6 Alternative models of growth and distribution with a simple formulation of endogenous technological change

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Introduction

There have been a number of attempts to show how alternative models of economic growth and the distribution of income between wages and profits can be developed using a common framework, which have arguably been useful in uncovering the essential features of these different models and showing how these features compare with those of other models.[1] The alternative models include those will full employment of labor and the full utilization of capital, as in orthodox-neoclassical models, those with growth based on saving and capital accumulation as in the classical-Marxian approach, and post-Keynesian ones in which growth depends on aggregate demand. These attempts, however, have typically assumed exogenously-given technology in the form of given input–output relations, focusing instead on growth due to factor accumulation, especially capital accumulation.

The purpose of this chapter is to extend the alternative-models approach to growth and distribution by incorporating technological change using a simple theory of theory of endogenous technological change. The main motivation for this extension is to allow technological change to interact with other determinants of growth and distribution in the models developed from the common framework, in line with the greater attention given to endogenous technological change in alternative models of growth, both orthodox-neoclassical (especially in what are called new or endogenous growth models) and heterodox (including post-Keynesian and classical-Marxian approaches). An additional motivation is to see whether new theories of growth and distribution emerge when endogenous technological change is incorporated into the common framework, and whether the differences between the theories based on the framework without technological change persist in this extended framework.

The rest of this chapter proceeds as follows. The second section presents the basic general framework of the paper. The third section presents simple versions of some alternative models based this framework. The fourth section presents variants of some of these models to more fully explore the role of technological change in different approaches to growth and distribution.

The general framework

We examine a general framework of a closed economy in which one good is produced with two homogeneous factors of production, capital and labor, with a fixed coefficients technology represented by the equation

$$Y = \min\,[BK, AL] \tag{6.1}$$

where Y is the level of output, K is the stock of capital, L is the level of labor employed, and A and B are labor and capital productivity. Labor productivity is assumed to be given at a point in time, and capital productivity is assumed to be constant throughout.

Income from production goes to wages and profits. We assume that firms hire only the workers they need for production but have to hold on to the capital they have already installed. We can express the division of income into wages and profits in terms of the wage–profit relation

$$1 = \frac{w}{A} + r\frac{K}{Y}, \tag{6.2}$$

where w is the real wage and r is the rate of profit. The two terms on the right-hand side of this equation are the wage and profit shares in income. We will henceforth denote the labor share, w/A, with the symbol ω, so that we can write it as

$$1 = \omega + \frac{r}{u}, \tag{6.2$'$}$$

where $u = Y/K$, the actual output-capital ratio, is a measure of capacity utilization. The actual output-capital ratio has an upper bound given by B, so that

$$u \leq B. \tag{6.3}$$

We assume that workers, who earn wage income, consume all their income, and a fraction, s, of profits is saved. Saving is therefore given by

$$S = srK. \tag{6.4}$$

Firms hire workers, produce, sell their product at a price P, and invest. Our alternative models will specify the precise behavior of firms. Over time, capital grows according to the level of investment, I, assuming away the depreciation of capital for simplicity, so that we have

$$g = \frac{I}{K}. \tag{6.5}$$

Over time employment grows according to the equation

$$l = y - a, \tag{6.6}$$

where lower case letters denote the time-rates of growth of the variables denoted by upper case letters, for instance, $y = (dY/dt)/Y$. We assume that labor supply grows at the exogenously given rate n.

The rate of growth of labor productivity, a, is a variable in our model. The theory of endogenous technological change adopted in this chapter assumes that labor productivity grows proportionately with the capital–employment ratio, so that

$$A = \theta \frac{K}{L}, \tag{6.7}$$

where $\theta > 0$ is a fixed parameter. This equation implies, in growth-rate form,

$$a = g - l. \tag{6.8}$$

This simple formulation is the same as, or closely related to, a number of approaches to endogenous technological change available in the growth-theoretic literature. It is closest to the approach used in several 'new' neoclassical growth theory models used to derive the so-called *AK* production function, which has proved to be a popular approach in that literature to depict production conditions without diminishing returns to capital and thereby generate endogenous growth with a neoclassical full employment setting. For instance, if firm i has the Cobb-Douglas production function given by

$$Y_i = \xi K_i^{\alpha} (AL_i)^{1-\alpha} \tag{6.1′}$$

with A, the efficiency factor of labor, common to all firms and representing externalities, is given by equation (6.7), where this factor depends on the overall capital/labor ratio of the economy. With the assumption that all firms are identical, the production function of the representative firm takes the form

$$Y = \xi\, \theta^{1-\alpha} K,$$

which takes the *AK* form with constants returns to capital. This is basically the approach used in Romer (1986), with the difference that labor productivity is proportional to capital stock per worker rather than to the capital stock, under the reasonable assumption that what affects productivity growth is not the total amount of capital but capital per worker. This approach is consistent both with learning by doing, where learning is measured by cumulative investment, or with investment in research and development. The approach is also related to Arrow's

(1962) theory of technological change due to learning by doing, which assumes that labor efficiency depends on capital stock but, rather than assuming diminishing returns to learning, takes learning to be proportional to capital stock with the additional difference, noted earlier, that it is the capital–labor ratio, rather than total capital, which measures learning. It is also related to Kaldor's (1957) technical progress function, which relates labor productivity growth to the rate of growth of the capital–employment ratio, although here our formulation implies that labor productivity growth is equal to the rate of growth of the capital–employment ratio, so that there are no 'diminishing returns' to capital deepening in terms of productivity growth.

We define an *equilibrium* position for the economy as a state of the economy in which the following conditions are satisfied. First, the goods market clears, so that $Y = C + I$, where I refers from now on to both the actual and planned levels of investment by firms, or that $S = I$, or, using equations (6.4) and (6.5),

$$g = sr. \tag{6.9}$$

Second, the variables g, r, ω, u, l, y and a all attain stationary values. It may be noted that we do not require that the economy either attains full capacity utilization or full employment or even a constant rate of unemployment, in equilibrium. Since u attains an equilibrium value, for equilibrium we must have

$$y = g, \tag{6.10}$$

that is, that output and capital grow at the same rate.

The general framework described so far is comprised of equations (6.2′), (6.6), (6.8), (6.9) and (6.10), that is, five equations in seven unknowns, ω, r, u, g, l, a and y. However, it can be seen that the five equations are not independent equations. Substituting equation (6.6) into (6.10) implies equation (6.8), that is, substituting the equilibrium condition that output and capital grow into the *definitional* equation from the growth rate of employment implies the equation representing the *theory* of endogenous technological change. This result is not a general one, but holds for our specific theory of endogenous technological change given by equation (6.7) which, as we have seen, has some popularity in the growth literature.

The general framework can be represented graphically as shown in Figure 6.1. The upper left quadrant shows equation (6.9), the relation between the rate of growth of capital and the rate of profit: it represents the savings function of the economy. The economy will be on this given line, but we do not know where exactly it will be. The negatively-sloped solid line in the lower left quadrant shows the relation between the wage share and the profit rate when $u = B$, that is, the economy is at full capacity utilization, so that

$$1 = \omega + \frac{r}{B}. \tag{6.11}$$

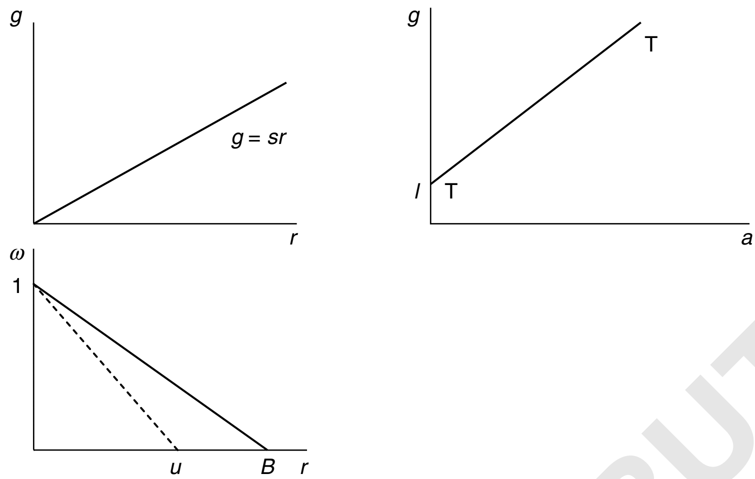

Figure 6.1 The general framework

The economy, of course, does not have to be at full capacity utilization, since (6.3) may be satisfied as an inequality. Thus, the economy may lie within the solid line, for instance on the dashed line for which the level of capacity utilization can be shown by the horizontal intercept of the line. Not only do we not know at which point on a given line the equilibrium will lie, but also which line it will be on. The positively-sloped line *TT* in the upper right quadrant shows the relation between the rate of growth of capital stock and the rate of labor productivity growth when employment grows at the rate *l*, and is given by

$$g = l + a. \tag{6.12}$$

The line has a vertical intercept of *l* and a slope of unity. This equation is derived from equations (6.6) and (6.10) and also equation (6.8). Not only do we not know where the economy will be on this line in the figure but because the value of *l* is unknown, even its intercept is unknown. Clearly, there is insufficient information to determine the equilibrium values of the variables of the model.

Alternative models of growth and distribution

To derive fully specified models of growth, distribution and technological change, we need to add additional information to our general framework to obtain additional equations. We may seek to obtain this additional information from major alternative traditions in the theory of growth and distribution, that is, neoclassical, classical-Marxian and post-Keynesian theories, as discussed in Marglin (1984) and Dutt (1990).

The neoclassical approach assumes perfect competition and full employment growth, and can thus be represented by the additional equations

$$u = B \tag{6.13}$$

and

$$l = n, \tag{6.14}$$

where n, the rate of growth of labor supply, is exogenously given. Equation (6.13) states that the economy produces at full capacity, which follows from the assumption of perfect competition, which ensures that as long as firms make positive profits, they will produce as much as they can. Equation (6.14) is necessary for full employment growth, although not sufficient, because it is consistent with any given rate of unemployment. The resulting model is not recognizable as a standard neoclassical model because, unlike standard neoclassical models which do not make distinctions between the saving behavior out of profit and wage income and allow for factor substitution in production, our framework assumes differences between the saving behavior out of wages and profits and assumes that the input–output relations in production are fixed. Nor is it a fully determined model, since adding these two equations to our general framework merely fixes the wage–profit relation in Figure 6.1 to be the one given by the solid line which represents full capacity utilization, and the *TT* line as one with a vertical intercept of n. The rates of capital accumulation and technological change, and the wage share and the rate of profit cannot be determined from this model.

The model, however, can be completed by assuming that the saving rate out of income is constant and does not depend on the distribution of income (because of differences in saving behavior out of wages and profit, as assumed in our framework), so that

$$S = \sigma Y, \tag{6.15}$$

where σ is the constant saving rate out of income, and allowing for capital-labor substitution and cost-minimization by firms. The former assumption implies that equation (6.9) must be replaced by

$$g = \sigma u. \tag{6.9′}$$

The implications of the latter assumption can be examined by assuming that the production function is of the Cobb-Douglas form given by equation (6.1′) rather than the fixed-coefficients form given by equation (6.1). In minimizing costs firms take A to be given, although it is, in general equilibrium, it is determined by equation (6.7). Cost minimization and the use of equation (6.7) implies that

$$\omega = \frac{1-\alpha}{\alpha\theta}, \tag{6.16}$$

and

$$u = \xi\theta^{1-\alpha}, \tag{6.17}$$

which replaces equation (6.13). Equations (6.9′) and (6.17) determine the rate of capital accumulation. Since this is given by the parameters of the model and independent of r, the saving curve for the economy in the upper left hand quadrant of Figure 6.2 is a horizontal line.

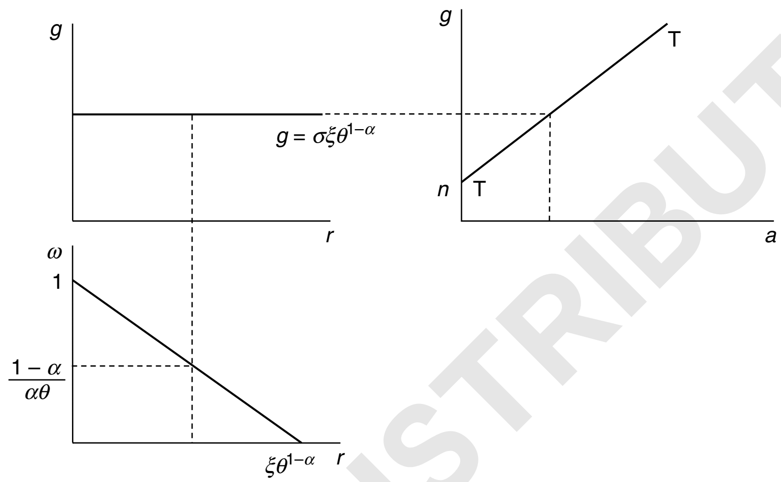

Figure 6.2

Equation (6.2′), using equation (6.17) gives the relationship between the wage share and the profit rate in the lower-left quadrant where the value of ω is determined by equation (6.16). The model is now fully determined: the rate of profit is determined in the lower left quadrant, the rate of capital accumulation in the upper-left quadrant (independently of r), and the rate of technological change in the upper-right quadrant, with the vertical intercept of the *TT* line fixed at n.

Having determined the equilibrium values of the variables of the model, we may examine the effects of changes in parameters. A rise in the saving rate, σ, will shift up the horizontal saving line upwards and increase the rates of capital accumulation and technological change (and hence per capita output growth), but leave the wage share and the rate of profit unchanged. A rise in overall productivity, represented by a rise in ξ, will shift the saving line up and rotate the wage-share profit rate line out, increasing both the rate of profit and the rates of capital accumulation and technological change, leaving the wage share unchanged. A rise in θ, the labor productivity parameter, will have a similar effect on the two curves, and thereby increase the rate of profit and the rates of capital accumulation and technological change, but reduce the wage share. The model may also be modified to obtain an upward-rising saving curve, using at least two modifications. One is to assume that the saving rate depends positively on the rate of profit. Another is to return to our assumption that saving is given by equation (6.4), so that we get the usual saving curve from our general framework. With these changes, an upward rotation or shift in the saving curve (due to an increase in the overall saving rate at a given profit rate or a rise in the saving rate of capitalists) will increase the rates of capital accumulation and technological change without changing the distribution of income or the rate of profit.[2]

The classical-Marxian approach assumes a given wage share, determined by the relative bargaining power of workers and firms owned by capitalists, or the 'state of class struggle', so that

$$\omega = \bar{\omega}, \tag{6.18}$$

and that firms produce at full capacity, so that equation (6.13) is satisfied, either due to the assumption of perfect competition, as in the neoclassical approach, or due to the propensity of firms to produce as much as possible to compete actively against other firms for markets. Otherwise we return to the general framework of the previous section.

When we add these two equations to our general framework, we find that although we can determine r and g (and y), we cannot determine l and a, that is, we cannot determine the way in which the increases in the demand for effective labor will be decomposed into increases in employment and technological improvements. This is shown in Figure 6.3, where the position of the TT curve, and hence, l and a are indeterminate.

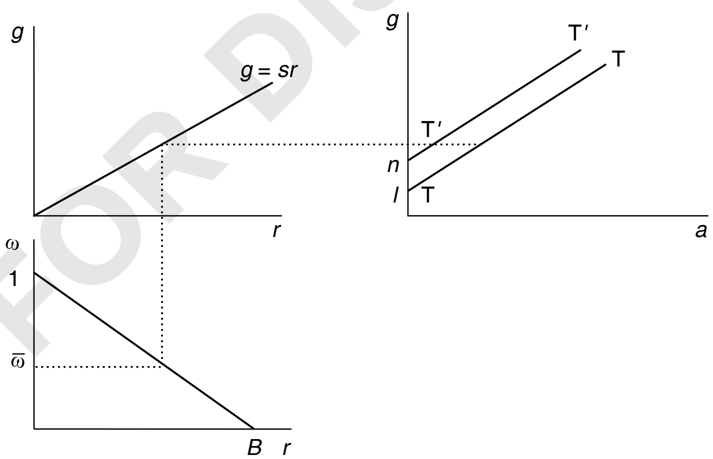

Figure 6.3 A classical-Marxian model

To close the model we can assume that equation (6.14) is satisfied, so that employment growth is at a rate equal to the rate of growth of labor supply, which is exogenous. This fixes the position of the TT curve at $T'T'$ in the figure, and determines the value of a, given by $a = g - n$.

In this modified model, we find that growth is consistent with fully employed labor or at least a constant rate of unemployment. The equilibrium rate of capital accumulation and output increases if s (or B) increases and if $\overline{\omega}$ falls, and this is accommodated by an increase in the rate of growth of effective labor supply due to endogenous changes in the rate of labor productivity growth without creating a shortage of labor. If there is an exogenous fall in the rate of growth of labor supply, n, the equilibrium rates of capital accumulation and output growth will be unaffected, but a will increase, which will imply a higher rate of growth of the real wage.

Two post-Keynesian models of growth and distribution have been examined in the literature, which have been called the neo-Keynesian and the neo-Kaleckian (or Kalecki-Steindl) models. Both stress the role of aggregate demand by departing from the assumption that all saving is automatically invested, as in the neoclassical and the classical-Marxian growth models, by assuming an independent desired investment function, making desired investment depend positively on the rate of profit or the rate of capacity utilization, the position of the curve determined by business confidence or animal spirits. The neo-Keynesian model assumes that the economy is at full capacity, so that equation (6.13) is satisfied, and that planned investment and saving are brought to equality, as required for goods market equilibrium, by variations in the wage share. In this approach, following Robinson (1962), it is assumed that desired investment depends positively on the rate of profit, so that

$$g = g(r) = \gamma_0 + \gamma_1 r \tag{6.19}$$

where a linear form is assumed for simplicity, with $\gamma_i > 0$. The Kalecki-Steindl model assumes, following the adjustment mechanism stressed by Kalecki (1971), that firms typically hold excess capacity, and set their price as a fixed markup on prime or labor costs, so that

$$P = (1+z)W/A. \tag{6.20}$$

The markup factor, z, represents the degree of monopoly, and depends on factors like the degree of industrial concentration, the importance of fixed or overhead costs, and the state of class struggle between workers and firms. This equation implies that the labor share is given by

$$\omega = \frac{1}{1+z}, \tag{6.21}$$

and that the rate of profit is given by

$$r = \frac{z}{1+z}u. \tag{6.22}$$

Since there is excess capacity in the economy, this approach assumes that goods market adjustment occurs through changes in the levels of output and capacity utilization, given the distribution of income. Since excess capacity exists in the economy, this approach typically follows Steindl (1952) and assumes that desired investment depends positively on the rate of capacity utilization, so that we have

$$g = g(u) = \gamma_0 + \gamma_2 u \tag{6.23}$$

where, again, $\gamma_i > 0$.[3]

Rather than examining both versions of the post-Keynesian model, we examine the second, Kalecki-Steindl one, which allows excess capacity to exist.[4] Substituting equation (6.22) into (6.23) we obtain

$$g = \gamma_0 + \gamma_2 \frac{1+z}{z} r$$

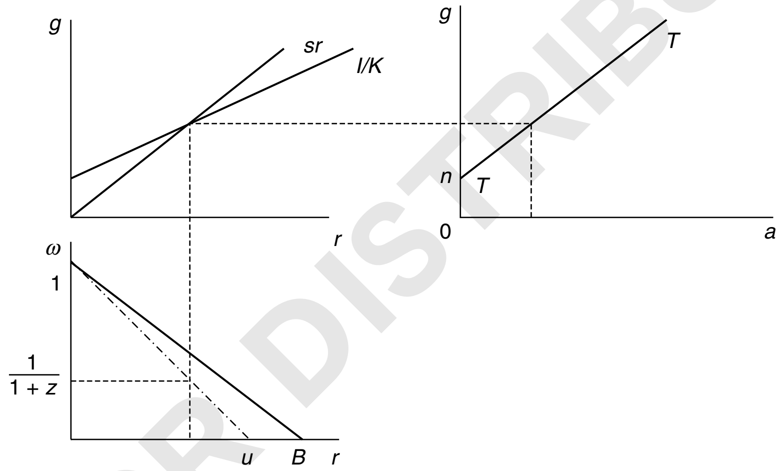

Figure 6.4 A post-Keynesian model

which is represented by the *I/K* in the upper left quadrant of Figure 6.4, assuming that it is flatter than the saving line.[5] The rates of investment and profit are determined at the intersection of the saving and investment lines in the upper left quadrant. The lower left quadrant shows the value of ω determined by equation (6.21), and the point inside the wage share-profit frontier in that quadrant shows the wage share and profit rate for the economy (to ensure that there is excess capacity in equilibrium). The rate of capacity utilization is shown by the horizontal intercept of the dashed line through this point and the point at which $\omega = 1$. In general, for this model, since l is undetermined, so is a, as in the classical-Marxian model: the extent to which output growth is accommodated by labor supply growth and labor productivity growth is undetermined. It may be noted that, in this model, an increase in animal spirits or business confidence, represented by an increase in γ_0, or a fall in the markup, z, will increase the rate of capital accumulation (by shifting up the investment line) and the rate of profit. The fall in the markup also increases the labor share, implying that capital accumulation in this model is wage led. A rise in the saving rate of capitalists rotates the saving line up and therefore reduces the rate of profit and rate of accumulation: we get the paradox of thrift.

If we assume that the model is closed with equation (6.14), the position of the *TT* curve is fixed in the upper right quadrant, so that $l(=n)$ and a are determined. This model is a post-Keynesian model in which in equilibrium labor supply and labor demand grow at the same rate, so that we have full employment growth. The effects of the parametric shifts in this modified model are the same as those discussed for the basic model, which did not determine the rate of technological change. Here, with endogenous technological change, changes in aggregate demand due to changes in autonomous investment, the markup and the saving rate have an effect on capital accumulation and technological change even if we assume full employment growth in equilibrium: when the rate of growth of output and labor demand change in this model, the rate of labor productivity growth changes endogenously to accommodate these changes.[6]

Toward an expanded role for technological change

A feature of technological change in the heterodox models discussed in the previous section is that it has a rather passive role in the growth process. Although in the neoclassical model the rates of capital accumulation and output growth are affected by the technological change parameter θ, as shown by equations (6.9′) and (6.17), as is distribution, as shown by equation (6.16), in the heterodox classical-Marxian and post-Keynesian models, these variables are independent of technology and technological change: all that endogenous technological change does, in the modified models with full employment growth, is to allow technological change to accommodate growth without creating a labor shortage. In Figures 6.3 and 6.4 the rate of accumulation and the distribution of income are determined in the left-hand quadrants, in which there is no mention of a technological change parameter. It can be argued that the approach adopted in these models does not give technological change its due.

A major reason for this inadequate treatment of technological change in these models is that the only way it enters the model is by affecting the rate of growth of labor productivity. The relegation of technological change to this role in these models – a role which is emphasized in neoclassical models – does an injustice to the rich role that technological change is given in heterodox growth traditions. In these traditions technological change can affect investment, income distribution and other features of the economy. To illustrate these effects we consider the effect on income distribution in the classical-Marxian model and the effect on investment in a post-Keynesian model.

For the classical-Marxian model we assumed in the previous section that the wage share, $\bar{\omega}$, is exogenously given, which implies that workers are able to increase their real wage in step with labor productivity growth, maintaining their share of the fruits of technological change. If this is not the case, we may formalize the dynamics of the wage share by noting that

$$\hat{\omega} = \hat{w} - a \tag{6.24}$$

where the overhat denotes the rate of growth of the variable, and assuming that

$$\hat{w} = \lambda_1(\overline{\omega} - \omega) + \lambda_2 a, \tag{6.25}$$

where λ_i are positive, finite, parameters and $\lambda_2 < 1$. This equation shows that the rate of growth of the real wage depends on the gap between the targeted wage share and the actual wage share, and incompletely on the rate of labor productivity growth. Substituting equation (6.25) into (6.24) and solving for the equilibrium value of the wage share, at which $\hat{\omega} = 0$, we obtain

$$\omega = \overline{\omega} - \frac{1-\lambda_2}{\lambda_1} a. \tag{6.26}$$

This equation shows, given our assumptions, that a higher a implies a lower equilibrium level of ω, since the real wage fails to keep up with the rate of productivity growth. This relationship is shown in the lower right quadrant of Figure 6.5. This approach can be seen as following Marx's analysis of technological change – which involves the adoption of labor-displacing machines – as a weapon in the hands of capitalists in class struggle (see Marx, 1867, ch. 15.5), which reduces the share of workers in overall income.

If we modify the classical-Marxian model by replacing equation (6.18) with equation (6.26), while assuming full employment growth in equilibrium, that is, making equation (6.14) hold, we get the model shown in Figure 6.5, in which the wage share is endogenous. Combining the three lines in the lower two quadrants and the upper-left one, we obtain the *AG* curve, which is derived from equations (6.9), (6.11) and (6.26), which yields

$$g = s(1-\overline{\omega})B + \frac{1-\lambda_2}{\lambda_1} Ba. \tag{6.27}$$

The figure assumes that $s(1-\overline{\omega})B > n$, that is, the rate of capital accumulation which results from a rate of profit implied by the targeted wage share (which gives an upper bound to the wage share) exceeds the rate of labor supply growth, and $\frac{1-\lambda_2}{\lambda_1} B < 1$, that is, the real wage lag behind productivity growth is not 'too' large. The intersection of the *AG* curve and the *TT* curve which has n as its vertical intercept determines the equilibrium levels of g and a. The rest of the figure solves for the equilibrium values of the other variables. Since *AG* incorporates information from the line in the lower right quadrant, the equilibrium levels of ω and a will lie on the latter line.

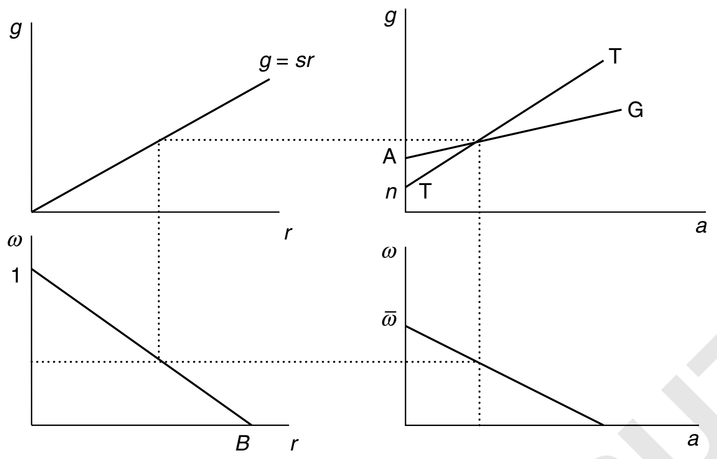

Figure 6.5 A classical-Marxian model with an endogenous wage

Now consider the effects of a fall in the growth of labor supply, *n*. The *TT* curve shift down in the upper right quadrant, implying an increase in equilibrium *a*, *g*, and *r* and a reduction in *ω*. The rates of growth of output and the real wage increase, and that of employment falls. The fall in the rate of labor supply growth increases labor market pressure and induces a higher rate of technological change, which reduces the wage share as wages fail to keep up with productivity growth, which increases the profit rate and results in a higher rate of capital accumulation. In equilibrium, labor demand grows at the lower rate of growth of labor supply, but productivity grows faster, as does the real wage and output. This result may be compared to the implications of a fall in *n* in the classical-Marxian model discussed in the previous section and the neoclassical model also discussed in that section. In the classical-Marxian model of the previous section, as we saw earlier, a fall in *n* increases productivity growth, but with the wage share exogenously given, there is no change in the rate of capital accumulation. Technological change has no effect for the rate of capital accumulation, unlike what happens in the model of this section. In the neoclassical model of Figure 6.2 there is also no effect on capital accumulation and output growth, although with labor supply growing more slowly, there is an increase in per capita income.

The rate of labor productivity growth may have additional effects on the parameters of the model. One such effect is that on capital productivity, given by *B*. If the price of higher labor productivity growth is a fall in capital productivity, we may have a negative effect on *B*. But if higher labor productivity growth leads to a concomitant increase in capital productivity, *a* will be positively related to *B*. These changes will result in additional changes in the rate of capital accumulation. Rather than analyse these effects, which is straightforward to do, we turn to a post-Keynesian model.

Several analysts of growth models determined by aggregate demand, including Kalecki (1971), have emphasized the role of technological change in increasing desired investment. To take this effect into account we may modify equation (6.23) and assume that

$$g = \gamma_0 + \gamma_2 u + \gamma_3 a. \tag{6.28}$$

Replacing equation (6.23) by (6.28) in the Kaleck-Steindl model, we find that it is no longer possible to draw the investment line in the upper left quadrant of Figure 6.4, since its position depends on *a*.

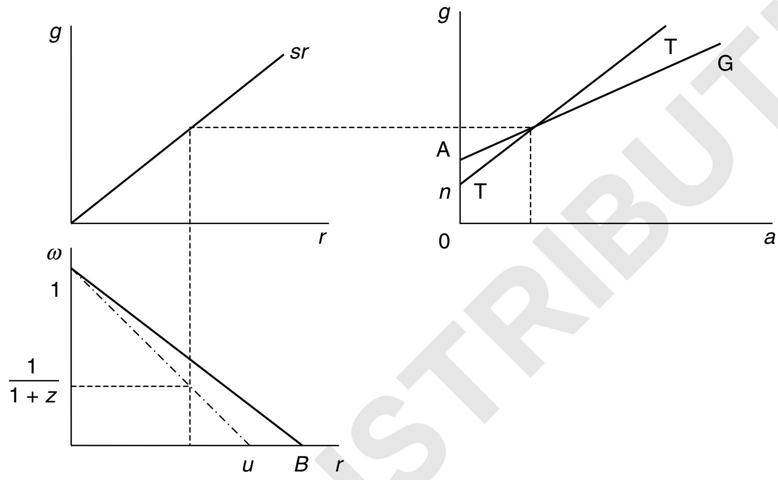

Figure 6.6 A post-Keynesian model with investment depending on technological change

To examine the implications of this amendment for Kalecki-Steindl model with full employment growth we use equations (6.9), (6.22) and (6.28) to obtain

$$g = \frac{\gamma_0 + \gamma_3 a}{1 - \dfrac{(1+z)\gamma_2}{zs}}. \tag{6.29}$$

Given the assumptions about the relative slopes of the saving and investment curves, the denominator of of the left-hand side is positive, so that the equation can be represented by the straight line *AG* with positive intercept and positive slope in the upper-left quadrant of Figure 6.6. We also assume that γ_3 is 'small', so that the effect of technological change on investment, while positive, is small. This line shows the equilibrium level of the rate of capital accumulation – which brings saving and investment to equality – for a given *a*. This ensures that the *AG* line has a slope which is less than unity. We are assuming also that autonomous investment, γ_0, is large enough compared to *n* to make the vertical intercept of the *AG* line larger than that of the *TT* line. The intersection of this line with the *TT* line – which shows how a higher rate of capital accumulation increases the rate of productivity growth (for instance, due to learning by doing) – determines the equilibrium rates of capital accumulation and technological change.

Consider, now, the effect of an increase in autonomous investment, γ_0. As in the post-Keynesian model, which did not include the effect of technological change on investment, this will increase investment spending. While in the earlier model this is shown by an upward shift in the *I/K* line in Figure 6.4, in this model it is shown by an upward movement in the *AG* line in Figure 6.6. While in both models *a* increases, in the previous model there is no feedback effect of this on investment. However, in the present model, the rise in *a* has a multiplier effect on *g*, induced by the higher rate of technological change. Thus, there is a stronger effect on capital accumulation in this model, because it takes into account the interdependence of investment and technological change which was absent in the previous model (which only took into account the effect of investment on technological change and not the reverse causation). Note also, in this model, that a higher γ_3, that is a greater response of investment to technological change, results in a higher rate of capital accumulation, technological change, output growth and real wage growth, an effect which did not exist in the previous model.

The post-Keynesian model can be further extended to take into account additional effects of technological change, including an effect on the markup and hence the distribution of income. This may reflect not only labor market dynamics of the type discussed for the classical-Marxian model of this section, but also the effects of technological change on industrial concentration. These extensions are not pursued here, since our goal is only to illustrate how the basic models can be extended to take into account additional effects of technological change.

Conclusion

This chapter has developed a simple general framework within which to examine and compare models of growth, distribution and technological change from alternative growth theory traditions, including what may be called the neoclassical (in which growth is constrained by effective labor supply), classical-Marxian (in which growth is constrained by saving and capital accumulation) and post-Keynesian (in which growth is limited by aggregate demand). In so doing, this chapter has extended earlier attempts to develop a general framework in which alternative models can be seen as providing alternative ways of 'closing' the general framework, but which ignored the role of technological change. The theory of endogenous technological change we have adopted is a simple one, but one which is related to a number of influential and widely-used approaches in the growth-theory literature on technological change. The main implications of our analysis are as follows.

1 Our extended general framework is able to encompass a larger range of models of growth and distribution than before, including neoclassical new growth or endogenous growth theories, and heterodox theories with endogenous

technological change. It is thereby able to make possible comparisons with a wider range of theories.

2 The extended framework is found to narrow down the differences between some of the alternative approaches to growth and distribution. For instance, it is shown that we may have classical-Marxian and post-Keynesian models which behave like neoclassical models in the sense of having full employment growth, but which have other properties that are just like those of standard heterodox models. For instance, aggregate demand has an effect on the long run even with full employment growth, unlike what is sometimes suggested in the growth literature which ignores aggregate demand issues from the start (see Dutt, 1986).
3 We are also able to extend the simple framework to consider effects of technological change other than those shown by simple changes in input–output coefficients. For instance, we have analysed the effects of technological change on income distribution and investment, and shown how capital accumulation, technological change and distribution can interact with each other in the long run.

If the analysis of this chapter is found to be useful, it can be extended to deal with additional complications. The implications of alternative theories of technological change may be examined, and the dynamics of the models outside long-run equilibrium can also be explored, as has been done in Dutt (2010b). The general framework can also be modified to deal with additional issues, such as the role of education and human capital formation as a determinant of technological change (as in Dutt, 2010a, and Dutt and Veneziani, 2010). Such extensions can lead to a fuller appreciation of the role of technological change in the growth process and of how it interacts with capital accumulation and income distribution.

Notes

1 For an early contribution using this framework to the analysis of theories of distribution, see Sen (1963). For applications to growth and distribution, the pioneering contribution is that of Marglin (1984), although a precursor of the general method can be found in Harris (1978). Subsequent contributions, drawing on Marglin's approach using alternative closures, include Dutt (1987) and Dutt (1990).
2 Additional neoclassical models may be obtained from these models. Assuming that a is exogenously given, the saving rate is fixed, and allowing for factor substitution, produces the Solow (1956) model. Maintaining the first and last assumption, but making the saving rate depend on the rate of profit produces in effect the overlapping generations model (as a reduced form without optimization by economic agents).
3 Variants of the model assume that desired investment depend positively on both the rates of capacity utilization and profits. This is the assumption made in the original presentations of this model by Rowthorn (1982) and Dutt (1984).
4 The neo-Keynesian one can be examined by assuming full capacity utilization and using equation (6.19) for the desired investment function.
5 This requires that $s > \gamma_2(1 + z)/z$, which ensures that variations in saving due to a change in the rate of profit (and the rate of capacity utilization) exceed variations in investment, a standard macroeconomic stability condition in models with quantity adjustment in goods markets.

6 See Dutt (1986) for a Keynesian model which examines the dynamics of technological change and capital accumulation to produce a model of this type, integrating the aggregate demand and aggregate supply sides of the economy.

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