
UNIT 4 GROWTH AND DISTRIBUTION

Structure

- 4.0 Objectives
- 4.1 Introduction
- 4.2 Joan Robinson's Model of Economic Growth and Capital Accumulation
 - 4.2.1 Assumptions
 - 4.2.2 The Model
 - 4.2.3 The Golden Age
 - 4.2.4 Criticisms
- 4.3 Kalecki's Theory of Distribution Under Monopolistic Competition
 - 4.3.1 Assumptions
 - 4.3.2 The Model
 - 4.3.3 Labour Share and Degree of Monopoly
 - 4.3.4 A Critical Appraisal
- 4.4 Kaldor's Model of Economic Growth
 - 4.4.1 Assumptions
 - 4.4.2 Working of the Model
 - 4.4.3 A Critical Appraisal
- 4.5 Pasinetti's Theory of Growth and Distribution
 - 4.5.1 Reformulating the Kaldorian Model
 - 4.5.2 Rate and Share of Profit in Relation to Rate of Growth
 - 4.5.3 Fundamental Relation between Profits and Savings
 - 4.5.4 Implications of the Model
 - 4.5.5 Conditions of Stability
- 4.6 Let Us Sum Up
- 4.7 Key Words
- 4.8 Some Useful Books
- 4.9 Answers / Hints to Check Your Progress Exercises

4.0 OBJECTIVES

After going through the unit, you will be able to:

state the nature of the investment function as determined by decisions of capitalists;

Describe a set of growth theories in which growth and income distribution emerge as intertwined processes;

Provide a critique of the neo-classical conception of saving and investment; and

Discuss and compare theories of distribution and growth put forward by Joan Robinson, Kaldor, Kalecki and Pasinetti.

4.1 INTRODUCTION

Growth theory that appeared in economic literature after the publication of Keynes' General Theory in 1936 is usually referred to as modern growth theory, which tried to make dynamic, the short-run static growth theory evolved by Keynes. Broadly there are three major branches of modern growth theory.

One relates to the growth rate of economy's aggregate output to that of its capital stock. In this approach capital is the only factor of production, explicitly considered and it is assumed that labour is combined with capital in fixed proportions. It holds that under laissez faire conditions there is no effective adjustment mechanism to equate investment with savings at full employment level. This fixed-proportion theory is commonly known as the Harrod-Domar theory. This approach to the growth theory rapidly changed and the theory that dominated after is known as neoclassical growth theory. This theory considers a production function where capital and labour is employed in varying proportions. The theory gives an explanation, similar to classical theory where full-employment savings will be watched by an equal amount of planned investment provided there is full utilisation of the factors of production.

A third branch of modern growth theory is described as modern Cambridge theory because of its close association with names like Joan Robinson and Nicholas Kaldor of Cambridge University. This theory is highly critical of neoclassical theory in many ways. For example, it rejects the classical approach to savings and investment given by neoclassical theory. Cambridge theory returns to Keynesian approach where investment is determined not by saving propensities but by capitalists' decisions, which, in fact, are considered to be dependent upon past experience, government policies and the willingness to bear risk. It also rejects production function and with it the entire marginal productivity theory of income distribution and offers alternative theories. The Cambridge school therefore presents both a theory of income distribution and theory of growth with its unique feature of incorporation of a Keynesian theory of income distribution.

4.2 JOAN ROBINSON'S MODEL OF ECONOMIC GROWTH AND CAPITAL ACCUMULATION

A major approach to growth theory was provided in 1956 by Mrs. Joan Robinson in her classic book 'The Accumulation of Capital'. The main contribution of Mrs. Robinson to Post-Keynesian growth economics lies in her successful bid to integrate the classical value and distribution theory with Keynes' saving-investment theory into a synthesised coherent system.

4.2.1 Assumptions

Mrs. Robinson builds her model on the following assumptions.

- 1) The economy is assumed to be closed one i.e. there is no foreign trade.
- 2) Such an economy reflects the conditions of a competitive, laissez-faire capitalism.
- 3) There are only two factors of production viz; capital and labour.
- 4) The technical horizon is assumed to be given and constant
- 5) The technical coefficients of production are fixed.

Where C, S, I is consumption, savings and investment respectively. As savings in Mrs. Robinson's Model are the sole prerogative of the entrepreneurs, wage-earners being assumed to consume their entire incomes; profits are, therefore meant to be ploughed directly into investment. As such we can write the equation (iv) in the following form:

$$S = \Pi K = I \quad \dots (v)$$

Instead of I , we can substitute ΔK which is the increase in real capital.

$$\text{i.e., } \Delta K = \Pi K$$

$$\text{or } \Pi = \Delta K / K \quad \dots (vi)$$

for getting equilibrium, we simply have to juxtapose the income and expenditure sides. Thus equilibrium condition(s) are

$$\Pi = p \cdot w / p / Q = \Delta K / K \quad \dots (vii)$$

This equilibrium condition manifests a double-sided relationship between the rate of profit and rate of accumulation. On the one hand, it tells us that the rate of accumulation going on in a particular situation determines the level of profits obtainable there from. It determines the rate of profit which the entrepreneurs would expect on their investment. On the other hand, the equilibrium condition shows that the rate of profit itself governs the rate of accumulation. Anything that determines the rate of profit would also determine the rate of growth of capital.

Accumulation and profit are, therefore, linked with each other in a circular way. "If they have no profit, the entrepreneurs can not accumulate and if they do not accumulate they have no profit." Thus, the basic mechanism underlying Mrs. Robinson's growth model is the desire of the firms to accumulate and the urge to accumulate is dependent on the expected rate of profit.

4.2.3 The Golden Age

The situation of smooth steady growth with full employment arising out of the equality of the 'desired' and 'possible' rates of accumulation has been designated by Mrs. Robinson as the 'golden age' equilibriums.

Suppose Q is constant under the conditions of full employment, then from the equation $K/N = Q$ we get,

$$K = QN$$

$$\therefore \Delta K = \Delta N Q$$

$$\text{or } \Delta N = \Delta K / Q$$

$$\text{or } \Delta N / N = \Delta K / Q / N = \Delta K / Q / K / Q \quad (\because N = K / Q)$$

$$\text{or } \Delta N / N = \Delta K / K \quad \dots (viii)$$

The equation (viii) implies that if Q is constant at the full employment level, their labour and capital grow at the same rate. This is the situation of 'golden age' equilibrium. The equality between the desired and possible rates of accumulation coexists with full employment of labour and capital. Besides, both labour and capital grow at the same rate. The economy is thus on a tranquil steady growth path – "a steady rate of accumulation than rolls smoothly on its way". There is harmony in all respects.

The entrepreneurs are in a state of equilibrium. As their desired rate of accumulation is being realised, the wage-earners, on the other hand, are in equilibrium state because there comes to prevail an overall harmony in the demand and supply of labour.

Stability of 'Golden Age' equilibrium: if certain forces operate so as to disturb the 'golden age' equilibrium of the economy, equilibrating mechanisms automatically come into being to restore the equilibrium. Let us see how?

The divergence from the 'golden-age' equilibrium path will take place if:

- a) $\Delta N/N > \Delta K/K$
- or
- b) $\Delta N/N < \Delta K/K$

In case (a), the population will grow faster than the capital stock. This signifies the situation of underemployment with the prevalence of surplus labour, money wage rates get depressed. But if price level is to remain unchanged the real wages will have to fall.

Now if real wages start falling, then as is clear from the basic equilibrium equation (vii), the rate of profit will ascend gradually. As such the rate of growth of capital accumulation will go on moving up till it catches up with the rate of growth of population. And the 'golden-age' equilibrium, would thus, again be established. However, the equilibrium would fail to be restored if the money wages remain inflexible or if the price level falls in consonance with the fall in the money wages.

Case (b) or the second possibility for divergence from the 'golden age' equilibrium occurs where $\Delta N/N < \Delta K/K$, i.e., the rate of population growth falls short of the growth rate of capital-stock. Such a situation manifests a state of excess capital accumulation. It can be seen that under such circumstances, appropriate changes in the capital-labour ratio (Q) or the labour productivity (P) can help to regain the 'golden age' equilibrium.

Limping golden age: Under this age, steady rate of accumulation coexists with unemployment. It is just possible that sufficient capital stock with a composition quite appropriate to the desired rate of accumulation exists. But it may not be enough in so far as the employment of the entire labour force is concerned. The steady rate of accumulation is taking place, but the conditions of full employment have not been achieved. Mrs. Robinson christens such a state of affairs as the 'limping golden age'.

The intensity of the limp may be of different degrees depending on the rate of fall or rise in employability vis-a-vis the labour force. If the rise in the level of employment occurs at a rate smaller than that of labour force, unemployment would increase with time. The limp in this case is rather severe.

However, if the rise in the level of employment occurs at a rate greater than that of labour force employment would increase more rapidly than the labour force, And, therefore, unemployment will shrink with time and the economy approached full employment rather quickly. The limp here is thus mild and it tends to die away in the long run. As such this age will be a transient one.

Leaden Age: It, in fact, is a special case of a 'limping golden age' in which the degree of unemployment is increasing due to inadequate rate of accumulation.

Restrained golden age: This is an age of full employment but the 'desired rate' of accumulation happens to exceed the 'possible rate' determined by the rate of growth

of labour force plus the rate of technological progress. The possible rate is kept down by factors such as financial stringency or monopsony in the labour market, so that the 'realised rate' of growth is kept down to the level of the 'possible rate'.

It may so happen that the stock of capital is appropriate to the desired rate of accumulation and the full employment has already been achieved. But it may fail to be realised on account of its being restrained by a stunted rate of growth of labour force and the rate of technical progress.

Bastard golden age: It denotes a situation where unemployment prevails but the real wages remain rigid downwards. As such the rate of accumulation is prevented from increasing in the absence of technical progress. The ultimate cause of less than adequate growth of capital stock may lie in the existence of an 'inflationary barrier'.

For the rate of accumulation to be raised, it is necessary to lower down the real wages. But generally there is some level of minimum acceptable real wages so that when prices rise, some increase in money wages follows due to the attempts of the organised labour to resist the erosion of real wages below the minimum acceptable level. Thus the attempts to raise the rate of accumulation would be arrested by the inflationary rise in money wages. This is the 'bastard golden age'.

4.2.4 Criticism

Mrs. Robinson's model is not free from flaws. Some of the main drawbacks are as follows:

- 1) **Only the various forms of Growth Process:** This model provides only a framework of studying the various forms of growth process. We can not predict on the basis of the model as to what possibly shall be the succeeding phase or type of growth. The different types of growth that have been analysed are left as 'isolated islands' in her model. The inter-connecting straits have not been explored.
- 2) Secondly, Mrs. Robinson studies that the prime variable of her model, viz., the rate of capital accumulation gets adjusted to the population growth via adjustments in wage rate, profit rate and labour productivity. This tantamount to suggest redistribution of income through relative factor prices, but it would be more practical and realistic to deploy fiscal and monetary measures for making adjustment in capital growth with population growth.
- 3) **Neglects Role of State:** Thirdly, in Robinson's model, state has been completely left out of the picture. It is indeed unrealistic and precarious to rely solely on the private entrepreneurs for the achievement of a stable growth of the economy in tune with the requirements of a growing population and rapidly changing technology.
- 4) **Wrong Assumption of constant technique:** This model is carried out under the assumption of a given and constant technological horizon, but is unrealistic. For instance, under the given technical conditions when the rate of accumulation happens to be higher than what is required for achieving the 'golden age' equilibrium, it will *ipso facto* alter the pace of technological progress. What is likely to happen in this case is that due to the pressure on the labour-supply, labour-saving innovations and inventions would be stimulated. Besides, there will be inducement for quick diffusion and introduction of labour-displacing technical improvements which had so far been held back due to an abundant and cheaper supply of labour.
- 5) It neglects the role of institutional factors as social cultural and institutional changes, on which the development of the economy considerably depends.

4.3 KALECKI'S THEORY OF DISTRIBUTION UNDER MONOPOLISTIC CAPITALISM

Kalecki was contemporary of Keynes and a Polish economist. He wrote on diverse aspects of economic theory, however, is known more for his theory on business cycles, pricing and degree of monopoly. As compared to other theories, his essay on the theory of growth came at a later stage in 1969 when he wrote - "Introduction to the Theory of Growth in a Socialist Economy". Kalecki's theory of distribution is dependent upon A.P. Learner's Microeconomic degree of Monopoly. Symbolically, it is denoted as $P-m/p$; where p stands for price and m stands for marginal cost. In other words, $p-m$ stand for profit share at micro level.

In Kalecki's formulation of the degree of monopoly, marginal cost includes cost of labour and raw materials per unit of output. Further, cost of labour includes only wages of manual labour since salaries of white collar people are merged with the earnings of the capitalist class. Thus $p-m$ indicates the income of the capitalist class including entrepreneurial profit and aggregate overhead cost i.e. interest, depreciation and salaries, per unit of output.

4.3.1 Assumptions

While discussing a theory of distribution, Kalecki postulated a closed economy and assumed

- That the short period marginal cost curve is equal to short period average cost on manual labour and raw materials to a certain point corresponding to practical capacity.
- that output in the firms in the real world is less than the maximum practical capacity. Thus in other words, he assumes the existence of excess capacity in the economy. and
- that there is imperfection in factor and commodity market.

4.3.2 The Model

Since Kalecki starts from Learner's measure of degree of monopoly of a single firm. For Learner's Degree of Monopoly;

$$M = \frac{P - m}{p}; \text{ where } M \text{ is degree of monopoly, } p = \text{price and } m = \text{marginal cost}$$

Since Kalecki assumes that marginal cost is equal to average cost, we can replace it in the formula and the equation can be rewritten as

$$M = \frac{P - a}{p} \quad \dots (i)$$

$$\text{or } pM = (p - a) \quad \dots (ii)$$

$(p-a)$ is the difference between price of the product and average cost of manual labour and raw materials per unit of output. Thus the difference $(p-a)$ is made up of profit share of a single employer on a single product. Let x be the total production of the firm. Multiplying equation 2 by x we get

$$\text{or } xpM = x(p - a) \quad \dots (iii)$$

$x(p-a)$ represents the total gross capitalists' income of the employer. In order to get gross capitalist's income for the economy, where there is large number of firms; we add the gross capitalist's income of all firms in the economy;

$$\sum xpM = \sum x(p-a) \quad \dots (iv)$$

$\sum x(p-a)$ equals the gross capitalists' income of all the firms of the economy taken together, $\sum xp$ represents aggregate turnover (T) of the economy. Thus $T = \sum xp$. Since T is made up of the value of gross national product and plus the value of the raw materials produced and sold; dividing both sides of the equation (4) by T, we get

$$\frac{\sum xpM}{T} = \frac{\sum x(p-a)}{T}$$

but $T = \sum xp$ so

$$\frac{\sum xpM}{\sum xp} = \frac{\sum x(p-a)}{T} \quad \text{or we get, Macro degree of monopoly } (\bar{M})$$

$$\bar{M} = \frac{\sum x(p-a)}{T} \quad \dots (v)$$

$$\text{or} \quad \text{Macro degree of Monopoly} = \frac{\text{Gross Capitalist Income}}{\text{Aggregate Turnover}}$$

Thus the equation (5) indicates that there is positive functional relationship between the macro degree of monopoly enjoyed in an economy and its gross capitalist share, provided the aggregate turnover remains constant.

4.3.3 Labour Share and Degree of Monopoly

Kalecki points out that during boom period competition increase, which reduces the degree of monopoly. The reduction in degree of monopoly tends to raise the share of labour in national income. However the rise in the price of raw material tends to reduce it. **Thus** the two forces work against each other and in boom period the relative shares of labourers' and capitalists' remain constant.

4.3.4 A Critical Appraisal

Kalecki's theory of distribution is an attempt to reinstate Marxian theory of distribution. Despite his significant contributions he has been criticised on many fronts. He is criticised by attributing only profits to the degree of monopoly power and ignoring other factors that affect distributive shares. The theory is based on unreal assumptions where marginal cost is equal to average cost. This is possible only when there are constant returns prevalent in the market. The theory also appeared to have ignored the role of trade unions. In his later contributions, however, he recognised this drawback and tried to justify their contribution while discussing theory of growth of a socialist economy.

- 1) Explain the concept of Golden Age Equilibrium in Joan Robinson's Model.

[illegible]

- 2) What are the main criticisms that can be made of Joan's model?

[illegible]

- 2) State the main assumptions and describe the **Kaleckian** model of distribution under monopolistic competition.

[illegible]

4.4 KALDOR'S MODEL OF ECONOMIC GROWTH

Prof. Kaldor in his 'A Model of Economic Growth' follows the Harrodian dynamic approach and the Keynesian techniques of analysis. The other classical models treat the technical progress as completely exogenous, but Kaldor attempts to provide a framework for relating the genesis of technical progress to capital accumulation.

4.4.1 Assumptions

- 1) It is based on the Keynesian full employment assumption in which the short-period supply of aggregate goods and services is inelastic.
- 2) Income consists of wages and profits where wages comprise salaries and earnings of manual labour and profit comprise incomes of entrepreneurs as well as property owners. i.e. $y = w + p$.
- 3) Total savings consists of savings out of wages and savings out of profits,
Since $S = f(Y)$ & $y = w + p$
 $\therefore S = f(w, p)$
i.e. $S_w + S_p = S$
- 4) Profits in the economy are a function of investment
- 5) Prices are assumed to be constant i.e. monetary policy has a very little role to play.
- 6) The choice of techniques is also assumed to alter with the accumulation of capital and the progress of technique is the capital-grade making industries.
- 7) Technical progress depends on the rate of capital accumulation. For this, Kaldor postulates "the technical progress function" which is a joint product of two tendencies: growth of capital and growth of productivity. As in figure 1, TT' is the technical progress function which is convex upwards but flattens out beyond a certain point, such as P in the figure when capital per workers starts diminishing. The annual percentage growth in capital per worker at time t is measured on x -axis and output labour ratio on y -axis. At point P $C/L = Y/L$. If the rate of capital accumulation is left of P, output will be growing faster than capital and the rate of profit on new investment will increase. There will be movement towards right till point P is reached, on the contrary if one happens to be on the right of P, capital will be growing faster than output, the rate of investment will decline and there will be movement towards left till point 'P' is reached.

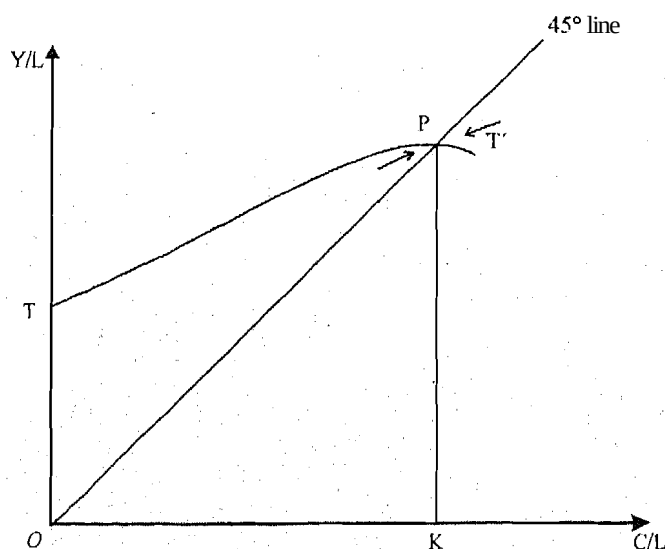


Fig. 4.1

The model operates under two stages:

- a) Constant working population and
- b) Expanding population

In the former, the proportionate growth rate of total real income will be the same as the proportionate growth rate of output per head. In the latter, the proportionate change in total real income is the sum of the proportionate change in output per head and the proportionate change in total working population.

a) Constant Working Population

For the operation of model, Kaldor postulates three functions

i) Saving Function

$$S_t = \alpha P_t + \beta(Y_t - P_t)$$

where $(1 > \alpha > \beta \geq 0)$

where P_t = profit in time period t , S_t = savings in time period t , Y_t = income in period t , α and β are MPS_s of profit and wage earning class in such a way that $1 > \alpha > \beta \geq 0$.

ii) Investment Function

$$K_t = \alpha' Y_{t-1} + \beta' (P_{t-1}/K_{t-1}) Y_{t-1}$$

and $I_t = K_{t+1} - K_t$

where K_t = stock of capital in times period t , Y_{t-1} = is the output of previous period, (P_{t-1}/K_{t-1}) = rate of profit on capital, α' and β' are the coefficients of output and rate of profit respectively in such a way that $\alpha' > 0$ and $\beta' > 0$.

iii) Technical Progress Function

$$(Y_{t+1} - Y_t) / Y_t = \alpha'' + \beta'' I_t / K_t$$

where $(Y_{t+1} - Y_t) / Y_t$ is the rate of growth of income, I_t / K_t = rate of net investment, α'' = coefficient of technical progress and β'' = capital per head C/L. Here $\alpha'' > 0$ but $1 > \beta'' > 0$.

Giving these three functions, the rate of growth of income, I_t / K_t = rate of growth of economy with constant population, can be shown with the help of following diagram in figure 2 where proportionate growth of capital $[(K_{t+1} - K_t) / K_t]$ is measured horizontally and the proportionate growth of income $(Y_{t+1} - Y_t) / Y_t$ vertically. Point G as determined by the technical progress function TT' and the 45° line is one of the steady growth points where proportionate growth of income equals proportionate growth of capital, starting from period t_1 where the growth of output G_1 is greater than growth of capital, i.e. C/O is less so investment will increase in the subsequent period so as to make capital equal to G_1 at A. This will, in turn, raise the growth of output in period t_2 to G_2 . The rate of investment will increase further to A, in period t_3 . So as to make A, equal to G_2 at point B. Similarly, the growth of output in subsequent periods will rise till point G is reached. This process will be reinforced by changes to the rate of profit on capital.

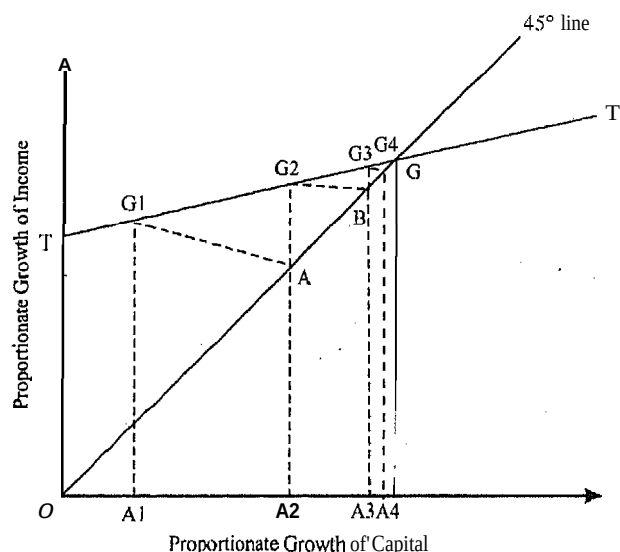


Fig. 4.2

b) Expanding Population

Leaving the assumption of constant working population, Kaldor studies the relation between growth in population and growth in income. The relation of population growth with the growth in income is expressed by Kaldor, algebraically as under

$$I_t = g_t (g_t \geq \lambda)$$

and $I_t = \lambda$

Where I_t is the percentage rate of growth of population, g_t is the percent rate of growth of income and λ is the maximum rate of population growth. If $g_t < \lambda$ and so is $I_t < \lambda$, the rates of growth of income and population will continue to

rise till the growth rate of population equals λ . This relation between population growth and income growth is represented in the figure 3 where proportionate rate of growth of income is measured horizontally and proportionate rate of growth of population is measured vertically. Oh is the growth path of income. PL λ is the curve of the growth rate of population. As the growth rate of income increases the growth rate of population also rises till the h curve becomes horizontal at a level where the rate of growth of income (OY) exceeds the former as at point E. In the long run population would grow at its maximum rate indicated by Lh portion of the dotted population growth rate curve. This assumes that the shape and position of the technical progress function, as given by the coefficient α'' and β'' in the equations (3) are not affected by the changes in population.

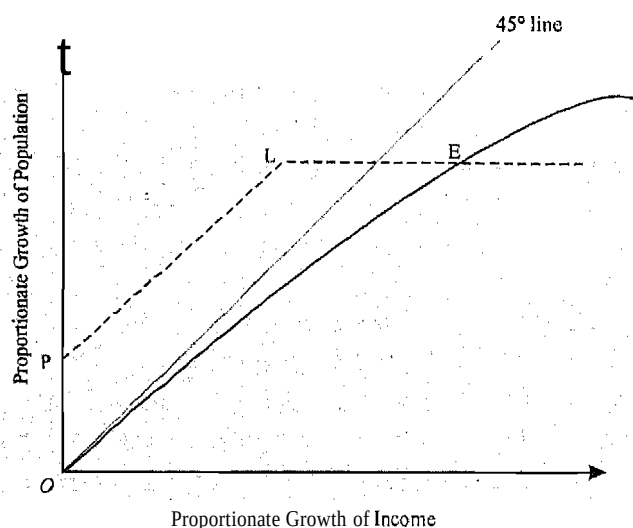


Fig. 4.3

But in a developing economy with a low capacity to absorb technical changes due to the scarcity of land and capital, the technical progress function will be lowered with the increase in growth rate of population. In this situation the technical progress function will cut the x-axis positively as at A in the figure 4. This implies that in order to maintain output per head at a constant level, a certain percentage growth in capital per head will be required. We have therefore two points of intersection P' and P of the technical progress function. Point P' is unstable equilibrium and point P of stable long run equilibrium. If the rates of growth of income and capital continuously diminish in the economy, both the output per head and capital per head may cease to grow. This may happen if the economy is to the left of point P'. If this situation persists, the technical progress function TT' may slip down as the dotted curve in any long run equilibrium. Rather, there may be stagnation in the economy.

The conclusion emerges from this analysis that the growth in population will lead to long-run equilibrium growth in income depending upon

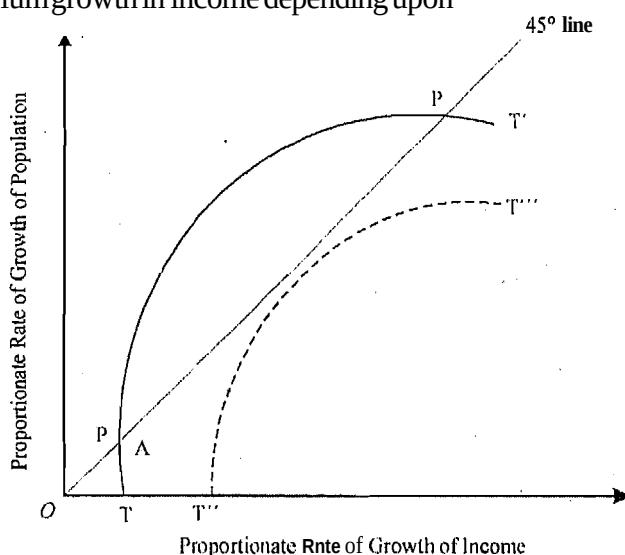


Fig. 4.4

the relative strength of the following two factors.

- 3 The maximum rate of population increase λ , and
- ii) The rate of technical progress, which causes a certain percentage increase in productivity, α in equation (3) above, when both population and capital per head are held constant

4.4.3 A Critical Appraisal

Kaldor's Model is based on the Keynesian tools of analysis and follows Harrod's dynamic approach regarding the rates of change in income and capital as the dependent variables of the system. But his model is quite different from the Harrodian and other models. In Kaldor's own words, "the ultimate causal factor was not savings or capital accumulation but, 'technical dynamism' — the flow of new ideas and the readiness of the system to absorb them".

- i) It explains the steady-path of the growth rather than steady state.
- ii) The division of the model into two stages—constant population and expanding population—is an attempt to reconcile the Harrodian warranted and natural rates of growth by demonstrating the long-run tendency for the two to converge by mutual interaction. The expanding population version of the model is particularly useful in demonstrating the effect of population growth on the growth of income in developing countries.

- iii) Kaldor's technical progress function is an improvement over the usual production function. As the former relates the technical progress to growth of productivity and capital accumulation while latter relates output per head to capital per head.

Despite these virtues of the Kaldor Model, it is not free from certain weaknesses.

- a) Kaldor's Model does not explain the determination of the rate of growth of the economy, as has been explained in the Harrod-Domar Models in terms of the volume of investment, saving income ratio and the capital-output ratio.
- b) Unlike the Harrod-Domar Model, this model does not give the reason for stability or instability in the economic system. Rather it analyses, certain features of the growth process which emphasise convergence and stability.

These drawbacks, however, do not detract one from the advances made by Kaldor in growth theory through this model.

4.5 PASINETTI'S THEORY OF GROWTH AND DISTRIBUTION

Pasinetti gave a more logical reconsideration of the theoretical framework provided by Cambridge economists where they have written to correct rate of profit and distribution to the rate of economic growth. Pasinetti gave a proof that the model, as originally formulated can not be maintained to achieve full employment so he modified the model and came to some general conclusions.

He criticised that for any given rate of population growth and of (Neutral) technical progress (neutral technical progress is discussed in the following unit in detail) there is only one saving ratio that keeps the system in equilibrium. According to him, "in any type of society, when any individual saves part of the income, he must also be allowed to own it, other wise he would not save at all". This means that the stock of capital which exists in the system is owned by those people (capitalists or workers) who in the past made the corresponding savings. So he divided total profits into two categories i.e. profits which accrue to the capitalists and profits which accrue to the workers. The latter comes as a part of the stock of capital that workers have saved and thus owned directly or through loans to capitalists, for which they will receive a share of total profits.

This distinction in the theory was missing that Pasinetti corrected and reformulated the model given by Kaldor. According to him, 'by attributing all profits to the capitalists it in advertently but necessarily imply that workers savings are all totally transferred as a gift to the capitalists clearly sounds as an absurdity.'

4.5.1 Reformulating the Kaldorian Model

While reformulating the model given by Kaldor, he added a identity:

$$P \equiv P_c + P_w$$

Where P_c and P_w stand for profits, which accrue to the capitalists and profits, which accrue to the workers; the saving functions now becomes $S_w = S_w(W + P_w)$ and $S_c = S_c P_c$; and the equilibrium condition becomes:

$$I = S_w(W + P_w) + S_c P_c = S_w \\ Y + (S_c - S_w) P_c \text{ (Where } Y \equiv W + P)$$

from which, we can obtain that there is distribution of income between wages and profits:

$$P_c / Y = 1 / (S_c - S_w) \cdot I / Y - S_w / (S_c - S_w) \quad \dots (1)$$

and corresponding to this, rate of profit remains given equilibrium condition, $I = S$

$$P_c / K = 1 / (S_c - S_w) \cdot I / K - S_w / (S_c - S_w) \cdot Y / K \quad \dots (2)$$

the expressions used so far do not refer to total profits. They only refer to that part of profits which accrue to the capitalists. Let us examine the implications.

As far as the distribution theory is concerned, equation (1) still retains a definite, but restricted, meaning. It now only expresses the distribution of income between capitalists and workers. The distribution of income between profits and wages is something different, and to obtain it, one must add the share of workers' profit into income (P_w / Y) to both sides of equation (1). Passinetti maintains that, as to the theory of the rate of profit, the consequences of our reformulation are even more serious. Expression (2) simply represents the ratio of a part of profits (P_c) to total capital, but this concept has no useful or interesting meaning. He argued that the expression which is really needed, is one for the ratio of total profits to total capital (rate of profit), and to obtain it, we must again add a ratio (P_w / K) to both sides of equation (2). In other words, we have to find suitable expressions for:

$$P / Y = P_c / Y + P_w / Y \quad \dots (3)$$

$$\text{and } P / K = P_c / K + P_w / K$$

Let us start with the latter equation. We know P_c / K already from (2). Thus, writing K_w for the amount of capital that the workers own indirectly – through loans to the capitalists – and i for the rate of interest on these loans, we obtain:

$$P / K = 1 / S_c - S_w \cdot I / K - S_w / S_c - S_w \cdot Y / K + i K_w / K.$$

An expression for K_w / K can easily be found. In dynamic equilibrium:

$$K_w / K = S_w / S = S_w (Y - P_c) / I = S_w S_c / S_c - S_w \cdot Y / I - S_w / S_c - S_w,$$

which, after substitution into the previous expression, finally gives us:

$$P / K = 1 / S_c - S_w \cdot I / K - S_w / S_c - S_w \cdot Y / K + i (S_w S_c / S_c - S_w \cdot Y / I - S_w / S_c - S_w) \quad \dots (4)$$

By exactly following the same procedure, the expression for equation (3) comes out as:

$$P / Y = 1 / S_c - S_w \cdot I / Y - S_w / S_c - S_w + i (S_w S_c / S_c - S_w \cdot K / I - S_w / S_c - S_w \cdot K / Y) \quad \dots (5)$$

These are the two general equations that Pasinetti gave. These equations contain all the elements which are necessary to correct the post-Keynesian theory of income distribution and of the rate of profit. Equations expressing the rate of profit, must be replaced by equation (4) and equation (3) for the distribution of income between workers and capitalists, and equation (5) for the distribution of income between wages and profits.

4.5.2 Rate and Share of Profits in Relation to the Rate of Growth

Pasinetti maintained that the most immediate consequence of the reformulation which has just been carried out is that, in order to say anything about share and rate of profits, one needs first a theory of the rate of interest. In a long-run equilibrium model, He argued that the obvious hypothesis to make is that of a rate of interest equal to the rate of profit. If we do make such a hypothesis, equations (4) and (5) become very simple indeed. By substitution P/K for i , equation (4), we get:

$$\begin{aligned} P/K [1 - (S_w S_c / S_c - S_w \cdot Y/I) + \\ (S_w / S_c - S_w)] = I / S_c - S_w \cdot I/K - S_w / S_c - S_w \cdot Y/K, \\ P/K (S_c (I - S_w \cdot Y) / I) = I - S_w \cdot Y/K. \end{aligned}$$

hence, provided that:

$$I - S_w Y \neq 0, \quad \dots (6)$$

(otherwise the ratio P/K would be indeterminate) the whole expression simply becomes:

$$P/K = (I/S_c) \cdot (I/K) \quad \dots (7)$$

And by an analogous process, equation (5) reduces to :

$$P/Y = I/S_c \cdot I/Y \quad \dots (8)$$

According to Pasinetti, in this reformulation unlike earlier models, we do not have to formally making any assumption whatsoever on the propensities to save of the workers. This is, in fact, the most striking result of our analysis. It means that, in the long run, workers' propensity to save, though influencing the distribution of income between capitalists and workers – equation (3) – does not influence the distribution of income between profits and wages – equation (8). Nor does it have any influence whatsoever on the rate of profit – equation (7)

4.5.3 Fundamental Relation between Profits and Savings

Pasinetti had build his model on the institutional principle inherent in any production system where wages are distributed among the member of society in proportion to amount the labour they contribute and profit are distributed in proportion to the amount of capital they own. In other word it implies that in the long run profit will be distributed in proportion to the amount of savings that are contributed. It, however, does not matter how many categories of individuals we may consider, the ratio of profits (that each category receive) to the savings will always be the same for all categories or

$$P_w / S_w = P_c / S_c \quad \dots (9)$$

4.5.4 Implications of the Model

Pasinetti came to two conclusions based on the above model:

- 1) The irrelevance of workers propensity to save gives the model a much wider generality than was earlier believed. Since the rate of profit and income distribution between profits and wages are determine independently of S_w , there is no need of any hypothesis on the aggregate saving behaviour of the workers.

4.5.5 Conditions of Stability

Check Your Progress 2

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- This image shows a full page of a handwriting practice worksheet. It consists of ten sets of horizontal dotted lines spaced evenly down the page, providing a guide for letter height and placement. The background is plain white, and there are no other markings or text present.

-
- This image shows a single sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.

4.6 LET US SUM UP

This unit discussed certain theories of growth and distribution put forward by a group of economists associated with Cambridge University, England. These theories jointly provide an approach to the study of economic growth where economic growth is analysed along with income distribution, particularly among the different factors of production, mainly labour and capital. The theories also critique the neo-classical theory of saving and investment.

The unit discussed the theories of Joan Robinson, Michal Kalecki, Nicholas Kaldor, and Luigi Pasinetti. Although there are some broad similarities in the four theories, each is also a distinct model with its own characteristics.

Joan Robinson's theory is mainly a theory of capital accumulation and economic growth. Mrs. Robinson takes more or less the classical theory of value and distribution with the Keynesian theory of saving and investment. Joan Robinson considers a competitive capitalistic system with fixed coefficients. Her theory gives primacy to capital accumulation driven by the desire of capitalists to make profits; also, in her theory, capital accumulation and the profit rate influence, and are influenced by, each other. Mrs. Robinson's theory also attempts to look at the picture of employment arising in such a scenario and describes certain 'ages'.

For Michal Kalecki, the distinguishing feature of modern capitalism is the presence of monopolies. Monopolies have to be studied not only in the case of static resource allocation, but also dynamic growth processes. Kalecki provided a formulation of the degree of monopoly. He attempted to look at the share of labour and capital under such monopoly capitalism. He however, did not consider bilateral monopoly, that is, where the buyer is a monopsonist. He also did not consider monopoly in the labour market where labour is a local monopolist as trade unions.

Nicholas Kaldor was heavily influenced by the work of John Maynard Keynes. He provided a model reminiscent of Harrod's model but in Kaldor the engine of growth was not so much saving and accumulation but technical progress. Kaldor also gave some suggestions about technical change being endogenous. The following unit on technical change and the unit in Block 3 on endogenous growth use these ideas. Luigi Pasinetti gave a logical underpinning to the Cambridge ideas and gave a coherent theory that linked growth with income distribution. He also ironed out some of the flaws of the Kaldorian model.

4.7 KEY WORDS

Degree of Monopoly	A measure proposed by Kalecki to look at strength of market power by a monopoly.
Golden Age Equilibrium	A state proposed by Joan Robinson where smooth steady growth takes place and the desired and possible rates of accumulation are equal.

4.8 SOME USEFUL BOOKS

Meade J.E 1964. *A Neoclassical theory of Economic Growth*, London

Kaldor, N. 1956. "Alternative Theories of Distribution", *The Review of Economic Studies* vol. XXIII, No.2, pp.83-100

Kalecki M. (1971/1937): *Selected Essays on the Dynamics of the Capitalist Economy*, Cambridge University Press, Cambridge.

Pasinetti, L.L. (1980): *Growth and Income Distribution: Essays in Economic Theory*, Cambridge University Press, Cambridge.

Robinson, Joan (1962). *Essays in the Theory of Economic Growth*. Macmillan, London.

4.9 ANSWERS/HINTS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress 1

- 1) See Sub-section 4.2.3 and answer.
- 2) See Sub-section 4.2.4 and answer.
- 3) See Sub-section 4.3.1 and 4.3.2, and answer.

Check Your Progress 2

- 1) See Sub-sections 4.4.1 and 4.4.3 and answer.
- 2) See Section 4.4 and Sub-section 4.4.5 and answer.

UNIT 5 TOTAL FACTOR PRODUCTIVITY AND GROWTH ACCOUNTING

Structure

- 5.0 Objectives
- 5.1 Introduction
- 5.2 Total Factor Productivity: Definition
- 5.3 Factors Affecting Total Factor Productivity
- 5.4 Total Factor Productivity and Growth Accounting
- 5.5 Total Factor Productivity Measurement: Alternative Approaches
 - 5.5.1 Data Envelopment Analysis (DEA)
 - 5.5.2 Index Numbers (TFP)
 - 5.5.3 Econometric Methods
 - 5.5.4 Limitations of Total Factor Productivity Measures
- 5.6 Issues and Debates Related to Total Factor Productivity
- 5.7 Let Us Sum Up
- 5.8 Key Words
- 5.9 Some Useful Books
- 5.10 Answers to Check Your Progress Exercises

5.0 OBJECTIVES

After reading this unit, you will be able to:

- Explain the concept of total factor productivity;
- State the factors that affect productivity;
- Elucidate the relationship of productivity and growth accounting;
- Describe the methods to measure productivity; and
- Discuss the issues and debates related to productivity analysis.

5.1 INTRODUCTION

Total Factor Productivity (TFP) or we may call it productivity is an important concept in the context of economic Growth of a nation particularly developing countries. Productivity contributes to industrial growth and to the competitiveness in international markets. It refers to the rate at which employment is generated from the employed resources. Increased productivity result in better utilisation of resources and reduces the cost and the prices of industrial products, which in turn, lead to a faster growth in demand in both domestic and international markets.

The origin of the term can be traced to the "Abramovitz residual," which refers to the growth of output unaccounted for by the factor inputs (Abramovitz, 1956). However ever since Solow (1957) decomposed output growth into the contribution of input growth and a residual productivity term; the concept has gained popularity and is used as a benchmark to rank firms or countries. Such rankings get credibility once

productivity is correlated with other indicators of success such as employment growth, export status, or technology adoption. Concept like low productivity is also found useful to predict exit of the firms in an economy, the ultimate performance standard. Its importance can also be gauged from the attention it receives as a criterion to evaluate policy interventions or firms' decisions. The concept has relevance and different meaning in different branches of economics. In industrial economics, for example, a large literature investigates the effect of R&D on productivity and the resulting impact on industry structure. In international economics, the efforts to evaluate the impact of trade liberalization range from estimating changes in price-cost margins to productivity changes. Fundamentally, the objective of productivity measurement is to identify changes in output that cannot be explained by changes in inputs.

Total Factor Productivity (TFP) as a concept is also important not only in the context of macro-economic aggregate measures of a country's performance in terms of per capita growth and productivity, but is of equal significance in measuring the determinants of productivity and competitiveness of firms. The hitherto more popular measure – labour productivity or value added per unit labour – suffers from the shortcoming that it does not reveal why the productivity has risen or vice-versa. Is it due to increased inputs of capital, or are there other causes? The TFP approach while analysing performance, attempts to go into the **WHY** of productivity changes and thus gives deeper insights into the underlying causes and sustainability of growth.

Productivity keeps on changing as production continues. It improves under favourable circumstances and deteriorates when unfavourable changes occur. The changes that lead to higher productivity of inputs are technological improvements, improvement in efficiency, increased education of labour, improvement in the quality of labour due to training, etc. Today, TFP is considered an important source of output growth worldwide due to rapid progress in science and technology and various efficiency-enhancing measures.

5.2 TOTAL FACTOR PRODUCTIVITY: DEFINITION

Total factor productivity as a concept has been formalised in the second quarter of the last century. Although the origin of the idea on its existence might be sought as early as the classical school, more serious attempts to find a stricter definition are observed after the 1930s. Behind this concept most often stands the understanding that besides the traditional factors of production labour and capital there is something else that leads to the increase in production. Usually this 'thing' is associated with technological progress. The latter concept itself can be interpreted in various ways, but eventually it always implies that the combination of labour force, machines, human knowledge and skills, leads to changes in total income that are not expected by changes in capital or labour considered separately.

Growth (increase in GDP) of an economy is generally attributed to factors that can be clubbed under two broad headings: Capital and Labour. But you will find when you calculate it that Capital and Labour cannot account for all the growth and in fact there is a residual factor that comes into play and accounts for the increase in GDP. This factor is known as Total Factor Productivity. Let us try to understand it on the basis of an equation:

$$Y = A f(K, L)$$

Where Y is the output (GDP), K is the stock of physical capital invested and L is the labour (number of man-hours). The letter A stands for Total Factor Productivity.

In the equation given above a higher value of A means that the same inputs lead to more output and vice versa. It shows how efficiently that input is being used to further the interests of the economy and it is the productivity of the capital and labour investment. Total Factor Productivity is considered to be the actual determining factor in the growth of an economy as both capital and labour cannot continue to be invested indefinitely. Moreover the growth of economy, if depended solely on capital and labour would decline as soon as these investments in these inputs are reduced and vice-versa. Thus it is not a stable growth. Hence increased Total Factor Productivity is the only way that an economy can maintain a stable growth.

Also, the Law of Diminishing Marginal Returns, tells us that a sustained influx of Labour and Capital will not achieve long term growth as the value of the inputs get maximised; they onset to deliver lower returns over a period of time. Thus the only way growth can be ensured and sustained is to maximise the efficiency of these inputs and to work on improving the quality and quantity of returns for the same amount of inputs i.e. to increase Total Factor Productivity.

5.3 FACTORS AFFECTING TOTAL FACTOR PRODUCTIVITY

In the earlier section, we learnt about the fact that there is change in productivity. What are these factors that affect productivity. Some of them are:

Technological Progress – With technological progress, the inputs (R&D) are utilized efficiently and there is an increase in Total Factor Productivity. Thus inventions and discoveries in the fields of information, communication, medicine, and other areas of science & technology lead to an increase in Total Factor Productivity.

Skill levels of the workers – Skill levels of workers in a particular country cause increase in the Total Factor Productivity. Countries and also some industries with higher level of education and skills have higher Total Factor Productivity as these workers are able to produce better outputs..

Foreign Investment – Studies on TFP show that an increase in foreign investment in a country would increase total factor productivity as inputs increase provided this investment is used to promote efficiency of industry.

Natural Calamities – Natural calamities like droughts, floods, fires, etc could lead to a decrease in Total Factor Productivity as they might lead to lesser outputs for the same inputs. This is especially true of developing countries and the countries that depend a lot on agriculture as a part GDP.

Level of Competition – Literature on productivity also refers to the level of competition as an important factor determining productivity. A country with competitive markets and a strong economy would have a higher Total Factor Productivity than others that are not free market economies.

Political Stability – Factors like corruption, bureaucracy and instability lead to a decrease in the level of output. The more stable a country is, the more it increases Total Factor Productivity.

Check Your Progress 1

- 1) Define and explain the concept of total factor productivity.

2) What are the factors that affect total factor productivity growth?

5.4 TOTAL FACTOR PRODUCTIVITY AND GROWTH ACCOUNTING

To reiterate, productivity is the main reason for economic growth. Some countries do better than others primarily because they are more productive. Also, the more productive a country is the better it is able to compete in the world markets as it can keep cost low while still producing a superior product. A high level of productivity also increases the standard of living of people in that country as they would get better outputs for the same inputs i.e. have better quality products at lower prices.

In order to conduct such an analysis, economists have built up a framework called growth accounting to obtain a different perspective on the sources of economic growth. Later we shall discuss that decomposing growth is essentially a growth accounting exercise. We start with a production function that tells us what output (Y_t) will be at some particular time t is a function of the economy's stock of capital (K_t), its labour force (L_t), and the economy's total factor productivity (A_t). If output changes, it can only be because of the change in the economy's capital stock, its labour force, or its level of total factor productivity. We are referring to the Cobb-Douglas form of the production function, which is:

$$Y_t = A_t K_t^\alpha L_t^{1-\alpha} \quad \dots(1)$$

In this equation we can see that we would get higher output because of three reasons – if more number of ~~man~~ hours are put in (higher L), if the people have more equipment, etc to work with (higher K) or if capital and labour are used more productively (higher A). The equation at (1) shows that it assumes perfect competition and the constant returns to scale as depicted by the coefficients of K and L. If we decompose the growth in output into each of the three elements allotting 1/3rd of the increase in growth to capital and 2/3rd to labour (which is what is seen in the most developed countries), the equation then becomes

$$Y_t = A_t K_t^{1/3} L_t^{2/3} \quad \dots(2)$$

Taking logs the growth in output (Y) is shown by the following equation

$$\ln Y = \ln A + 0.33 \ln K + 0.67 \ln L \quad \dots(3)$$

Where $\ln Y$ is the growth in output, $\ln K$ is the increase in capital, $\ln L$ is the increase in labour and $\ln A$ is the increase in Total Factor Productivity (all these are for a particular time period)

We can also use this equation to calculate growth in output per worker i.e. Labour Productivity (Y/L). This can be written as

$$Y/L = A (K/L)^{1/3} \quad \dots(4)$$

When we apply the growth in output formula to this equation, it becomes

$$\ln Y/L = \ln A + 0.33 \ln K/L \quad \dots(5)$$

Where $\ln Y/L$ is the growth in output per worker, $\delta(K/L)/(K/L)$ is the increase in the amount of capital per worker and $\delta A/A$ is the increase in Total Factor Productivity.

Thus equation (5) shows that the output per worker can rise because of two reasons - increase in Total Factor Productivity and increase in the amount of capital per worker.

In order to see the effect of change in each component of this equation let us consider decomposing each component of the equation given at 3 and then see what happens

Changes in Capital

Consider, first, the effect on output of a change in the capital stock from its current value K_t to a value $K_t + \Delta K$ —an increase in the capital stock by a proportional amount $\ln K_t$. In this production function K_t is raised to a power, $\pm$, so we can apply our rule-of-thumb for the proportional growth rate of a quantity raised to a power to discover that the proportional increase in output from this change in the capital stock is:

$$\ln Y = \pm \ln K$$

Thus if the diminishing-returns-to-scale parameter $\pm$ were equal to 0.33, and if the proportional change in the capital stock were 3%, then the proportional change in output would be:

$$\ln Y = 0.33 \ln K = 0.33 \times 3\% = 0.99\%$$

Changes in Labour

Now consider, second, the effect on output of a change in the labour force from its current value L_t to a value $L_t + \Delta L$ —an increase in the capital stock by a proportional

amount $\ln L_t$. In this production function L_t is raised to a power, $1-\alpha$, so we can apply our rule-of-thumb for the proportional growth rate of a quantity raised to a power to discover that the proportional increase in output from this change in the labour force is:

$$\ln Y = (1-\alpha) \ln L$$

Thus if the diminishing-returns-to-scale parameter α were equal to 0.33, and if the proportional change in the labour force were 1%, then the proportional change in output would be:

$$\ln Y = (1-0.33) \ln L = 0.67 \times 1\% = 0.67\%$$

Changes in Total Factor Productivity

Lastly, let us see the effect on output of a change in total factor productivity. Our equation tells that a proportional increase in total factor productivity produces the same proportional increase in output:

$$\ln Y = \ln A$$

Thus if the proportional change in total factor productivity were 2%, then the proportional change in output would be:

$$\ln Y = 2\%$$

Putting Together

So if we consider a real-world situation in which all three—the capital stock, the labour force, and total factor productivity are changing—then the proportional growth rate of output is as given in equation (3), which is the key. If we know the proportional growth rates of output, the capital stock, and the labour force, and if we know the diminishing-returns-to-scale parameter α in the production function, then we can use this growth-accounting equation to calculate the (not directly observed) rate of growth of total factor productivity A , and to decompose the growth of total output Y into (i) the contribution from the increasing capital stock K , (ii) the contribution from the increasing labour force L , and (iii) the contribution from higher total factor productivity A .

Since growth-accounting equation at (3) allows us to break down growth into components that can be attributed to the observable factors of the growth of the capital stock and of the labour force, and to a residual factor—often, in fact, called the Solow residual or a *measure of ignorance*—that is the portion of growth left unaccounted for by increases in the standard factors of production. Changes in the Solow residual or total factor productivity can come about for many reasons explained earlier. Economists often refer to total factor productivity as "technology," but if it is technology it is technology in the widest possible sense. Not just new ways of constructing buildings, newly-invented machines, and new sources of power affect total factor productivity, but changes in work organization, in the efficiency of government regulation, in the degree of monopoly in the economy, in the literacy and skills of the workforce, and in many other factors affect total factor productivity as well.

The approach that has been used here in the measurement of total factor productivity is the so-called growth accounting, which, although being simple with respect to the computation technique, leads to sufficiently illuminating results. In growth accounting the concept 'total factor productivity' does not have a stand-alone meaning, until the influence of capital and labour is taken into consideration (and also other factors, for which statistics is available). Generally, the calculation of total factor productivity in addition to the contributions of labour and capital indicates an inability to identify or

quantify the remaining objectively existing factors, which determine economic growth. This inability most frequently stems from the lack of suitable statistical data or from the lack of preliminary studies of the values of the omitted factors. When we isolate the influences of the production factors, for which we have available statistical data, there remains the contribution of all other factors, which are generalized in literature with the term 'total factor productivity'. Moreover, the computation of the increase of the total factor productivity taking data on capital and labour is incomplete by definition, since in practice, more than two factors of growth have been identified. These include human capital, technological development and human knowledge, skills, health status, etc., which are inter-related factors having influence on economic growth.

Check Your Progress 2

- 1) Taking a Cobb-Douglas production function, explain how you will explain changes in output resulting from changes in capital, changes in labour and overall change in productivity.

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- 2) What do you understand by 'Solow residual'? Explain how total factor productivity is measured using the growth accounting method

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5.5 TOTAL FACTOR PRODUCTIVITY MEASUREMENT: DIFFERENT APPROACHES

There are two different methods to the measurement of TFP: growth accounting and econometric. Within these, there are five widely used approaches that can be categorized into three broad classes. The first two, index numbers and data envelopment analysis, are flexible in the specification of technology, but do not allow for measurement errors in the data. The other three are econometric methods that calculate productivity from an estimated production function.

5.5.1 Data Envelopment Analysis (DEA)

The first approach to productivity measurement is completely nonparametric and uses linear programming. It dates back to Farrell (1957) and it was operationalised by Charnes, Cooper, and Rhodes (1978). No particular production function is assumed. Instead, the ratio of a linear combination of outputs over a linear combination of inputs is compared across observations. While there is no theoretical justification for the linear aggregation, it is natural in an activities analysis framework. This approach has some drawbacks. The flexibility in weighting can be a drawback. It has the implication that each firm with the highest output-input ratio for any combination of outputs and inputs will be considered efficient. The method is not stochastic, which is demanding on the data and makes the method sensitive to outliers. One might object to the label "100% efficient" for the best practice firms in the sample. In some situations no firm might be efficient, e.g. due to regulation.

5.5.2 Index Numbers (TFP)

The second approach provides a theoretically motivated aggregation method for inputs and outputs, while remaining fairly sceptic on the shape of the underlying technology. According to this approach, under a number of assumptions, it is possible to calculate the term 'A' at (1) from observables, without having to specify the exact production function, nor forcing it to be uniform across observations. The work of Solow (1957) and Diewert (1976) are considered important that refer to two types of index numbers respectively. One is Solow index and the other is Translog Index.

Solow Index

Let Y denote output (value added), L labour input and K capital input. Let α be the income share of capital in value added. Then, the Solow index of TFP is given by the following equation:

$$\ln A = \ln Y - (1 - \alpha) \ln L - \alpha \ln K \quad \dots (6)$$

In the above equation, $\ln Y$ is the growth rate of output, $\ln L$ is the growth rate of labour input and $\ln K$ is the growth rate of capital input. $\ln A$ is the growth rate of total factor productivity.

Solow index assumes the elasticity of substitution between labour and capital to be equal to one. In other words, the assumption is that if wage rate goes up by 5 per cent, then employment will fall by 5 per cent. The assumption of unitary elasticity of substitution implies that the income shares of labour and capital remain constant.

The translog index of TFP does not make rigid assumptions about elasticity of substitution between factors of production. It allows for variable elasticity of substitution. Moreover this index does not require technological progress to be Hicks-neutral where increase in the marginal productivity of labour and capital is proportional. The translog index provides an estimate of the shift of the production function even if the technological change is non-neutral i.e. it is labour-saving or capital-saving in character.

The translog index of TFP growth is given by the following equation:

$$\Delta \ln TFP_t = \Delta \ln Y_t - \left[\frac{SL_t + SL_{t-1}}{2} \times \Delta \ln L_t \right] - \left[\frac{SK_t + SK_{t-1}}{2} \times \Delta \ln K_t \right] \dots (7)$$

In the above equation, Y is output, L labour and K capital. SL is income share of labour and SK denotes income share of capital. $\Delta \ln TFP$ is the rate of technological change or the rate of growth of total factor productivity.

One of the main advantages of the index number approach is the ease of calculation. Also, the specification of technology is flexible; allowing firms to produce with different technologies, and the method can easily handle multiple outputs and a large number of inputs.

The main disadvantages are the requirements on data quality and the assumptions regarding firm behaviour and market structure. It is impossible to account for measurement errors or to deal with outliers, except for some ad hoc trimming of the data. Factor prices information and returns to scale have to be estimated or available independently.

5.5.3 Econometric Methods

Third approach is the use of econometric methods in order to measure productivity. In the econometric approach, we apply regression analysis to estimate a production function and get the rate of technological progress from the estimated production function. The Cobb-Douglas production function is commonly been used in productivity studies. Estimation of Cobb-Douglas production function is already explained in the earlier section. Some researchers have done some variations by using different procedures such as Instrumental Variable Estimation (IVE), Stochastic Frontier Estimation (SF) and last but not the least some Semi-parametric procedures to address the issue of productivity. A detailed analysis of these methods is, however, outside the purview of this unit.

5.5.4 Limitations of Total Factor Productivity Measures

As the discussion above shows the growth accountancy method to TFP measurement is based on certain highly restrictive assumptions: constant returns to scale, perfect competition, and factors of production being paid according to their marginal product. These assumptions are not realistic, especially for a developing country where the markets are imperfect and the incomes received by factors of production are unlikely to be equal to their marginal product.

The econometric method, which is based on the estimation of production function does not require these restrictive assumptions and thus have an edge. However, this

approach also has some limitations. It assumes that same rate of technological progress for all the years under study. The estimates of the rate of technological change are often seriously affected by the problem of multi-colinearity.

Check Your Progress 3

- 1) Discuss the various approaches to measuring total factor productivity.
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- 2) Discuss the limitations of the total factor productivity measures.
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5.6 ISSUES AND DEBATES RELATED TO TOTAL
FACTOR PRODUCTIVITY

There are many issues and debates related to total factor productivity. These include dichotomy between technology and capital; the slowdown in productivity; productivity and information technology and; productivity and environment.

The dichotomy between technology and capital is age-old and a vast empirical literature has attempted to sort out this dichotomy; however, without any clear consensus. A number of early studies favoured productivity as the main explanation for output growth (see Griliches: 1996). The alternative view is supported in many studies (see Young:

1995). Another issue that has received attention in literature is the slowdown in productivity particularly since late 1960s or early 1970s onwards. In India, many studies refer to the controversy on whether productivity has gone down or vice-versa during this period (For example see Goldar: 1986; Ahluwalia: 1991; Balakrishnan and Pushpangadan: 1998). This issue again has never been solved satisfactorily, despite a significant research effort.

Similarly there is debate between growth and welfare, posed by environmentalists. They argue that GDP growth overstates the actual improvement in economic welfare, but it fails to measure the depletion of natural resources and spill over of negative externalities. This attack is still broadened to include the unintended consequences of industrial revolution like poverty, urban decay, displacement and so on. Another issue raised is why hasn't widely hyped information revolution reversed the productivity slowdown? This brings into picture the new economy paradox, which is largely overlooked so far in productivity studies.

5.7 LET US SUM UP

This unit dealt with total factor productivity and its growth. The unit began by defining total factor productivity. The unit then went on to discuss the factors that affect total factor productivity. Several factors from skill of workers to political stability were discussed. The subsequent topic discussed total factor productivity and growth accounting. We saw how growth in output can be explained by looking at change in capital, change in labour, and change in total productivity.

The unit also discussed the concept of Solow residual. The unit provided a detailed discussion on the various ways that productivity is measured in practice empirically, from econometric methods, data envelopment analysis method, and index number methods like the translog index and Solow index.

5.8 KEY WORDS

Growth Accounting Formula

Growth accounting formula is an equation that states that the growth rate of productivity equals capital's share of income times the growth rate of capital per hour of work plus the growth rate of technology.

Solow Residual

Solow residual is a measure of the change in total factor productivity in a Solow growth model. This is a way of doing growth (TFP) represents output growth not accounted for by the growth in inputs.

5.9 SOME USEFUL BOOMS

Goldar, B.N. (1986) *Productivity Growth in Indian Industry*, Allied Publishers, New Delhi:

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5.10 ANSWERS/HINTS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress 1

- 1) Read section 5.2 and answer.
- 2) Read section 5.3 and answer

Check Your Progress 2

- 1) Read section 5.4 and answer.
- 2) Read section 5.4 and answer.

Check Your Progress 3

- 1) Read section 5.5 and answer.
- 2) Read Sub-section 5.5.4 and answer.

UNIT6 TECHNICAL CHANGE AND PROGRESS

Structure

- 6.0 Objectives
- 6.1 Introduction
- 6.2 Technical Change and the Production Process
- 6.3 Classification of Technical Change
 - 6.3.1 Embodied and Disembodied Technical Change
 - 6.3.2 Hick's Classification of Technical Change
 - 6.3.3 Harrod's Classification of Technical Change
 - 6.3.4 Solow's Classification of Technical Change
- 6.4 The Neo-Classical Model with Technical Change
- 6.5 Some Issues Related to Technical Change
 - 6.5.1 What about embodied technical progress?
 - 6.5.2 Nature of Capital
- 6.6 Let Us Sum Up
- 6.7 Key Words
- 6.8 Some Useful Books
- 6.9 Answers/Hints to Check Your Progress Exercises

6.0 OBJECTIVES

After going through the unit, you would be able to:

- Define technical progress;
- Distinguish between technical change and technological change;
- Explain the various types of technical progress;
- Describe augmented, embodied and neutral technical progress; and
- Analyse the neoclassical growth model with technical progress.

6.1 INTRODUCTION

We studied two growth models in block 1. In the Harrod-Domar model, we considered the model without any technical change. In the Solow model as well, we discussed the model without technical change. Technical change, however, is a fact of life, which is taking place all the time in modern economies. We have seen the experiences of developed countries that have progressed due to technical change and progress. But what is technical progress? How does it differ from technological change? How do we show it in the economic production process and growth? These are some of the issues that this unit takes up for discussion.

In this unit we discuss the various conceptions of technical change **and** also look at the neoclassical growth model in the presence of **technical change**. In the previous unit you

have been acquainted with growth accounting and total factor productivity growth. This unit explains technical change more generally and broadly, and also brings out the relationship between technical change and total factor productivity growth.

6.2 TECHNICAL CHANGE AND THE PRODUCTION PROCESS

You would have guessed by now that technical change has something to do with improving the production process, and indeed so it is. We depict the change in technical level by looking at the production function. At this point we are going to give you some suggestion: pick up your course on microeconomics and go over the unit on production. Although now we are discussing the story at an economy-wide level, the concepts of production function, isoquants, and so on, go through just fine.

Let us suppose for simplicity that there is one single 'homogeneous' good in the economy. This good gets produced by using capital and labour. (This is what we have assumed in units 3 and 6). The simplest way to conceptualise technical progress is to understand that technical progress means that more output is produced using the same amount of inputs. If you visualise a production function, you can see that the production function shifting upward over time as technical progress takes place. Another way to look at technical change (improvement) is to say that the nature of the production function has changed to a superior one, or that the same amount of output can be produced by using less of one or more factors than before.

The general way we have used to represent technical change as shifts in the production function (it may also be depicted as shifts in the position of each isoquant) can be expressed by bringing in time into the production function explicitly. The production function now becomes:

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

The argument t is a production function shifter.

If we take $k = K/L$ and $y = Y/L$ then we can write the per-worker production function as

$$Y = f(k, t)$$

Although the above formulation is the most general way of depicting technical progress, there is another way of depicting technical change, where technical progress takes place through shifts in the production function even though the amount of inputs used may not have increased. It is as though the factors of production (one or both – we have only two in our simplified picture of the economy) were somehow *augmented* and they are able to produce more output than before. This can be represented as

$$Y = F(J(t)K, Z(t)L)$$

Now Y is no more merely a function of quantities of labour and capital. The stock of capital and labour are multiplied by factors J and Z respectively which are both functions of time. The expressions $J(t)$ and $Z(t)$ are referred to as effective capital and effective labour respectively. These can be explained as follows: if dZ/dt , the rate of change of Z is greater than zero, then over time, the effective labour force is increasing even though the actual labour force stays constant. Similarly, if dJ/dt is greater than zero,

then the effective capital stock goes up even though actual capital stock does not increase. You can think of factor augmenting technical change by visualising that after technical change five workers and /or three machines can produce as much as seven workers and / or four machines did previously. Alternatively, you can think that the seven workers and / or four machines can now produce much more than they were doing previously.

If dJ/dt is positive and $Z(t)=1$, then technical progress is said to be **purely capital augmenting**, and if, on the other hand, dZ/dt is positive and $J(t)=1$, then technical progress is said to be **purely labour augmenting**. If dJ/dt and dZ/dt are both positive, then technical progress is said to be **equally capital and labour augmenting**. However, it must be remembered that this type of formulation says nothing about cause or source of technical change.

Suppose $(dJ/dt)/J(t)$, that is, the rate of growth of effective capital is a constant u , then pure capital augmenting technical change is supposed to be taking place at a constant rate u , while if $(dZ/dt)/Z(t)$ is a constant u then pure labour-augmenting technical change is said to be taking place at a rate u . Suppose both effective capital and effective labour are growing at the rate u , then factor augmenting technical progress is said to be taking place at the rate u . In the presence of constant returns to scale, the production function can be written as

$Y=A(t)F(K, L)$. This depicts that the technical change is equally capital and labour augmenting at the constant rate u .

Whether technical change should be taken to be happening at a constant rate is open to question. It seems to be reasonable if technical change is considered exogenous, or given from outside the model. If however, there is conscious decision to invest in R and D, then technical change might not be quite exogenous. The later units on endogenous growth models and Schumpeter's theory of capitalistic development will have much to say on this.

Check Your Progress 1

- 1) Explain the concept of effective capital and effective labour in aggregate production function.

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- 2) Distinguish between pure capital augmenting; purely labour augmenting; and equally capital and labour augmenting technical change.

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6.3 CLASSIFICATION OF TECHNICAL CHANGE

To understand technical change, we have to bear in mind that there are several types of technical change. They have mostly to do with the capital-labour intensity, and by implication, on the relative shares of capital and labour in the total product. This has repercussions on the remunerations of capital and labour, that is, on the wage rate and rental of capital.

To discuss the various types of technical change, let us briefly review the theory of production, particularly the production function. You can also refer to the courses on microeconomics and quantitative techniques. We have output as a function of only two factors of production labour and capital. Thus other factors like land are not being considered for simplicity.

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

Let us denote output per worker by y and capital per worker by k . Let us denote worker-output ratio by $m = L/y$.

Then capital / output = (capital / labour) X (labour / output)

= $k \times m$. Let us denote it by n . Then

$$n = km, \text{ or, } k = n / m.$$

Here, m and n are called **technical coefficients** (capital-output ratio and worker-output ratio are technical coefficients) and k is called **capital intensity**. If the capital-labour ratio capital intensity) goes up, it is called **capital deepening**.

Getting back to the production function, differentiating output with respect to capital and labour, we get

$$\partial Y / \partial K \text{ and } \partial Y / \partial L \text{ respectively.}$$

These are called **marginal product of capital and labour** respectively. Let us denote these by F_K and F_L respectively.

It so happens that in general,

$$F_K > 0, F_L > 0 \text{ and } F_{KK} < 0 \text{ and } F_{LL} < 0$$

Thus the marginal product of capital is positive but decreases as increasing amount of capital is used. It is the same in the case of labour.

Along an isoquant $F(K, L)$ is constant. Hence, for any change along an isoquant, with Y constant, we have

$$F_K dK + F_L dL = 0.$$

If L is substituted for K for a given Y , then the **marginal rate of substitution** is:

$$- dK / dL = F_L / F_K,$$

Let us denote the wage rate by w and the rental of capital by r .

Then, according to marginal productivity theory, which states that the factors of production are paid their marginal product,

$$\partial Y / \partial L = w, \text{ and } \partial Y / \partial K = r.$$

We have a theorem, called the **product exhaustion theorem**, which states that if there are constant returns to scale, it must be true that

$$(\partial Y / \partial L) w + (\partial Y / \partial K) r = Y.$$

The first expression on the left hand side shows the total amount of remuneration to labour (marginal product of labour times the number of workers). Similarly the second term denotes the total remuneration to capital. Thus the theorem says that provided there are constant returns to scale, the gross output is exhausted in meeting the total remuneration to labour and capital. You can think of the reward of labour either as rental r (as we have done till now), or profits, denoted by π . You may think of 'owners' of capital, rather than a homogeneous production unit that 'hires' capital.

Another concept that is of relevance here is that of **elasticity of substitution**, introduced by Sir John Hicks in his book *The Theory of Wages, in 1932*. It is defined as the proportionate change of the ratio of capital to labour with respect to a change in the ratio of the prices of capital and labour. Since we have invoked the marginal productivity theory and have seen that the prices of the factors of production are equal to their marginal products, the elasticity of substitution can equally well be defined as the proportionate change of the ratio of capital to labour with respect to a change in the ratio of the marginal productivities of capital and labour.

6.3.1 Embodied and Disembodied Technical Change

Now let us begin our study of the classification of technical change. Before doing so, let us recall our discussion of factor augmented technical progress. We introduce a related concept here. Technical change can be **embodied** or **disembodied**. Embodied technical change means that technical change assumes the form in the change in the type of factor of production, usually capital. In other words, embodied technical change

is embodied in the form of new types of machines (a new process or new technology). Disembodied technical progress, on the other hand, means that regardless of the type of machines, new or old, the same amount of factors can produce greater amounts of output, or the same amount of output can be produced using lesser quantities of inputs; in other words, the isoquant shifts inwards. The factor augmenting technical change that we studied in the previous section is a depiction of disembodied technical change. For most of this unit, we will have occasion to consider disembodied technical change. Only in the final section do we touch upon embodied technical change, and once you grasp the concept, you will find greater use of the concept in some of the later units. In embodied technical change, investment in new equipment or new skill is the essential vehicle of improvements in technique.

Another concept with regard to technical change is neutrality. Neutrality broadly means that technical change is neither labour saving nor capital saving. We shall now present the classification of various types of technical change in terms of how neutrality has been viewed. We discuss Hicks's, Harrod's and Solow's concepts of neutral technical change.

6.3.2 Hicks's Classification of Technical Change

Sir John Hicks presented a classification of technical progress in his book *The Theory of Wages*, published in 1932. Hicks looked at technical progress in terms of the effect of technical change on the ratio of marginal product of capital to that of labour. If after the technical change the ratio increases, in Hicks's terminology it is to be called labour saving. If the ratio stays the same it is neutral and if the ratio falls, it is called capital saving.

To explain this further, let us use some notation. Let

$F_K(t_1)$ be marginal product of capital before technical progress.

$F_K(t_2)$ be marginal product of capital after technical progress.

$F_L(t_1)$ be marginal product of labour before technical progress.

$F_L(t_2)$ be the marginal product of labour after technical progress.

Then

If $[F_K(t_2)/F_L(t_2)] > [F_K(t_1)/F_L(t_1)]$ then the technical progress is labour-saving according to Hicks

If $[F_K(t_2)/F_L(t_2)] = [F_K(t_1)/F_L(t_1)]$ then the technical progress is neutral in the Hicksian sense.

If $[F_K(t_2)/F_L(t_2)] < [F_K(t_1)/F_L(t_1)]$ then the technical progress is capital-saving in the Hicksian classification of technical change.

There is another way of looking at the Hicksian classification of technical progress. We know that in equilibrium the marginal product to each factor of production equals its price. Thus the marginal product of capital F_K equals rental on capital r and the marginal product of labour F_L equals the wage rate w . In Hicks's classification, a labour saving technical progress increases the ratio r/w while a capital saving technical progress reduces the ratio r/w . A technical change that saves labour reduces the wage rate relative to the rental of capital. A similar argument carries through in the case of capital saving technical progress.

Think of the concave-below upward sloping curve (the per-worker production function) showing the relationship between Y/L and K/L with the former plotted on the vertical axis and the latter on the horizontal axis. This kind of diagram you have encountered in unit 3 on the neo-classical growth model. A technical progress (over time) merely shifts this curve upwards. The Hicksian classification of technical progress, if it is to be used to compare the ratios of marginal productivity on two distinct points on the two curves can only be used to compare two points at which the K/L ratio is same because the K/L ratio changes at every point on each of the two curves. Thus to compare the ratios of marginal product on one curve with the ratios of marginal product on the other curve, the two points must lie vertically above the same point on the horizontal axis which represents K/L .

We can now state the Hicksian classification of technical progress in the following way: A technical progress will shift the per-worker production function upward. This technical progress is said to be **labour-saving** if at any given value of capital-labour ratio, the ratio of marginal product of capital to the marginal product of labour has increased. If this ratio decreases for a given value of capital-labour ratio, the technical progress is said to be **capital saving**, and if the ratio stays the same it is **Hicks-neutral**.

Since we are looking at technical change by making use of marginal product of factors and factor prices, we can represent technical change in terms of share of factor remuneration in terms of the relative share of the factors in the total product or total national income.

The relative share of capital in total product is rK/Y while the relative share of labour in total product is wL/Y . The ratio of the relative shares is $[rK/Y] / [wL/Y] = rK/wL$. Let us denote this by S . Since the title of Hicks's book is Theory of Wages you can understand that he was interested in studying what happens to the share of labour as technical change takes place. We have seen that in the Hicksian classification we see what happens to F_K / F_L to r/w . we have also seen that Hicksian classification is relevant where K/L is constant. You can understand that if K/L stays constant and r/w changes, rK/wL , that is, S will be affected. So we could state Hicks's classification in terms of relative factor shares. We say that technical progress is labour saving in the sense of Hicks if, at any constant value of K/L , the ratio of relative shares $S = rK/wL$ is increasing, that is dS/dt is positive where dS/dt is the derivative with respect to time. Technical progress is capital saving in the sense of Hicks if, at any constant value of K/L , the ratio of relative shares $S = rK/wL$ is decreasing, that is dS/dt is negative. Technical progress is Hicks-neutral if, at any constant value of K/L , the ratio of relative shares $S = rK/wL$ stays the same, that is dS/dt is equal to zero.

It has been proved by Uzawa that Hicks-neutral technical progress is equivalent to factor augmenting, that is equally labour and capital augmenting technical progress. In other words, Hicks neutrality implies that the production function can be written as

$$Y = F(J(t)K, Z(t)L), \text{ or, equivalently as}$$

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

6.3.3 Harrod's Classification of Technical Change

Sir Roy Harrod (whose growth model you studied in block I) put forward a classification of technical progress which was different from Hicks's classification, and came some years after Hicks's contribution. Harrod first put forward his classification in an article

in 1937, but expanded it in a book published in 1948. He defined as neutral a technical change one where the capital coefficient (capital-output ratio) does not change in the presence of a constant interest rate. Broadly, he suggested that if, when the interest rate is constant, the distribution of the total national product between capital and labour stays constant, then it is neutral technical progress.

If we consider perfect competition and take interest rate as equal to the rental of capital and hence equal to the marginal product of capital, then Harrod-neutral technical progress is a statement about the relationship between capital-output ratio and the marginal product of capital. If we consider the per-worker production function, then an upward shift in the per-worker curve is said to represent Harrod-neutral technical change if at any constant value of capital-output ratio, the marginal product of capital stays the same.

Technical change is said to be labour-saving in Harrod's classification if, at any constant value of the capital-output ratio, the ratio of relative shares $S = rK/wL$ is increasing, that is, if K/Y is constant and dS/dt is greater than zero. Technical change is capital saving in Harrod's sense if when K/Y is constant, dS/dt is < 0 , that is, S is decreasing. If in the presence of constant K/Y , S remains constant, that is, dS/dt is $= 0$, then technical progress is Harrod-neutral. Thus in Harrod-neutral technical progress, if K/Y is constant, rK/wL is unchanging.

Mrs. Joan Robinson in 1938 provided a geometric proof that Harrod-neutral technical progress is exactly equivalent to labour-augmenting technical progress. In other words, if technical progress is Harrod-neutral, and is proceeding at a constant rate u then the aggregate production function can be written as

$$Y = F(K, Z(t)L) \text{ with } [dZ(t)/dt] / Z(t) = u$$

Is there any form of technology where technical progress can be interpreted as either Hicks-neutral or Harrod-neutral, that is, the two forms of neutrality are equivalent. It can be shown that for this to be true, the distribution of income will be the same at all levels of capital-labour ratio. This can happen only if the elasticity of substitution will be equal to one. The Cobb-Douglas production function

$Y = K^\alpha L^{1-\alpha}$ is the production function where elasticity of substitution is constant and equal to 1.

6.3.4 Solow's Classification of Technical Change

Solow's classification of technical progress is similar to Harrod's and Hicks's classification except in one respect. Hicks's classification compares points on different per-worker output curves at points of constant capital-labour ratio and Harrod's scheme compares points on different per-worker output curves at points of constant capital-output ratio. Solow's classification compares points on old and new per-worker production at points at which the labour-output ratio is constant. Thus Solow-neutrality is when at points where L/Y is constant, $dS/dt \approx 0$ that is, the relative shares of capital and labour remains constant. It can be shown that a Solow-neutral technical progress is capital augmenting.

Check Your Progress 2

1) Explain the concept of elasticity of substitution.

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2) Bring out the difference Harrod neutrality and Solow neutrality.

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6.4 THE NEO-CLASSICAL MODEL WITH TECHNICAL CHANGE

We have studied the neo-classical model in unit 3 but that was without technical change. We merely took an aggregate production function and elaborated upon the model. However, we know that in the Solow model the key to growth is not accumulation of capital, or increasing the saving rate. The mainspring of growth in the Solow model is technical progress. We have got an idea of this in the previous unit where we came across a concept called Solow residual in accounting for growth. After capital accumulation and growth in labour force or population had been accounted for, some part is left over which is roughly an indicator of technical progress. Let us now look at the neoclassical growth model in the light of our discussion in the previous sections.

Which classification of technical progress is likely to serve us well in analysing growth models, in particular the neoclassical one? Let us first take Hicks's scheme. Consider the simple neoclassical model that you studied in unit 3. Given the rate of growth of labour force, say g , and propensity to save s , we know the economy will reach an

equilibrium level of output per worker (let us denote it by y^*) and an equilibrium level of capital per worker (let us denote it by k'). Here $f(k, t_0) = (n/s)k$, where t_0 denotes initial time period. Suppose in the next time period t_1 , the per-worker production function shifts up to $f(k, t_1)$, and the economy gets new equilibrium levels of q and k (say q^{**} and k^{**}). If the economy is on a balanced growth path, and the rate of growth of the labour and saving rate are fixed constants, any upward shift in the per-worker production function will mean that the equilibrium value of k has changed, that we get a new capital-labour ratio. Recall that Hicks's technical progress classification requires that comparison of points pre-technical progress and post-technical progress per-worker output curves are restricted to points having the same capital-labour ratio. So to study steady-state models of technical change, the Hicksian scheme of classification is not of much use. We shall see that it is Harrod's schema is of more useful in studying steady-state growth.

This point can be repeated by saying that if long-term, sustained steady-state has to take place with technical progress, then the technical progress has to be of Harrod-neutral, that is, of a labour-augmenting form. Get this well. It is not Harrod's entire classification schema that is being talked about. Specifically, for steady state growth to occur in simple growth models with technical progress, the technical progress must be specifically Harrod-neutral, or labour-augmenting.

Let us consider the Solow model of growth. Earlier we took the aggregate production function as $Y = F(K, L)$, but now we need to consider a labour-augmented production function $Y = F(K, Z(t)L)$. The only difference is that instead of measuring the labour force in natural units, we need to measure them in efficiency units, that is, consider effective labour force $Z(t)L$. Earlier we had $y = Y/L$, but now we need to consider output per effective worker (denoted by say y^e) so that $y^e = Y/Z(t)L$ and similarly $k^e = K/Z(t)L$, that is capital per worker in efficiency units.. Let us suppose $Z(t)L$ is growing at the rate u , that is, $[dZ(t)L/dt]/Z(t)L = u$. this means Harrod-neutral technical change is taking place at the rate u . then the fundamental equation of the Solow model becomes

$$\dot{k} = sf(k) - (n+u)k$$

The expression $sf(k)$ here represents savings per 'effective' worker and steady-state growth occurs where this curve intersects the line $(n+u)k$. we have not drawn the diagram here but it is analogous to the diagram in unit 3.

We can summarise the neoclassical growth model in the presence of technical change as follows. With Harrod neutral technical change and in the steady state, output Y will grow at the constant rate of $n+u$; capital stock K will grow at the constant rate $n+u$; the labour force will grow at the rate n when measured in natural units and will grow at the rate

$n+u$ when measured in efficiency units, capital per worker k will grow at the rate u when measured in natural units, ($k = K/L$) and will remain constant when measured in efficiency units, that is $k = K/Z(t)L$. Output per worker grows at the rate u when measured in natural units and remains constant when measured in efficiency units. In steady state K/N stays constant, that is why it is only Harrod-neutral technical change that is compatible with steady state growth. Output per worker and capital per worker, that is, the capital-labour ratio stay constant when measured in efficiency units.

6.5 SOME ISSUES RELATED TO TECHNICAL CHANGE

We have discussed the nature of technical change and seen Hicks, Harrod and Solow have classified technical progress. In this section, we briefly discuss some issues that have been raised in the course of the discussion in the earlier sections. We merely raise the issues here and do not provide anything like an exhaustive discussion as that would take us beyond the scope of our presentation. However, this is as good a place as any to tell you, and we have mentioned this point earlier as well, that the theme of technical progress is a recurrent one in this course and will present itself to you in several of the subsequent units, like the units on endogenous change, on multi-sector growth models and on Schumpeter's theory of capitalistic development.

6.5.1 What about Embodied Technical Progress?

Recall that we had said that disembodied technical progress does not depend on the nature of machines or shape of technology but proceeds as though factors have just got augmented. In the real world technical progress is often in the form of new machines and techniques, which may sometimes even render old machines obsolete. Therefore disembodied technical progress is often only a simplifying device which makes the analysis easier. Disembodied technical progress, in many growth models, is exogenous and it is as though it just drops from heaven.

Solow, in a 1960 paper *Investment and Technical Progress*, provided some analysis of technical progress that is embodied. He took technical progress to proceed at a constant rate but took it to be embodied which affected only new capital goods. Another fact about embodied technical progress is that in the economy capital goods or machines may be of different vintages. The economy has a large stock of machines of different ages, and modern machines may be more efficient simply because they embody new technology. Solow in his paper provided an index of effective capital.

6.5.2 Nature of Capital

This is just an elaboration of the point made above. Recall that output or income is a flow while the capital stock is just that, a stock. Moreover, it is hard to speak of the stock of capital, and there are machines of different ages and types. It is difficult to ascribe a value to the capital stock, and there may be an 'index number problem. Measurement of capital is a tricky issue, and to use the notion in models of technical progress one has to be careful.

Kaldor has been a critic of the idea of representing technical change by a shift of the per-worker production function. According to him, it is sometimes difficult to distinguish the effect of capital accumulation shown by a movement along the curve from the effect of technical progress shown by a shift of the curve. He also gave the germ of a suggestion which was later developed into the modern endogenous growth theory.

Check Your Progress 3

- 1) Discuss the neoclassical growth model in the presence of Harrod-neutral technical change.

- 2) Discuss the problems that may be created for analysis if technical change is taken to be embodied.

6.6 LET US SUM UP

This unit presented a detailed discussion of technical change. The unit began by defining technical change and discussing the concepts of capital augmenting, labour augmenting and factor augmenting technical progress. The unit then went on to discuss various types of technical progress. In doing so, first certain concepts arising out of the production and production function were discussed, like factor exhaustion theorem and elasticity of substitution.

The unit then went on to discuss various conceptions of neutral technical progress. Specifically, Hicks's, Harrod's and Solow's conceptions of neutral technical progress were discussed. Subsequently the unit discussed the neoclassical growth model in the presence of technical progress. Finally the unit brought up for discussion the idea of embodied technical progress, and certain controversies about the nature of capital.

6.7 KEYWORDS

Capital augmenting

If effectiveness is multiplied by capital K but not by labour L , then we say the effectiveness variable is capital-augmenting.

Capital deepening

It is an increase in capital intensity, measured by something analogous to the capital stock available per labor hour spent., or the amount of capital available for a worker to use. but this use is rare.

Embodied or disembodied is an attribute of the way technological progress affects productivity. If any improvement in technology instantaneously affects the productivity of all factors of production, we say productivity improvements are disembodied. If on the other hand, technical change is a property of only of new capital investment, we say technologies are embodied in the new equipment.

Harrod neutrality A technological innovation is Harrod neutral if the technology is labor-augmenting.

Wicks neutrality A technological innovation is Hicks neutral if the ratio of capital's marginal product to labour's marginal product is unchanged for a given capital to labour ratio.

Labour-Augmenting If effectiveness is multiplied by labour L but not by capital K , then we say the effectiveness variable is labour-augmenting.

Neutral technological change Neutral technological change refers to the behaviour of technological change in models.

Putty-putty Putty-putty describes an attribute of capital in some models. Putty-putty capital can be transformed into durable goods then back into general, flexible capital. This contrasts with putty-clay capital can be converted into durable goods but which cannot then be converted back into re-investable capital.

Solow Neutrality A technology is Solow-neutral if it is capital augmenting

Technical change Technical change technical change is a change in the amount of output produced from the same inputs. Such a change is not necessarily technological; it might be organizational, or the result of a change in a constraint such as regulation, prices, or quantities of inputs.

A technological change is a change in the set of feasible production possibilities. This is different than a technical change

6.8 SOME USEFUL BOOKS

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6.9 ANSWERS/HINTS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress 1

- 1) Read section 6.2 and answer.
- 2) Read section 6.2 and answer

Check Your Progress 2

- 1) Read section 6.3 and answer.
- 2) Read Sub-sections 6.3.3 and 6.3.4 and answer.

Check Your Progress 3

- 1) Read section 6.4 and answer.
- 2) Read Sub-section 6.5.1 and answer.