. Lucas has put forth the idea of 'effective labour force' which is shown as the product of size of the labour force and the time spent on producing goods and services for a given level of human capital.

$$N_e = \int_0^{\infty} \mu(h).N(h).dh$$

Here, $N(h)$ is the size of labour force and Ne is the effective labour force and $\mu(h)$ is the proportion of time spent in production.

Q 3. What do mean by external effect of human capital?

Ans. In his model, Lucas states that the human capital investments and its attainments by the private individuals are largely determined by the average level of human capital for the country as a whole. This is termed as external effect of human capital. In order to know about the external effect of human capital, it is important to know about the average level of human capital which can be calculated as below.

$$h_a = \frac{\int_0^\infty h.N(h).dh}{\int_0^\infty N(h).dh}$$

Here, h_a is average level of human capital in a country. Since every individual wishes to attain at least the average level of human capital to improve its employability, therefore, this level sets the minimum target to be achieved by the individuals.

Q 4. Differentiate between optimal growth and equilibrium growth path as suggested by Lucas.

Ans. Lucas in his model tried to differentiate between the optimum growth path and the equilibrium growth path. By optimal path he means that the society wants to maximise its utility function by achieving the optimal level of per capita income with an optimal combination of $K(t)$, $N(t)$, $c(t)$, $h(t)$ and $h_a(t)$. On the other hand, equilibrium path means that there is simultaneous equilibrium in all firms and households as well the economy as a whole. Assuming that $h_a(t)$ is exogenously determined and it is expected that each individual will follow the same path so that the actual behaviour coincides with the expected behaviour and there is no gap between demand and supply (i.e. AD = AS), for given physical and human capital stock. The solution will be achieved in both the cases if $h(t) = h_a(t)$. Any divergence between the two will mean the divergence from the equilibrium as well as the optimal growth path.

12.7 EXAMINATION ORIENTED QUESTIONS

1. Give a detailed overview of endogenous growth models.
2. Critically examine Romer's Model of endogenous growth.

3. Discuss Lucas' Model of endogenous growth. What are its weak points?

12.8 SUGGESTED READINGS

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12.10 MODEL TEST PAPER

I. Answer the following in brief.

Q 1. Give the basic idea of endogenous growth models

Q 2. What did Lucas mean by 'effective labour force'?

Q 3. What do mean by external effect of human capital?

Q 4. Differentiate between optimal growth and equilibrium growth path as suggested by Lucas.

II. Answer the following in detail

1. Give a detailed overview of endogenous growth models.

2. Critically examine Romer’s Model of endogenous growth.

3. Discuss Lucas’ Model of endogenous growth. What are its weak points?

THE AK MODEL-PRODUCTION FUNCTION APPROACH TO ECONOMIC GROWTH

13.1 INTRODUCTION

The neo-classical approaches to economic growth were largely considered to be unsatisfactory due to several inherent flaws. These models view improvements in total factor productivity (technological progress) to be the ultimate source of growth in output per worker, but they do not provide an explanation as to where these improvements come from. In the language of economists, long-run growth is determined by something that is exogenous in the model. Diminishing returns to the accumulation of capital, which plays a crucial role in limiting growth in the neoclassical model, is an inevitable feature of an economy in which the other determinants of aggregate output, namely technology and the employment of labour, are both given. However, there is a class of model in which one of these other determinants is assumed to grow automatically in proportion to capital, and in which the growth of this other determinant counteracts the effects of diminishing returns, thus allowing output to grow in proportion to capital. These models are generally referred to as AK models, because they result in a production function of the form Y = AK, with 'A' constant. The AK model is actually considered the first version of endogenous growth theory. However, the earlier version of this model go back to Harrod (1939) and Domar (1946) who assumed an aggregate production function with fixed coefficients. Frankel (1962) developed the first AK model with substitutable factors and knowledge externalities, with the purpose of reconciling the positive long-run growth result of Harrod-Domar with the factor substitutability and market clearing features of the neoclassical model. The Frankel model showed a constant savings rate, whereas Romer (1986) developed an AK model with intertemporal consumer maximization. The idea that productivity could increase as the result of learning-by-doing externalities, was put forth by Arrow (1962). Then Lucas (1988) developed an AK model where the creation and transmission of knowledge occurs through human capital accumulation. Similarly, we can cite a number of other models which have followed the AK framework. Hence, it is important here to examine this approach and its contribution to economic theory.

13.2 OBJECTIVES

This lesson has the following objectives:

1. To discuss about the basic flaws of the neo-classical growth models.
2. To understand the basic framework of the AK model.
3. To examine the long run growth of the economy in simple AK model

4. To understand the long run growth of economy by incorporating human capital in the AK model.

5. To review the limitations of the AK model

13.3 SIMPLE AK MODEL

As we have already discussed that 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:

$$Y = AK$$

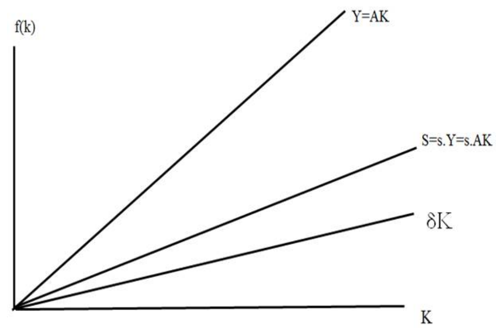
where A is a positive constant that reflects the level of technology and 'K' here is taken in a broader sense as it includes physical as well as human capital. This model shows constant marginal product to capital (as $MP_k = dY/dK = A$) indicating that long run growth is possible. Thus, AK model is a simple way of illustrating endogenous growth. Assuming a closed economy, the savings are equal to investment under conditions of full employment. Since savings are the function of income and capital depreciates at a constant rate i.e. 'δ' the change in capital stock can be traced through following equations.

$$I = S = s.Y = s.AK$$

and, since capital depreciates at a constant rate, the change in capital stock i.e.

can be expressed as $\dot{K} = s.Y - \delta.K.$ This change in capital stock can also be represented by a diagram given below.

Figure 1: The AK Model



In this figure Y-axis show output per worker while the X-axis show the capital stock. The line *Y=AK* having a constant slope shows the constant marginal productivity of capital; the line *S=s.Y* is the gross investment line while the line δK shows the depreciation line or the total replacement investment. The difference between the gross investment line and the replacement line i.e. area between *S=s.Y* line and δK line shows net investment in the economy which is positive and increasing.

The growth of capital stock can be found by dividing both sides of the equation showing change in capital stock with 'K', we get

$$\frac{\dot{K}}{K} = s.\frac{Y}{K} - \delta$$

Since, Y=AK, i.e. Y/K =A, therefore, above equation can be rewritten as

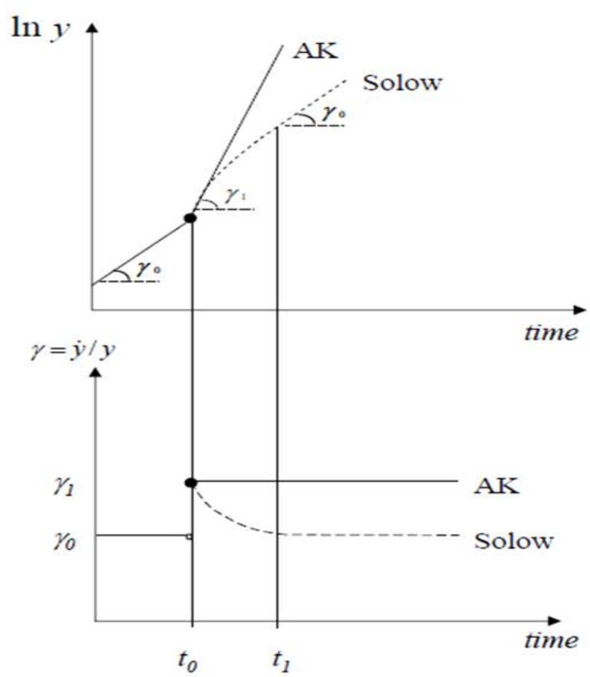
$$\frac{\dot{K}}{K} = s.A - \delta$$

As, growth of output is equal to the growth of capital stock,

$$\frac{\dot{Y}}{Y} = \frac{\dot{K}}{K} = s.A - \delta$$

Further, assuming that s.A > δ, the growth of capital stock as well as growth of output i.e. $\frac{\dot{Y}}{Y} > 0$, showing that the economy will be ever increasing as compared to the Solow model which shows that the income increases at a declining rate before stagnating for a given technology. We can easily compare how the paths of per capita income would differ in case of Solow model of exogenous growth and the AK model of endogenous growth. This comparison has been shown through figure 2.

Figure 2 : The AK Model and the Solow Model Compared for Rising Saving Rate



Source : Miguel Lebre de Freitas, Introduction to Economic Growth.

Figure 2 compares the impact of rate of change in savings upon the growth of income. The top part of the diagram shows the levels of income and the bottom part shows the growth rate of the same. In the upper part, we can see that a once for all increase in saving rate in t0 time period leads to an ever growing income curve (shown as *ln y*) in case of AK model while in case of Solow model, the income increases initially but ultimately reaches at the same level after t_1. This can be observed through the angle 'γ'. In case of Solow type growth path, as savings increase or say, due to exogenous change in technology in t_0 time period, the income curve immediately and its slope rises as we can see that the size of angle 'γ' increases from γ_0 to γ_1 but after t_1 time period, it again comes back to the previous level i.e. γ_0. However, in case of AK type growth the increase in income is forever, shown by an ever increasing curve and once for all increase in the size of angle γ_0 to γ_1. The growth path can better be elaborated through growth rate of income in the lower segment of the diagram. We can see that in to time period, the growth rate of income increases immediately from γ_0 to γ_1 but the Solow type growth path shows that it comes back to γ_0 level while the AK growth path shows that growth of income is constant at stays at γ_1 level even in the long run.

13.4 AK MODEL WITH HUMAN FACTOR

In its more realistic form, we can also add labour as an input along with capital. In this context, first of all, we can discuss Arrow's model with knowledge spillovers. In this model, the production function for final output can be written as

$$Y = B.K^{\alpha} L^{1-\alpha} \qquad (1)$$

which is a Cobb-Douglas type production function showing constant returns to scale with inputs K and L. In a model with technology and population growth as exogenous factors, the population, equal to labour input L, can be normalized to one and the individual firm takes total factor productivity B as given. However, we suppose that B is in fact endogenously determined.

Specifically, the accumulation of capital generates new knowledge about production in the economy as a whole. In particular, we assume that

$$B=AK^{1-\alpha} \qquad (2)$$

where, A is constant and is greater than zero i.e. $A > 0$

That is, an incidental by-product of capital accumulation by firms in the economy is the improvement of the technology that firms use to produce. Technological progress, modelled as a by-product of capital accumulation, is external to the firm. Combining the two preceding equations gives

$$Y=A.K.L^{1-\alpha} \qquad (3)$$

This is exactly the AK model above, noting that $L = 1$. However, in further formulation of the AK model, we can include human capital as a separate variable having a positive effect upon the level of output. Thus, more skilled labour force will be assumed to produce more output than an unskilled individual, and the total stock of such "skills" is called human capital. Crucially, human capital can be accumulated through education. Thus, both types of capital can be accumulated—this turns out to imply that the model has similar properties to the AK model. In this perspective, we can have a production function of the following type:

$$Y_t=A_t.K_t^{\alpha}H_t^{1-\alpha} \qquad (4)$$

where K_t is physical capital and H_t is human capital. So, growth is determined by

$$\frac{\dot{Y}_t}{Y_t}=\frac{\dot{A}_t}{A_t}+\alpha\frac{\dot{K}_t}{K_t}+(1-\alpha)\frac{\dot{H}_t}{H_t} \qquad (5)$$

Assuming that like physical capital, human capital also depreciates for given attainments. This can be understood in this way that if a person does not updates its knowledge, the knowledge accumulated so far depreciates in a dynamic economy. For simplifying the analysis, let us assume that both the physical as well as human capital depreciates at the same rate, then we can easily derive the equations for accumulation of each type of capital stock. This simplification is expected not to disturb the relevant conclusions of the model. Hence, the change in physical capital stock is defined as :

$$\dot{K}_t = s_k Y - \delta K \qquad (6)$$

and the change in human capital stock can be defined as

$$\dot{H}_t = s_H Y - \delta H \qquad (7)$$

Similarly, we can also define the capital output ratios for both the physical and human capital.

The capital output ratio for physical capital is

$$x_K = \frac{K}{Y}$$

while for human capital, it is

$$x_H = \frac{H}{Y}$$

For finding the growth rate of physical as well as human capital, we can divide the equations (6) and (7), respectively with 'K' and 'H' and substitute the above values of respective capital output ratios, we have

$$\frac{\dot{K}}{K} = \frac{s_K}{x_K} - \delta \qquad (8)$$

and

$$\frac{\dot{H}}{H} = \frac{s_H}{x_H} - \delta \qquad (9)$$

In AK model, for a steady growth path, the growth for physical and human capital stock should be the same i.e.

$$\frac{\dot{K}}{K} = \frac{s_H}{x_H} - \delta = \frac{s_H}{x_H} - \delta = \frac{\dot{H}}{H} \qquad (10)$$

This implies that

$$\frac{s_K}{x_K} = \frac{s_H}{x_H} \Rightarrow \frac{x_K}{x_H} = \frac{s_K}{s_H} \Rightarrow \frac{K}{H} = \frac{s_K}{s_H} \qquad \text{..... (11)}$$

So, along the steady growth path, the stock of human capital can be written as

$$H = \frac{s_H}{s_K} K \qquad \text{........ (12)}$$

This value of 'H' can be put in equation (4), we get

$$Y = AK^{\alpha}\left(\frac{S_H}{S_K} K\right)^{1-\alpha}$$

Or, $$Y = A.K\left(\frac{S_H}{S_K}\right)^{1-\alpha} \qquad \text{.......(13)}$$

Again, under the steady growth path, growth of income is equal to the growth of capital stock

$$\frac{\dot{Y}}{Y} = \frac{\dot{K}}{K}$$

from equation (8) and putting the value of $x_K = \frac{K}{Y}$, we get,

$$\frac{\dot{Y}}{Y} = \frac{S_K Y}{K} - \delta = A.S_K\left(\frac{S_H}{S_K}\right)^{1-\alpha} - \delta$$

Hence,

$$\frac{\dot{Y}}{Y} = A.(S_K)^{\alpha}(S_H)^{1-\alpha} - \delta \qquad \ldots\ldots \quad (14)$$

Thus, allowing for both type of inputs- physical as well as human capital, which are continuously accumulated produce same results as that of the AK model as equation (14) is another form of growth of income in AK model with capital input only. In this case, the steady growth rate is $A \,.\, (S_K)^{\alpha}$ $(S_H)^{1-\alpha} - \delta$ instead of AS – δ as in simple AK model. Here, the simple saving rate has been replaced with a geometric average of the two saving rates in the two factor model while leaving the broader implications unchanged. Lucas on the other hand tried to incorporate the role of human capital in terms of effective labour force and an attempt has also been made to measure the human capital accumulation in terms of allocation of time between production time and time spent in human capital accumulation. Thus the effect of human capital accumulation can be observed in the standard AK model. Although, we have already discussed the Lucas model in the lesson on endogenous growth models, yet it is important here to look at it briefly in AK framework. For this purpose, we now consider a simple endogenous growth model with human capital accumulation in which *Y* is a function in physical capital *K* and "effective labour" *h*. *L*, where '*h*' is level of human capital per person and 'L' is the size of the labour force.

$$Y = K^{\alpha}(h.L)^{1-\alpha}$$

Lucas assumes that human capital per person evolves according to

$$\dot{h} = (1-u)h$$

where u is time spend working and (1 – *u*) is time spend accumulating skills. The growth rate of h is given by

$$\frac{\dot{h}}{h} = 1-u$$

Since h enters the production function like labour-augmenting technological progress in the Solow model, we can conclude that the long-run growth rate of output is equal to the growth of human capital stock which is equal to the growth of physical capital stock on steady state equilibrium path. Hence, $\frac{\dot{Y}}{Y} = \frac{h}{h}$ or $\frac{\dot{Y}}{Y} = 1 - u$ This implies that every policy measure which affects u has an impact on the long-run growth rate.

Thus, we have observed that AK model gives a new framework for the long run growth of the economies. However, there are still some reasons to doubt the predictions about long-run growth generated by this class of models. The first line of criticism is related with the non-accumulable factors. In the real world, there are factors of production that are in fixed supply, such as land, or that cannot simply be accumulated indefinitely such as energy. Remember that the AK model results are of a knife-edge variety: Any move away from all factors being accumulable, and we move back to the Solow model results. Moreover, similar treatment to all type of human capital is also criticised by many as they say that the strict parallel between human capital and physical capital in the model just described is probably not completely accurate. For instance, not all expenditures on education will produce the same effect on output. The marginal boost to aggregate output of primary teaching is altogether different to that of higher education; training the non-skilled informally and the formal training of the professional also differ in their marginal returns. By clubbing all these different types of human capital together hardly proposes an effective policy suggestion for countries with a varied structure of human capital. Another source of the difficulties faced by the AK model is that it does not make an explicit distinction between capital accumulation and technological progress. In effect it just lumps together the physical and human capital. Lastly, it also criticised for not giving any explanation for any possibility of convergence among the economies.

13.5 SUMMARY AND CONCLUSIONS :

AK model is considered the simplest version of endogenous growth. Although, we can observe many neo-classical approaches in the AK framework such as that of Harrod and Domar who assume an aggregate production function with fixed coefficients but the important implication of modern AK type production function is that it can explain long-run growth using the same basic assumptions as the neoclassical model but adding knowledge externalities among firms that accumulate physical capital. The idea that productivity could increase as the result of learning-by-doing externalities, was most forcefully pushed forward by Arrow and then Lucas developed an AK model where the creation and transmission of knowledge occurs through human capital accumulation. All these models clearly state that the economies can experience long term growth or the increasing returns to scale through knowledge spillovers and since the developed countries have a higher stock of human capital as compared to the developing ones, the former grow at a faster pace than the latter one and the economies of two types of economies go on diverging from each other. However, like all the endogenous growth models, the AK model also does not address the structural rigidities of the developing countries which hinder the process of creation as well as accumulation of human capital which is an important factor for ensuring sustained long run growth of the economies.

13.6 GLOSSARY

(i) Capital Accumulation : Capital accumulation involves acquiring more assets that can be used to create more wealth or that will appreciate in value.

(ii) Externality : In economics, an externality is the cost or benefit that affects a party who did not choose to incur that cost or benefit. This can also be termed as a consequence of an industrial or commercial activity which affects other parties without this being reflected in market prices, such as the pollination of surrounding crops by bees kept for honey.

(iii) Natural Growth Rate : The natural growth rate is the rate of economic growth required to maintain full employment. It is generally considered to be equal to the natural increase in population or the labour force of the economy. The natural increase in the population can simply be defined as the difference between the live births and the number of deaths during the year.

(iv) Productivity : In simple words productivity means output per unit of inputs. It is thus a measure of efficiency of a human factor, capital unit or land area who contribute in the production process. It is calculated by dividing the total output or the value added by a factor to total output with the units of the factor. Productivity is also a critical indicator of cost efficiency of a production unit.

13.7 SHORT ANSWER TYPE QUESTION

Q 1. What do you understand by AK Models?

Ans. The neo-classical approaches to economic growth largely considered the improvements in total factor productivity (technological progress) to be the ultimate source of growth in output per worker, but they do not provide an explanation as to where these improvements come from. Diminishing returns to the accumulation of capital, which plays a crucial role in limiting growth in the neoclassical model, is an inevitable feature of an economy in which the other determinants of aggregate output, namely technology and the employment of labour, are both given. However, there is a class of model in which one of these other determinants is assumed to grow automatically in proportion to capital, and in which the growth of this other determinant counteracts the effects of diminishing returns, thus allowing output to grow in proportion to capital. These models are generally referred to as AK models, because they result in a production function of the form Y = AK, with 'A' constant. The AK model is actually considered the first version of endogenous growth theory.

Q 2. Discuss simple framework of AK Model.

Ans. 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:

$$Y = AK$$

where A is a positive constant that reflects the level of technology and 'K' here is taken in a broader sense as it includes physical as well as human capital. This model shows constant marginal product to capital (as $MP_k = dY/dK = A$) indicating that long run growth is possible. Thus, AK model is a simple way of illustrating endogenous growth. Assuming a closed economy, the savings are equal to investment under conditions of full employment. Since savings are the function of income and capital depreciates at a constant rate i.e. 'δ' the change in capital stock can be traced through following equations.

$$I = S = s.Y = s.AK$$

and, since capital depreciates at a constant rate, the change in capital stock i.e. can be expressed as $\dot{K} = s.Y - \delta.K$. This growth of capital stock is an important determinant of the growth of the economy.

Q 3. Discuss Arrow's version of AK Model.

Ans. In Arrow's model with knowledge spillovers, the production function for final output can be written as :

$$Y = B.K^{\alpha}L^{1-\alpha}$$

which is a Cobb-Douglas type production function showing constant returns to scale with inputs K and L. In a model with technology and population growth as exogenous factors, the population, equal to labour input L, can be normalized to one and the individual firm takes total factor productivity B as given. However, we suppose that B is in fact endogenously determined. Specifically, the accumulation of capital generates new knowledge about production in the economy as a whole. In particular, we assume that

$$B = AK^{1-\alpha}$$

where, A is constant and is greater than zero i.e. A > 0

That is, an incidental by-product of capital accumulation by firms in the economy is the improvement of the technology that firms use to produce. Technological progress, modelled as a by-product of capital accumulation, is external to the firm. Combining the two preceding equations gives

$$Y = A.KL^{1-\alpha}$$

This is exactly the AK model above, noting that $L = 1$.

Q 4. Give Lucas' version of AK type production function.

Ans. Lucas' version of AK framework can be understood with the help of equation given below. In this equation, a simple endogenous growth model with human capital accumulation is considered in which Y is a function in physical capital K and "effective labour" $h. L$, where 'h' is level of human capital per person and 'L' is the size of the labour force.

$$Y = K^{\alpha} (h.L)^{1-\alpha}$$

Lucas assumes that human capital per person evolves according to

$$\dot{h} = (1-u)h$$

where u is time spend working and $(1 - u)$ is time spend accumulating skills. The growth rate of h is given by

$$\frac{\dot{h}}{h} = 1-u$$

Since h enters the production function like labor-augmenting technological progress in the Solow model, we can conclude that the long-run growth rate of output is equal to the growth of human capital stock which is equal to the growth of physical capital stock on steady state equilibrium path. Hence, $\frac{\dot{Y}}{Y} = \frac{\dot{h}}{h}$ or $\frac{\dot{Y}}{Y} = 1-u$

This implies that every policy measure which affects u has an impact on the long-run growth rate.

13.8 EXAMINATION ORIENTED QUESTIONS

1. Give a detailed account of AK model. What are its merits and demerits?
2. Critically analyse AK type production function with human capital.

13.9 SUGGESTED READINGS

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13.11 MODEL TEST PAPER

I. Answer the following in brief.

Q1. What do you understand by AK Models?

Q2. Discuss simple framework of AK Model.

Q3. Discuss Arrow's version of AK Model.

Q4. Give Lucas' version of AK type production function.

II. Answer the following in detail

1. Give a detailed account of AK model. What are its merits and demerits?

2. Critically analyse AK type production function with human capital.

M. A. ECONOMICS **LESSON NO. 14**

COURSE NO. : ECO 302 **SEMESTER III** **UNIT-IV**

GROWTH ACCOUNTING – EMPIRICAL EVIDENCE

14.1 INTRODUCTION

In any production process there will be in fact be a vast number of inputs. But in the end all these inputs can be reduced to three components i.e. labour, land (including natural resources such as oil and minerals) and capital. There are only two ways in which output per person in any society can be increased. The first is by increasing the amount of land or capital relative to the number of workers. Since the land area is generally fixed relative to population the way in which incomes increase through expanding the inputs in modern economies is generally by the mechanism of capital accumulation. The second way, through which output per person can be increased, is by improvements in the production process so that the same inputs produce more output. This is referred to as efficiency or Total Factory Productivity (TFP) gains. Efficiency gains can come from a variety of sources. The first is better production technology while another source of efficiency gains can be economies of scale. Now the question is what has been the relative contribution of each source, capital accumulation and efficiency gains in modern growth? Growth accounting is such an empirical methodology that allows the breakdown of observed growth of GDP in to components associated with changes in factor inputs and in production technologies. Since it is not possible to measure the contribution of technology directly, it can be derived as a residual after deducting the contribution of the observable factors from the total GDP growth. An accounting exercise is actually viewed as a first step in the analysis of fundamental determinants of economic growth which ultimately leads to finding the relations of growth of factor inputs, factor shares and/or technical progress with other elements such as government policies, household preferences, initial levels of human as well as physical capital or other related factors. Hence, it is important to discuss the methodology of growth accounting in detail.

14.2 OBJECTIVES

This lesson has the following objectives:

1. To discuss about the basic set up of growth accounting.
2. To analyse the growth of technology as the fundamental source of growth.
3. To analyse the growth of capital stock as the fundamental source of growth.
4. To incorporate the effect of prices in growth accounting method.
5. To generalise the growth accounting technique in the economy with diverse commodities and heterogeneous inputs.

14.3 THE BASIC SET UP OF GROWTH ACCOUNTING

To start with, let us take the case of a single sector model in which the production is function of capital (K), land (Z) and labour (L) and the efficiency of the production sector (A). Then the simple production function can be displayed as

$$Y = A.\, f(K,L,Z) \qquad \text{........(1)}$$

In this equation, output, capital, labour and land are directly observable quantities in any economy, the efficiency level A is not directly observable but must be inferred from the changes in other variables. We can only measure changes in the efficiency of economies by inference. Thus, growth of output attributed to this source is frequently called the "residual." Let ΔY is the change in output in any year, ΔK the change in the capital stock in a year, and ΔA the change in the level of efficiency of the economy. Hence, the annual growth rate of output g_Y will be

$$g_Y = \frac{\Delta Y}{Y}$$

Similarly the annual growth rate of the capital stock will be,

$$g_K = \frac{\Delta K}{K} \;;$$

the growth of labour force will be $g_L = \frac{\Delta L}{L}$ and that of natural resources $g_Z = \frac{\Delta Z}{Z}$

Also the growth rate of the efficiency of the economy will be,

$$g_A = \frac{\Delta A}{A}$$

The change in income or output at any point of time will be equal to the sum total of the change in units of the factors and the changes in their marginal products. Denoting the marginal product of each of factor input as MPi , we can easily construct the equation for change in output which is given as below:

$$\Delta Y = MP_K \Delta K + MP_L \Delta L + MP_Z \Delta Z + f(K,L,Z).\Delta A$$

Thus, the changes in output have two basic sources, changes in inputs and changes in the efficiency with which the economy translates inputs into output. Further, in a competitive economy, with constant returns to scale, all factors are paid according to the value of their marginal products. Thus, the value of the marginal product of labour, MP_L, is just the wage rate 'w'. Similarly the value of the marginal product of capital will be 'r', and the value of the marginal product of land, the rent 's'. Thus,

$$\Delta Y = r\Delta K + w\Delta L + s\Delta Z + f(K,L,Z).\Delta A$$

Dividing both sides by 'Y', and after some simple mathematical manipulations in each of the components in the right side of the equation, we get

$$\frac{\Delta Y}{Y} = \left(\frac{rK}{Y}\right)\left(\frac{\Delta K}{K}\right) + \left(\frac{wL}{Y}\right)\left(\frac{\Delta L}{L}\right) + \left(\frac{sZ}{Y}\right)\left(\frac{\Delta Z}{Z}\right) + \left(\frac{A.f(K,L,Z)}{Y}\right)\left(\frac{\Delta A}{A}\right)$$

Since, $Y = A.f(K,L,Z)$, above equation can be further rewritten as

$$\frac{\Delta Y}{Y} = \left(\frac{rK}{Y}\right)\left(\frac{\Delta K}{K}\right) + \left(\frac{wL}{Y}\right)\left(\frac{\Delta L}{L}\right) + \left(\frac{sZ}{Y}\right)\left(\frac{\Delta Z}{Z}\right) + \left(\frac{\Delta A}{A}\right) \qquad \text{.........(2)}$$

Under constant returns to scale, if all the factors are paid according to their marginal products, total product is fully exhausted i.e. $rK + wL + sZ = Y$

Or

$$\frac{rK}{Y} + \frac{wL}{Y} + \frac{sZ}{Y} = 1$$

If we denote $\frac{rK}{Y} = a$, $\frac{wL}{Y} = b$ and $\frac{sZ}{Y} = c$, then above equation can be written as

$$a + b + c = 1$$

and equation (2) becomes

$$\frac{\Delta Y}{Y}=a\left(\frac{\Delta K}{K}\right)+b\left(\frac{\Delta L}{L}\right)+c\left(\frac{\Delta Z}{Z}\right)+\left(\frac{\Delta A}{A}\right)$$

Since, we have already taken $g_Y=\frac{\Delta Y}{Y}$; $g_K=\frac{\Delta K}{K}$; $g_L=\frac{\Delta L}{L}$; $g_Z=\frac{\Delta Z}{Z}$ and $g_A=\frac{\Delta A}{A}$, therefore above equation can be rewritten as

$$g_y = a.g_K + b.g_L + c.g_Z + g_A \qquad \text{……….(3)}$$

This implies that the rate of growth of output is equal to the rate of growth of capital, labour and natural resources, each weighted by their share in national income, plus the rate of growth of productivity. Although, rate of growth of national income or output is an important indicator but we are often more interested in rate of growth of per capita output or, say per worker output which is $y = Y/L$. This indicator is particularly important when we are interested in measuring the growth of material well being of the society which depends on output per worker. Hence, the rate of growth of output per worker can be written as

$$g_{Y/L}=\frac{\Delta\left(\frac{Y}{L}\right)}{\left(\frac{Y}{L}\right)}$$

For small changes in Y and L, year by year, this is approximately equivalent to $\frac{\Delta Y}{Y}-\frac{\Delta L}{L}$

Thus,

$$g_Y = g_{Y/L} \approx g_Y - g_L$$

Similarly, we can also calculate the growth of capital per worker $\left(k = K/L\right)$ as

$g_K - g_L$, and the rate of growth of resources per worker $\left(z = Z/L\right)$ as $g_Y - g_L$.

Subtracting 'g_L' from each side of equation (3), we get,

$$g_Y - g_L = a.g_K + b.g_L + c.g_Z + g_A - g_L$$

As we have seen above that $a + b + c = 1$, then above equation can also be written as

$$g_Y - g_L = a.g_K + b.g_L + c.g_Z + g_A - (\mathrm{a} + \mathrm{b} + \mathrm{c})g_L$$

i.e.

$$g_Y - g_L = a.(g_K - g_L) + b.(g_L - g_L) + c.(g_Z - g_L) + g_A$$

or,

$$g_y = ag_k + c.g_z + g_A \qquad \text{.........(4)}$$

This is termed as the fundamental equation of growth. This explains that the rate of growth of output per worker depends upon growth of capital per worker times the share of capital in national income, rate of growth of land per worker times the share of land in national income and the rate of growth of technology. This indicates that the growth of output is positively affected by the increase in growth of capital stock, improvement in technology as well as decline in population growth. In absence of growth of resources per worker or share of land and natural resources in payments to owners close to zero in the long run, so that either $c \approx 0 \; or \; g_z = 0$ the fundamental equation of growth shows that growth of per worker output in the long run depends upon the growth of capital per worker and growth of technology i.e.

$$g_y = ag_k + g_A \qquad \text{........(5)}$$

The empirical evidences have suggested that for most developed economies, the major source of growth of income per capita is advances in technology or efficiency parameter i.e. 'A'. Typically, the growth of output in these economies can be split in to two-third contribution of growth from efficiency and one-third from capital accumulation. This indicates that for the advanced economies, after reaching a certain level of capital stock, it is the growth of technology that assumes more importance in the growth of per capita income. However, the empirical evidences have also suggested a close association between efficiency and capital stock. The countries with higher growth rate of capital stock also have higher growth of efficiency and the opposite is true for poor economies. This fact only strengthens the idea propounded by equation (5) that both the growth of capital stock as well as efficiency are the important sources of growth. But the close association between the two also raises the question whether any one of these two factors will solve the purpose of raising the growth rate as both of these move together or there is some other factor which governs the growth of efficiency as well as that of the capital stock. Most of the researches agree on one point that the efficiency growth is the main driver of growth of per capita output as well as growth of per capita availability of capital stock.

14.4 EFFICIENCY AS THE FUNDAMENTAL SOURCE OF GROWTH

Most of the empirical evidences from the developing as well as the developed economies point out that the efficiency growth is the fundamental force behind the growth of capital accumulation as well as per capita output. Any gain in efficiency for a given stock of capital, labour and land in an economy will increase the marginal product of capital. The marginal product of capital from equation (1) is

$$MP_k = A.\frac{\Delta F(K, L, Z)}{\Delta K}$$

Where $\Delta F/\Delta K$ is the change in F(K, L, Z) produced by a one unit increase in K.

By definition $\Delta F/\Delta K$ does not change when the level of efficiency A increases. Thus as A increases the marginal product of capital increases.

But the increase in the marginal product of capital means that the rental price of capital, 'r', is now less than the marginal product of capital. This situation cannot persist in a competitive market. Either the rental on capital must rise to equal the new higher marginal product of capital, or the stock of capital has to increase so that capital is more abundant relative to labour and land and consequently its marginal product lower. In practice gains in efficiency and in incomes have not increased the rental price of capital in modern economies. Thus efficiency gains have generally induced more capital investment. The constant rental cost of capital thus explains the link between efficiency growth and capital stock growth. It is possible to illustrate this process by specifying a particular function for the link between inputs and output posited in equation (1). In its simplest functional form, the production function can be shown in form of Cob-Douglas formula,

$$Y = A.K^{a}L^{b}Z^{c} \qquad \text{.......(6)}$$

Where, a, b and c are the shares of capital, labour and land in national income. The Cobb-Douglas structure implies that the share of capital, labour and land in earnings in the economy is constant over time. With such a specification the marginal product of capital can be found by differentiating equation (6) partially with respect to capital (K) and is given as under

$$\frac{\partial Y}{\partial K} = MP_K = A.a.K^{a-1}L^{b}Z^{c} = \frac{A.a.K^{a}L^{b}Z^{c}}{K} = a.\frac{Y}{K}$$

Thus, the marginal product of capital depends just on the capital-output ratio. The more of capital is employed relative to output, the lower will be the marginal product of capital. If efficiency growth raises the output, Y, but does not affect the rental cost of capital, ‘r’, then the stock of capital must rise proportionately with output. Thus,

$$K = \frac{a}{r}.Y$$

Thus, the growth of capital will be equal to the growth of output. Thus, efficiency growth will not only have a direct and positive effect on growth of output but also an indirect effect through raising the stock of capital along with output. Thus, substituting $g_k = g_y$ in equation (5), we get,

$$g_y \approx a.g_y + g_A$$

i.e. $$(1-a).g_y = g_A$$

or, $$g_y = \frac{g_A}{(1-a)} \qquad \text{......(6)}$$

Thus, we can easily find that the growth of income per capita depends upon the growth of technology. Thus, a 1 per cent growth in efficiency leads to a more than 1 per cent growth in output. If the share of capital in income is 0.25 for example, a 1 per cent increase in efficiency will create a 1.33 per cent growth in output. It implies that the growth of efficiency explains not just the majority of economic growth; it explains almost all growth in output per person in the modern world. Since income growth from efficiency gains also explains most of the capital accumulation, it may be termed as fundamental source of modern economic growth.

14.5 CAPITAL AS THE FUNDAMENTAL SOURCE OF GROWTH

Although, most of the researchers have been obsessed with the idea of efficiency as the main engine of growth but equally strong arguments erupt that where does this efficiency come from? Even if we believe that growth of capital stock and growth of efficiency move together, then the question is what is the cause and what is the effect? Some economists argue that all efficiency growth is really a form of capital investment. People are devoting much of their times and money in searching for new methods and more cost effective ways of doing things. The inputs of this kind are also like investment in capital stock. Now the measured capital stock of societies does include the investments firms make in research and development (R&D). Capital investment in increasing knowledge has external benefits which are not captured by the investor. The investment in knowledge may have lower private returns and higher social returns. If we try to capture the returns to investment in creation of knowledge and its impact on productivity of capital as well as output in growth accounting equation, then we may find that for a true contribution of increases in the capital stock, output increases will be much greater than $r.\Delta K$, which merely measures the private benefits, and the contribution of efficiency gains $F(K,L,Z).\Delta A$ will be correspondingly less. Consequently in the growth accounting equation,

$$g_Y = ag_K + bg_L + cg_Z + g_A$$

we have to replace the observed share of capital a, with a new share a^*, where $a^* > a$, and hence $a^* + b + c > 1$.

If the true contribution of capital to economic growth is under-measured we can explain why there is a correlation between capital growth and efficiency growth. Where capital growth is large, the under-measurement of the contribution of capital will be greatest. Thus where the growth rate of capital is large the growth of efficiency will appear large. If most of the economic growth is to stem from capital investment, the true coefficient on capital, a* has to be many times higher than the payments to capital as a share of national income and thus the social return from investing any capital has to be many times higher than the private returns, so the external benefits will be higher than the private benefits. But measuring the external benefits of any capital stock is simply hard to measure and what remains unmeasured is assigned to the efficiency component in the growth accounting equation.

14.6 GROWTH ACCOUNTING AND THE CHANGE IN PRICES

We have seen that the efficiency growth can be measured by deducting the weighted total of growth of all factor inputs from total growth of income.

$$g_A = g_Y - (a.g_K + b.g_L + c.g_Z)$$

Or,

$$g_A = g_Y - a.g_K - b.g_L - c.g_Z$$

This method of calculating efficiency growth implies constructing measures of the movement over time of physical outputs, and weighting them by some estimate of the shares of each input in national income. Constructing such indices requires a lot of information about economies – we need to add up all the inputs and outputs for each economy. There is another method of calculating efficiency growth, however, which is much less information intensive. This is to construct measures of prices and payments to factors. If there is a competitive market knowing just a few prices will tell us what the general price level for any good or factor is. On the basis of the information regarding prices of factors and the final output, we can simply find that

$$p.Y = rK + wL + sZ \tag{7}$$

We can easily incorporate the changes in the prices and the physical quantities of the inputs. Let the quantities next year be Y+ΔY, K+ΔK, etc and the prices p+Δp, r+Δr, etc. Next year that the value of output, which is now (p + Δp)(Y + ΔY) must equal the value of the inputs. Thus,

$$(p + \Delta p)(Y + \Delta Y)=(r + \Delta r)(K + \Delta K)+(w + \Delta w)(L + \Delta L)+(s + \Delta s)(Z + \Delta Z) \tag{8}$$

To simplify we can measure all prices in terms of the price of output in each year (that is we set p = 1). In that case if we subtract each side of (7) from each side of (8) and throw out the terms such as Δp. ΔY which will be very small, then we get :

$$\Delta Y = \Delta r.K + r.\ \Delta K + \Delta w.L + w.\ \Delta L + \Delta s.Z + s.\ \Delta Z$$

where r is the real interest rate on capital, w is the real wage, and s the real land rent (measured in terms of output prices). Taking all the terms with quantity changes to the left hand side gives us

$$\Delta Y - r.\ \Delta K - w.\ \Delta L - s.\ \Delta Z = \Delta r.K + \Delta w.L + \Delta s.Z$$

Dividing both sides by Y and rearranging we get,

$$\frac{\Delta Y}{Y} - a\frac{\Delta K}{K} + b\frac{\Delta L}{L} + c\frac{\Delta T}{T} = a\frac{\Delta r}{r} + b\frac{\Delta w}{w} + c\frac{\Delta s}{s}$$

$$g_Y - a.g_K - b.g_L - c.g_Z = a.g_r + b.g_w + c.g_s \tag{9}$$

But we have already noted that

$$g_A = g_Y - a.g_K - b.g_L - c.g_Z$$

Therefore, equation (9) becomes

$$g_A = a.g_r + b.g_w + c.g_s \tag{10}$$

Finally, allowing the effect of general price movements in the price of output, equation (10) becomes

$$g_A = a.g_r + b.g_w + c.g_s - g_p$$

Thus, the rate of productivity growth can be calculated as the weighted sum of the rates of growth of input prices minus the rate of growth of the output price. This says that the rate of efficiency growth is the weighted sum of the rate of growth of real capital rents, real wages and real land rents. The empirical evidences from most of the developed economies have suggested that the real capital rents have tended to be constant since 1750, and real land rents have not grown very rapidly, and therefore, this implies that the real wages of workers tend to be for modern economies a very good metric of the efficiency level of the economy. Most efficiency growth in modern economies has shown up in higher real wages.

So far, we have discussed the sources of growth in per capita income derived for an economy with only one sector economy, having homogenous factors but in reality there may be diverse sectors in the economy having heterogeneous factors. but we can easily find an analogous expression for an economy with many types sectors producing different commodities with many types of labour, capital and land. Thus, in an economy with 'i' types of output, the growth of output becomes

$$g_Y = \sum \theta_i g_{Y_i}$$

Where, θ_i is the share in the value of output of the commodity or service 'i'. The growth of the labour input becomes

$$g_L = \sum \frac{b_j}{b} g_{L_j}$$

where *bj* is the share in the total payments to the factors of production paid to workers of type *j*. And the growth of the capital stock is similarly

$$g_K = \sum \frac{a_j}{a} g_{K_j}$$

Finally, the effect of the growth of productivity in any sector 'j', g_{A_j} on national productivity growth is given from the formula

$$g_A = \sum_j \theta_j g_{A_j}$$

Where, θj is the share of national income derived from sector j.

14.7 SUMMARY AND CONCLUSIONS

Growth accounting is an empirical methodology that allows the breakdown of observed growth of GDP into components associated with changes in factor inputs and in production technologies. Since it is not possible to measure the contribution of technology directly, it can be derived as a residual after deducting the contribution of the observable factors from the total GDP growth. An accounting exercise is actually viewed as a first step in the analysis of fundamental determinants of economic growth which ultimately leads to finding the relations of growth of factor inputs, factor shares and/or technical progress with other elements such as government policies, household preferences, initial levels of human as well as physical capital or other related factors. For this purpose in this lesson, we have discussed firstly, the basic growth accounting model, then tried to explore the contribution of capital and technology as important sources of growth. Finally, the basic framework of growth accounting with assumptions of single sector and homogenous factors can be adapted easily to a case of many commodities and all the inputs of heterogeneous nature. However, there are several limitations of the growth accounting method. First of all it is based upon the assumptions of perfect competition, where factors are paid according to their marginal product and are similar similar across all sectors of the economy. This assumption has little applicability in the developing economies and the violation of this assumption leads to wrong conclusions regarding the contribution of various factors in output growth. The second problem is related with the assumption of constant returns to scale. If the returns to scale are increasing or diminishing and the factors are paid according to their marginal products, the value of total output will altogether deviate from the sum total of payments made to the factors and accounting for the contributions of each factor of production will not be possible. Thirdly, accounting the contribution of each factor needs a lot of information regarding the physical quantities of all inputs, their marginal productivities, the relative prices and the changes therein. Such type of information flow is hard to imagine in developing economies which have diverse sectors and have plural economic structures. Moreover, the differences in inputs and output are not taken into consideration. Finally, growth accounting is considered more an accounting exercise rather than a model of growth.

14.8 GLOSSARY

(i) Homogeneous factors: By homogenous factors, we mean to say that the quality of all units of any factor of production is same that each unit is equally efficient or productive.

(ii) The Cobb-Douglas production function: The Cobb-Douglas production function is a particular form of the production function. It is widely used because it has many attractive characteristics which simplify the analysis in a given framework. This production function assumes a single sector economy with homogenous factors which exhibits constant returns to scale.

(iii) External benefit: A favourable impact of a product that does not affect its market price since demand for that impact lies outside that product market. An example of an external benefit is provided by educational services since an educated work force benefits businesses operating outside of the educational system.

(iv) Real Value: Under dynamic economic conditions, the prices of the factors as well as that of the commodities rise showing an increase in general price level. Therefore, in order to find the actual rise in output, the value of output must be adjusted according to the increased prices. Real value of a variable is thus found by removing the impact of rise in prices from the money values at the given market prices. Therefore, output at the constant prices is termed as the real value of output.

(v) **Private and Social Benefits:** Private benefits include the profits made by producers in selling goods and services or the utility gained by consumers from consuming goods and services to satisfy needs and wants. On the other hand, social benefit is the total benefit to society from producing or consuming a good/service. Social benefit includes all the private benefits plus any external benefits of production / consumption. If a good has significant external benefits, then the social benefits will be greater than the private benefits.

14.9 SHORT ANSWER TYPE QUESTIONS

Q1. What do you mean by growth accounting?

Ans. Growth accounting is an empirical methodology that allows the breakdown of observed growth of GDP in to components associated with changes in factor inputs and in production technologies. Since it is not possible to measure the contribution of technology directly, it can be derived as a residual after deducting the contribution of the observable factors from the total GDP growth.

Q2. Give the basic equation of growth accounting process.

Ans. Single sector model in which the production is function of capital (K), land (Z) and labour (L) and the efficiency of the production sector (A). Then the simple production function can be displayed as

$$Y = A.f(K, L, Z) \qquad \text{........(1)}$$

In this equation, output, capital, labour and land are directly observable quantities in any economy, the efficiency level A is not directly observable but must be inferred from the changes in other variables. We can only measure changes in the efficiency of economies by inference. Thus, growth of output attributed to this source is frequently called the "residual." Let ΔY is the change in output in any year, ΔK the change in the capital stock in a year, and ΔA the change in the level of efficiency of the economy. Hence, the annual growth rate of output g_Y will be

$$g_Y = \frac{\Delta Y}{Y}$$

Similarly the annual growth rate of the capital stock will be,

$$g_K = \frac{\Delta K}{K};$$

the growth of labour force will be $g_L = \frac{\Delta L}{L}$ and that of natural resources

$$g_Z = \frac{\Delta Z}{Z}$$

Also the growth rate of the efficiency of the economy will be,

$$g_A = \frac{\Delta A}{A}$$

And ultimately we derive the following equation

$$g_Y = a.g_K + b.g_L + c.g_Z + g_A$$

This implies that the rate of growth of output is equal to the rate of growth of capital, labour and natural resources, each weighted by their share in national income, plus the rate of growth of productivity. From this equation the growth of efficiency can be calculated as below:

$$g_A = g_Y - (a.g_K + b.g_L + c.g_Z)$$

Q3. What are the fundamental sources of growth?

Ans. In growth accounting model there are two different views. One view says that it is the growth of efficiency that is the main force behind the growth of output while the another view says that it is the growth of capital stock that induces all types of growth. According to this view, even the growth of technology is itself possible due to growth of capital stock.

Q4. How real growth of efficiency can be measured under the conditions of general rise in prices?

Ans. Allowing the effect of general price movements in the price of output, equation showing growth of efficiency becomes

$$g_A = a.g_r + b.g_w + c.g_s - g_p$$

Thus, the rate of productivity growth can be calculated as the weighted sum of the rates of growth of input prices minus the rate of growth of the output price. This says that the rate of efficiency growth is the weighted sum of the rate of growth of real capital rents, real wages and real land rents.

Q5. What are the limitations of growth accounting model.

Ans. There are several limitations of the growth accounting method. First of all it is based upon the assumptions of perfect competition, where factors are paid according to their marginal product and are similar similar across all sectors of the economy. This assumption has little applicability in the developing economies and the violation of this assumption leads to wrong conclusions regarding the contribution of various factors in output growth. The second problem is related with the assumption of constant returns to scale. If the returns to scale are increasing or diminishing and the factors are paid according to their marginal products, the value of total output will altogether deviate from the sum total of payments made to the factors and accounting for the contributions of each factor of production will not be possible. Thirdly, accounting the contribution of each factor needs a lot of information regarding the physical quantities of all inputs, their marginal productivities, the relative prices and the changes therein. Such type of information flow is hard to imagine in developing economies which have diverse sectors and have plural economic structures. Moreover, the differences in inputs and output are not taken into consideration. Finally, growth accounting is considered more an accounting exercise rather than a model of growth.

14.10 EXAMINATION ORIENTED QUESTIONS

1. Elaborate the basic set up of growth accounting model. Also discuss its generalised version.
2. Discuss the contribution of various sources of growth.
3. Discuss the real contribution of growth of efficiency in an economy facing a rise in general price level.

14.11 SUGGESTED READINGS

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14.13 MODEL TEST PAPER

I. Answer the following in brief.

Q1. What do you mean by growth accounting?

Q2. Give the basic equation of growth accounting process.

Q3. What are the fundamental sources of growth?

Q4. How real growth of efficiency can be measured under the conditions of general rise in prices?

II. Answer the following in detail

1. Elaborate the basic set up of growth accounting model. Also discuss its generalised version.

2. Discuss the contribution of various sources of growth.

3. Discuss the real contribution of growth of efficiency in an economy facing a rise in general price level.

LIMITS TO GROWTH

15.1 INTRODUCTION

The Limits to Growth is one of the seminal publications by Meadows et al. (1972) in the history of Sustainable Development. It came at a time when it was being anticipated that mankind might exhaust the resources of the earth. A world model was built specifically to investigate five major trends of global concern – accelerating industrialization, rapid population growth, widespread malnutrition, depletion of non-renewable resources, and a deteriorating environment. It was being felt that if the present growth trends in world population, industrialization, pollution, food production, and resource depletion continue unchanged, the limits to growth on this planet will be reached sometime within the next one hundred years. The most probable result will be a rather sudden and uncontrollable decline in both population and industrial capacity. However, it is also being expected that it is possible to alter these growth trends and to establish a condition of ecological and economic stability that is sustainable far into the future. The state of global equilibrium could be designed so that the basic material needs of each person on earth are satisfied and each person has an equal opportunity to realize his individual human potential. But it is possible only If the people in the world decide to strive for this second outcome rather than the first, the sooner they begin working to attain it, the greater will be the chances of success.

15.2 OBJECTIVES

This lesson has the following objectives:

1. To find the main components of growth of the world economic system.
2. To understand the process of growth of population and industrial output in the world economy.
3. To know about the limits of growth of population as well as output.
4. To construct a unified world economic system to find the limits to growth.
5. To observe the impact of technology on the limits to growth of the world system.
6. To examine the state of global equilibrium.

15.3 THE MODEL

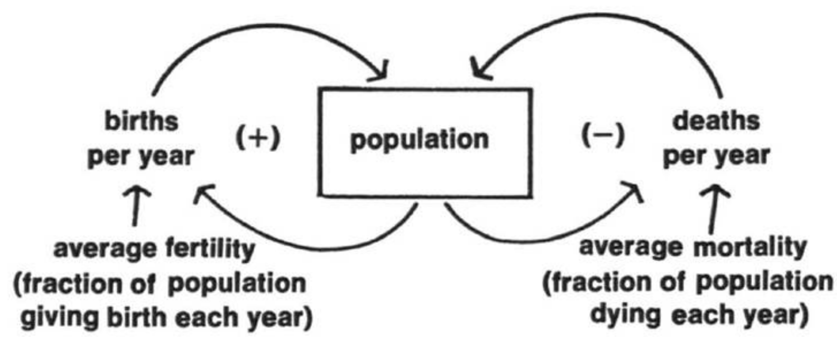
The ‘Limits to Growth’ Model is based on the report of the club of Rome’s project on the predicament of mankind which was published by D. H.

Meadows, D. L. Meadows, J. Randers and W. W. Behrens in 1972. This model led them to examine the interaction of five sub systems of the larger global economic system. These are population, food production, pollution, industrial production and consumption of non-renewable natural resources. The release of this model had popularised the environmental issues and the sustainability debate. It was the first integrated model which linked the world economy with the environment. The main features of this model are discussed below:

15.3.1 The Nature of Exponential Growth : All five elements basic to the model of Limits to Growth--population, food production, industrial production, pollution and consumption of Non-renewable natural resources--are increasing. The amount of their increase each year follows a pattern that mathematicians call exponential growth. Such exponential growth is a common process in biological, financial, and many other systems of the world. None of the five factors we are examining here is independent. Each interacts constantly with all the others. We have already mentioned some of these interactions. Population cannot grow without food, food production is increased by growth of capital, more capital requires more resources, discarded resources become pollution, pollution interferes with the growth of both population and food.

Exponential growth is a dynamic phenomenon, which means that it involves elements that change over time. When many different quantities are growing simultaneously in a system, however, and when all the quantities are interrelated in a complicated way, analysis of the causes of growth and of the future behaviour of the system becomes very difficult. This model has tried to measures these growths over a time of 30 years i.e. from 1970 to 2000. This exercise has been termed as System Dynamic model. This model suggests that any exponentially growing quantity is somehow involved with a ‘positive feed-back loop’. A positive feedback loop is sometimes called a "vicious circle" e.g. an increase in wages causes prices to increase, which leads to demands for higher wages, and so forth. In a positive feedback loop a chain of cause-and-effect relationships closes on itself, so that increasing any one element in the loop will start a sequence of changes that will result in the originally changed element being increased even more. This model has mainly discussed two basic positive feedback loops that account for exponential population and industrial growth are simple in principle. It was estimated that the population would double in 33 years. In figure 1, we can see that the growth of population will depend upon the births per year (the positive feedback loop) and the deaths per year (the negative feedback loop). With economic growth, the death rates have declined more sharply and therefore, the population of the world has also grown sharply.

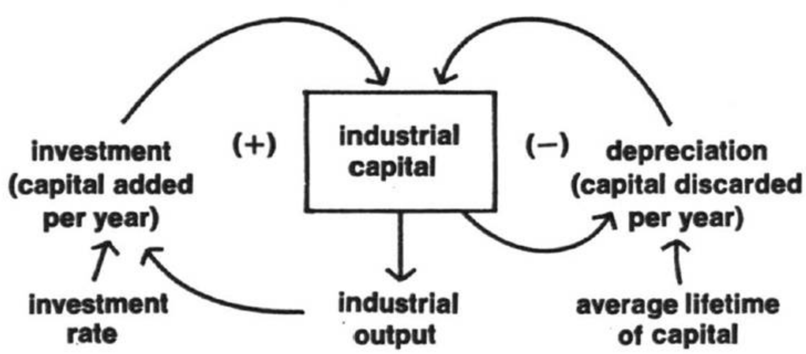
Figure 1: Growth of Population



Source : Meadows et al. (1972).

Another quantity that has been increasing in the world even faster than human population is industrial output. Its positive feedback loop is increase in capital formation while the negative feedback loop is decline in investment due to depreciation of capital. This can be observed from figure 2. With a given amount of industrial capital (factories, trucks, tools, machines, etc.), a certain amount of manufactured output each year is possible. The output actually produced is also dependent on labour, raw materials, and other inputs. For simplifying the analysis, it was assumed in this model that the other inputs are sufficient, so that capital is the limiting factor in production. More capital creates more output, some variable fraction of the output is investment, and more investment means more capital. The new, larger capital stock generates even more output, and so on. However, capital stock is not permanent. As capital wears out or becomes obsolete, it is discarded. To model this situation we must introduce into the capital system a negative feedback loop accounting for capital depreciation. The more capital there is, the more wears out on the average each year; and the more that wears out, the less there will be the next year. This negative feedback loop is exactly analogous to the death rate loop in the population system. As in the population system, the positive loop is strongly dominant in the world today, and the world's industrial capital stock is growing exponentially.

Figure 2: Growth of Industrial Output



Source : Meadows et al. (1972).

Since, at any point of time in the modern world, the growth of population will be lower than the growth of industrial production, it can be easily derived that the level of well being of the individuals should be increasing under the assumption of equitable distribution of world output across the countries. However, most of the world's industrial growth is actually taking place in the already industrialized countries, where the rate of population growth is comparatively low. The study by Meadows et al. shows that neither the growth of population nor the growth of industrial output is equally distributed across the countries. Actually the poor economies have higher growth of population while the richer economies have a higher growth of industrial output. It has been shown by a phrase that 'rich grows richer and the poor get children' which demonstrates this process would actually widen the absolute gap between the rich and the poor nations of the world. In this perspective, an important question arises if the given growth of population and the industrial output in the economy are sustainable or not? How many people can be provided for on this earth, at what level of wealth and for how long?

15.3.2 The Limits to Exponential Growth : Main question which has been raised by this model is –what will be needed to sustain world economic and population growth? This model has identified two main categories – the physical necessities and the social necessities. The physical necessities that ultimately limits the growth in this world, support all physiological and industrial activity-food, raw materials, fossil and nuclear fuels, and the ecological systems of the planet which absorb wastes and recycle important basic chemical substances. These ingredients are in principle tangible, countable items, such as arable land, fresh water, metals, forests, the oceans. On the other hand, the social necessities include peace and social stability, education and employment, and steady technological progress. These factors are much more difficult to assess or to predict. Therefore, the focus of the model is to assess the physical necessities.

Food, resources, and a healthy environment are necessary but not sufficient conditions for growth. Even if they are abundant, growth may be stopped by social problems. Assuming for the moment that best possible social conditions prevail, then it is important to know how much growth the physical system will support? It is generally being observed that a significant proportion of the population in the less developed economies is malnourished and they find it hard to maintain even their inadequate levels of per capita availability of the food grains. Therefore, there is an urgent need to raise the food production but the primary resource necessary for food production is land. Increasing more of the land under cultivation needs more of capital as good cultivable and accessible land is already under cultivation. Moreover, with industrialisation and urbanisation more of the land will shift to non-agricultural sectors, infrastructure and housing etc. leading to a fall in per capita availability of land. Therefore, even under the most optimistic conditions, the world is ought to witness the shortage of land under cultivation even if we allow constant growth of population, rise in agricultural productivity etc. leading to food scarcities, rise in food prices and increasing proportion of the malnourished population. Things turn even an uglier face due to social inequalities. The availability of food can even be further constrained by the availability of fresh water which is also diminishing. Though, better technology may postpone the crisis of availability of arable land as well as that of the fresh water but it would need more of the capital. Availability of capital will thus pose another constraint for the availability of food. Opening new land, farming the sea, or expanding use of fertilizers and pesticides will require an increase of the capital stock devoted to food production. The resources that permit growth of that capital stock tend not to be renewable resources, like land or water, but non-renewable resources, like fuels or metals. Thus the expansion of food production in the future is very much dependent on the availability of non-renewable resources whose consumption is also growing at an exponential rate. The capacity of the available resources to meet the needs of exponentially growing population will depend upon the behaviour of the resource consuming societies. They might continue to increase resource consumption according to the present pattern. They might learn to reclaim and recycle discarded materials. They might develop new designs to increase the durability of products made from scarce resources. All of these possible courses involve trade-offs. The tradeoffs are particularly_ difficult in this case because they involve choosing between present benefits and future benefits. In order to guarantee the availability of adequate resources in the future, policies must be adopted that will decrease resource use in the present. Most of these policies operate by raising resource costs.

Another exponentially increasing quantity in the world system is pollution. This model points towards four basic points in this regard. These are:

1. The few kinds of pollution that actually have been measured over time seem to be increasing exponentially.

2. We have almost no knowledge about where the upper limits to these pollution growth curves might be.

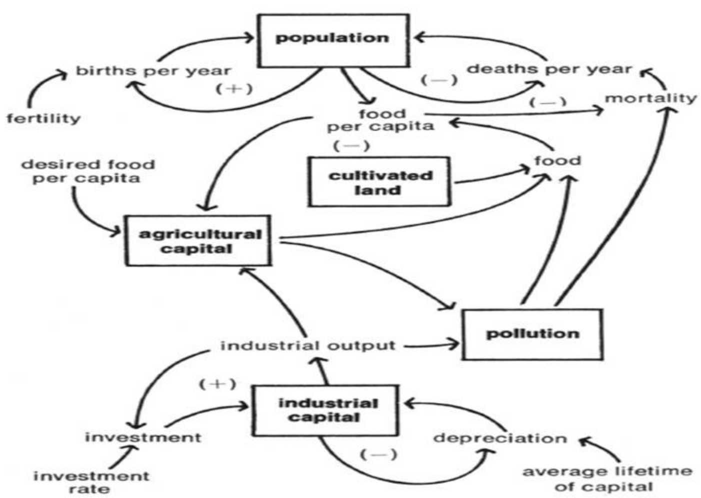
3. The presence of natural delays in ecological processes increases the probability of underestimating the control measures necessary, and therefore of inadvertently reaching those upper limits.

4. Many pollutants are globally distributed; their harmful effects appear long distances from their points of generation.

Virtually every pollutant that has been measured as a function of time appears to be increasing exponentially. The rates of increase of the various examples shown below vary greatly, but most are growing faster than the population. Some pollutants are obviously directly related to population growth (or agricultural activity, which is related to population growth). Others are more closely related to the growth of industry and advances in technology. Most pollutants in the complicated world system are influenced in some way by both the population and the industrialization positive feedback loops. Thus, we have observed that there are a number of conflicting goals before the society. But currently, the society aims at have more of the food and industrial output for increasing number of people.

15.3.3 Growth in the World System : In above discussion, we can easily recognise the interconnections among all the variables affecting growth. Population cannot grow without food, food production is increased by growth of capital, more capital requires more resources, discarded resources become pollution, pollution interferes with the growth of both population and food. Hence, we must extend our intuitive capabilities so that we can follow the complex, interrelated behaviour of many variables simultaneously. This model has tried to build a complex system to answer the questions regarding the limits to growth. The interactions among the availability of food, population growth, industrial output and pollution can be observed from figure 3.

Figure 3



Source: Meadows et al. (1972).

The figure shows that the population and capital influence each other in many ways. The amount of agricultural capital and land area under cultivation strongly influences the amount of food produced. The food per capita (food produced divided by the population) influences the mortality of the population. Both industrial and agricultural activity can cause pollution. In the case of agriculture, the pollution consists largely of pesticide residues, fertilizers etc. Pollution may affect the mortality of the population directly and also indirectly by decreasing agricultural output. In the world model, service capital (such as houses, schools, hospitals, banks etc.) can also be added as another component showing the interrelationships among all the factors discussed above. Industrial output includes goods that are allocated to service Capital. Services per capita influence the level of health services and thus the mortality of the population. Services also include education and research into birth control methods as well as distribution of birth control information and devices. Services per capita are thus related to fertility. Thus, there can be many interrelated feedback loops influencing the limits to growth. As the world's population and capital plant grow, the amount of resources consumed each year can be found by multiplying the population times the per capita resource usage rate.

Per capita resource usage rate is not constant, of course. As a population becomes more wealthy, it tends to consume more resources per person per year. Looking in to these inter-relationships, this model tries to answer some basic questions such as when and where the limit to growth would be achieved and what will the world be like when growth comes to an end?

Several alternatives are considered to answer these questions. The first alternative assumes that there will be in the future no great changes in human values nor in the functioning of the global population-capital system as it has operated for the last one hundred years. This scenario suggests that population growth increases. Industrial output, food, and services per capita increase exponentially but the resource base depletes. The collapse will occur due to depletion of non-renewable resources. The industrial capital stock grows to a level that requires an enormous input of resources. In the very process of that growth it depletes a large fraction of the resource reserves available. As resource prices rise and mines are depleted, more and more capital must be used for obtaining resources, leaving less to be invested for future growth. Finally investment cannot keep up with depreciation, and the industrial base collapses, taking with it the service and agricultural systems, which have become dependent on industrial inputs (such as fertilizers, pesticides, hospital laboratories, computers, and especially energy for mechanization). For a short time the situation is especially serious because population, with the delays inherent in the age structure and the process of social adjustment, keeps rising. Population finally decreases when the death rate is driven upward by lack of food and health services. Though, the exact timings of these events are not meaningful, given the great aggregation and many uncertainties in the model, however, it has been estimated that in this scenario growth may stop well before the year 2100.

In the optimistic scenario, it can be assumed that new discoveries or advances in technology can double the amount of resources economically available. In this case the primary force that stops growth is a sudden increase in the level of pollution, caused by an overloading of the natural absorptive capacity of the environment. The death rate rises abruptly from pollution and from lack of food. At the same time resources are severely depleted, in spite of the doubled amount available, simply because a few more years of exponential growth in industry are sufficient to consume those extra resources. It is also expected that the improvements in technology may postpone the timings when the world would reach its limits to growth.

15.3.4 Technology and Its Limits to Growth : Over the past three hundred years, mankind has compiled an impressive record of pushing back the apparent limits to population and economic growth by a series of spectacular technological advances. Since the recent history of a large part of human society has been so continuously successful, it is quite natural that many people expect technological breakthroughs to go on raising physical ceilings indefinitely. However, in the world model, technology can not be taken as a single variable as it would be influencing all the positive and negative feedback loops of population, pollution, industrial and food output and use of the natural resources. Therefore, it is not possible to aggregate and generalize the dynamic implications of technological development because different technologies arise from and influence quite different sectors of the model. Birth control pills, high-yield grains, television, and off-shore oil-drilling rigs can all be considered technological developments, but each plays a distinct role in altering the behaviour of the world system. When we introduce technological developments that successfully lift some restraint to growth or avoid some collapse, the system simply grows to another limit, temporarily surpasses it, and falls back. It is not really difficult to understand how the collapse mode comes about. Everywhere in the web of interlocking feedback loops that constitutes the world system we have found it necessary to represent the real-world situation by introducing time delays between causes and their ultimate effects. These are natural delays that cannot be controlled by technological means e.g. technology can not change the births, fertility, deaths and ageing of population beyond a limit. So its impact upon population growth will be limited further leading to limited impact on production of food and industrial goods and so on. Thus, technology may not have long lasting influence on the essential problems of the society and hence the collapse of world economic system may not be postponed beyond 2100. Still, it is believed that society will receive each new technological advance by establishing the answers to three questions before the technology is widely adopted. The questions are:

1. What will be the side-effects, both physical and social, if this development is introduced on a large scale?

2. What social changes will be necessary before this development can be implemented properly, and how long will it take to achieve them?

3. If the development is fully successful and removes some natural limit to growth, what limit will the growing system meet next? Will society prefer its pressures to the ones this development is designed to remove?

15.3.5 The State of Global Equilibrium : We have seen that positive feedback loops operating without any constraints generate exponential growth. In the world system two positive feedback loops are dominant now, producing exponential growth of population and of industrial capital. In any finite system there must be constraints that can act to stop exponential growth. These constraints are negative feedback loops. The negative loops become stronger and stronger as growth approaches the ultimate limit, or carrying capacity, of the system's environment. Finally the negative loops balance or dominate the positive ones, and growth comes to an end. In the world system the negative feedback loops involve such processes as pollution of the environment, depletion of non-renewable resources, and famine. The delays inherent in the action of these negative loops tend to allow population and capital to overshoot their ultimately sustainable levels. The period of overshoot is wasteful of resources. It generally decreases the carrying capacity of the environment as well, intensifying the eventual decline in population and capital. The growth-stopping pressures from negative feedback loops are already being felt in many parts of human society. The major societal responses to these pressures have been directed at the negative feedback loops themselves. Technological solutions, prove only to be short term solutions in relieving pressures caused by growth, but in the long run they do nothing to prevent the overshoot and subsequent collapse of the system. Another response to the problems created by growth would be to weaken the positive feedback loops that are generating the growth. Such a solution has almost never been acknowledged as legitimate by any modern society, and it has certainly never been effectively carried out.

In the state of equilibrium we have to find the balance between two types of forces. In the dynamic terms of the world model, the opposing forces are those causing population and capital stock to increase (high desired family size, low birth control effectiveness, high rate of capital investment) and those causing population and capital stock to decrease (lack of food, pollution, high rate of depreciation or obsolescence).

By choosing a fairly long time horizon for its existence, and a long average lifetime as a desirable goal, we can arrive at a minimum set of requirements for the state of global equilibrium. They are:

1. The capital plant and population are constant in size. The birth rate equals the death rate and the capital investment rate equals the depreciation rate.

2. All input and output rates – births, deaths, investment, and depreciation are kept to a minimum.

3. The levels of capital and population and the ratio of the two are set in accordance with the values of the society. They may be deliberately revised and slowly adjusted as the advance of technology creates new options.

An equilibrium defined in this way does not mean stagnation. Within the first two guidelines above, corporations could expand or fail, local populations could increase or decrease, income could become more or less evenly distributed. Technological advance would permit the services provided by a constant stock of capital to increase slowly. Within the third guideline, any country could change its average standard of living by altering the balance between its population and its capital. Furthermore, a society could adjust to changing internal or external factors by raising or lowering the population or capital stocks, or both, slowly and in a controlled fashion, with a predetermined goal in mind. The three points above define a dynamic equilibrium.

Technological advance would be both necessary and welcome in the equilibrium state. A few obvious examples of the kinds of practical discoveries that would enhance the workings of a steady state society include:

- New methods of waste collection, to decrease pollution and make discarded material available for recycling;

- More efficient techniques of recycling, to reduce rates of resource depletion;

- Better product design to increase product lifetime and promote easy repair, so that the capital depreciation rate would be minimized;

- Harnessing of incident solar energy, the most pollution-free power source;

- Methods of natural pest control, based on more complete understanding of ecological interrelationships;

- Medical advances that would decrease the death rate;

- Contraceptive advances that would facilitate the equalization of the birth rate with the decreasing death rate.

Equality is another desirable goal in the state of equilibrium. Present patterns of population and capital growth are actually increasing the gap between the rich and the poor on a worldwide basis, and that the ultimate result of a continued attempt to grow according to the present pattern will be a disastrous collapse. There is, of course, no assurance that humanity's moral resources would be sufficient to solve the problem of income distribution, even in an equilibrium state. However, there is even less assurance that such social problems will be solved in the present state of growth, which is straining both the moral and the physical resources of the world's people. Therefore, equilibrium state would not be free of pressures; since no society can be free of pressures. The equilibrium society will have to weigh the trade-offs engendered by a finite earth not only with consideration of present human values but also with consideration of future generations. To do that, society will need better means than exist today for clarifying the realistic alternatives available, for establishing societal goals, and for achieving the alternatives that are most consistent with those goals. But most important of all, long-term goals must be specified and short-term goals made consistent with them. The two important ingredients are a realistic, long-term goal that can guide mankind to the equilibrium society and the human will to achieve that goal. Without such a goal and a commitment to it, short-term concerns will generate the exponential growth that drives the world system toward the limits of the earth and ultimate collapse. With that goal and that commitment, mankind would be ready now to begin a controlled, orderly transition from growth to global equilibrium.

15.4 SUMMARY AND CONCLUSIONS

"The Limits to Growth" was a seminal publication in 1972, when it was becoming apparent that mankind's growth in population and wealth might exceed planet earth's capacity. This model analysed various aspects of dynamics of the world economy which are interrelated with each through many positive and negative feedback loops. Since all the main five components discussed in the model viz. Population, agricultural, industrial output, pollution and use of non-renewable resources are increasing exponentially, per capita availability of food and resources would decline gradually and therefore putting the limits to growth, technological progress can only delay the limit of the growth to reach but it has no capacity to avoid it forever. Thus, there is a need to recognise the urgency to keep balance between the negative and positive outcomes of growth. It is possible to alter these growth trends and to establish a condition of ecological and economic stability that is sustainable far into the future. The state of global equilibrium could be designed so that the basic material needs of each person on earth are satisfied and each person has an equal opportunity to realize his individual human potential.

15.5 GLOSSARY

(i) Birth Rate and Death Rate: Birth rate is defined as number of births per thousand of population while the death rate is defined as number of deaths per thousand of population.

(ii) Depreciation : A reduction in the value of an asset over time, due to wear and tear or just aging and rusting of the machinery is termed as depreciation.

(iii) Exponential Growth : A quantity exhibits exponential growth when it increases by a constant percentage of the whole in a constant time period.

(iv) Tangible and Intangible Assets : Tangible assets include both fixed assets, such as machinery, buildings and land, and current assets, such as inventory. The opposite of a tangible asset is an intangible asset. Nonphysical assets, such as patents, trademarks, copyrights, goodwill and brand recognition, are all examples of intangible assets.

(v) Trade Off : Trade-off refers to two conflicting goals when the achievement of one is based upon the sacrifice of another goal.

15.6 SHORT ANSWER TYPE QUESTIONS

Q 1. Discuss basic five elements of limits to growth model.

Ans. Five elements basic to the model of Limits to Growth--population, food production, industrial production, pollution and consumption of Non-renewable natural resources--are increasing. Each interacts constantly with all the others. Population cannot grow without food, food production is increased by growth of capital, more capital requires more resources, discarded resources become pollution; pollution interferes with the growth of both population and food and so on.

Q 2. What do you mean by a positive feed back loop?

Ans. In a positive feedback loop a chain of cause-and-effect relationships closes on itself, so that increasing any one element in the loop will start a sequence of changes that will result in the originally changed element being increased even more e.g. an increase in wages causes prices to increase, which leads to demands for higher wages, and so forth.

Q 3. Discuss the positive and negative feedback loops of population and industrial output.

Ans. The growth of population will depend upon the births per year (the positive feedback loop) and the deaths per year (the negative feedback loop). With economic growth, the death rates have declined more sharply and therefore, the population of the world has also grown sharply. Another quantity that has been increasing in the world even faster than human population is industrial output. Its positive feedback loop is increase in capital formation while the negative feedback loop is decline in investment due to depreciation of capital.

Q 4. Discuss the growth in the world system and its limits to growth.

Ans. For finding an integrated world economic system and its limits to growth, we have to find the interactions of population, industrial output, use of land, pollution etc. The population and capital influence each other in many ways. The amount of agricultural capital and land area under cultivation strongly influences the amount of food produced. The food per capita (food produced divided by the population) influences the mortality of the population. Both industrial and agricultural activity can cause pollution. In the case of agriculture, the pollution consists largely of pesticide residues, fertilizers etc. Pollution may affect the mortality of the population directly and also indirectly by decreasing agricultural output. In the world model, service capital (such as houses, schools, hospitals, banks etc.) can also be added as another component showing the interrelationships among all the factors discussed above. Industrial output includes goods that are allocated to service Capital. Services per capita influence the level of health services and thus the mortality of the population. Services also include education and research into birth control methods as well as distribution of birth control information and devices. Services per capita are thus related to fertility. Thus, there can be many interrelated feedback loops influencing the limits to growth. As the world's population and capital plant grow, the amount of resources consumed each year can be found by multiplying the population times the per capita resource usage rate. Per capita resource usage rate is not constant, of course. As a population becomes wealthier, it tends to consume more resources per person per year. As population growth increases, the industrial output, food, and services per capita increase exponentially but the resource base depletes. The collapse will occur due to depletion of non-renewable resources. The industrial capital stock grows to a level that requires an enormous input of resources. In the very process of that growth it depletes a large fraction of the resource reserves available. As resource prices rise and mines are depleted, more and more capital must be used for obtaining resources, leaving less to be invested for future growth. Finally investment cannot keep up with depreciation, and the industrial base collapses, taking with it the service and agricultural systems, which have become dependent on industrial inputs (such as fertilizers, pesticides, hospital laboratories, computers, and especially energy for mechanization).

Q 5. What type of technological advance can lead to a steady state society?

Ans. Technological advance would be both necessary and welcome in the equilibrium state. The limit to growth model cites a few examples of practical discoveries that would enhance the workings of a steady state society. These include:

- New methods of waste collection, to decrease pollution and make discarded material available for recycling;
- More efficient techniques of recycling, to reduce rates of resource depletion;
- Better product design to increase product lifetime and promote easy repair, so that the capital depreciation rate would be minimized;
- harnessing of incident solar energy, the most pollution-free power source;
- Methods of natural pest control, based on more complete understanding of ecological interrelationships;

- Medical advances that would decrease the death rate;
- Contraceptive advances that would facilitate the equalization of the birth rate with the decreasing death rate.

15.7 EXAMINATION ORIENTED QUESTIONS

Q 1. Elaborate the basic model of exponential growth of different elements in an economy along with the limits to the exponential growth.

Q 2. Examine the growth of an integrated world economic system and its limits to growth. What is the role of technical progress in reaching the limits to growth in an integrated world economic system?

Q 3. Discuss the state of global equilibrium under the model of limits to growth.

15.8 SUGGESTED READINGS

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15.10 MODEL TEST PAPER

I. Answer the following in brief.

Q1. Discuss basic five elements of limits to growth model.

Q2. What do you mean by a positive feedback loop?

Q3. Discuss the positive and negative feedback loops of population and industrial output.

Q4. Discuss the growth in the world system and its limits to growth.

Q5. What type of technological advance can lead to a steady state society?

II. Answer the following in detail

Q1. Elaborate the basic model of exponential growth of different elements in an economy along with the limits to the exponential growth.

Q2 Examine the growth of an integrated world economic system and its limits to growth. What is the role of technical progress in reaching the limits to growth in an integrated world economic system?

Q3. Discuss the state of global equilibrium under the model of limits to growth.

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