5

The Consequences of Technical Change

The performance of the economy depends to a large extent on the nature of its implemented technology. The empirical determination of the role of technology, however, is not a simple matter, as can be seen from the voluminous work on the subject. Basically, the difficulty arises from the fact that technology is not an observed quantity but rather an abstract concept. The standard approach has been to identify technology with a production function; technological change has thus been associated with shifts in the production functions. The concept of a production function is borrowed from the sciences, where input-output relationships are generated by what are thought to be well-described processes. As such, the production functions describe some laws of nature. Empirical applications that are close in spirit to such a concept are given by agricultural production functions (see Heady and Dillon, 1961). Examples from agriculture had a general flavor in the early days of economic theory, when agriculture accounted for a large part of total output. This attribute has diminished with time, and it became desirable to have applications similar to nonbiological processes, leading to "engineering production functions" (Chenery, 1949). Thus, in the words of Solow (1967, p. 26), "The pure theory of production is fundamentally microeconomic in character: it deals with physically identifiable inputs and outputs. In the classroom one usually says that the economic theory of production takes for granted the 'engineering' relationships between inputs and outputs and goes on from there. By contrast, much (though not quite all) of the recent interest in the theory of production has been macroeconomic in character. Since the 'inputs' and 'outputs' are statistical aggregates like 'labor,' 'plant,' 'equipment,' 'durable manufactures,' there is no possibility of finding engineering relationships. Econometric methods have to do the duty instead. Still, it remains an intriguing idea to deduce economically useful production functions from raw technological information."

The role attributed to econometric analysis in this statement is rather narrow and basically an impossible one. For one thing, the aggregation of inputs and outputs depends on prices, and to do it right, it requires a knowledge

of the production functions, exactly what one wants to estimate with the aggregated variables. But more important, micro "engineering functions" change with time and as such affect the relationships among the aggregates. Thus there is no pure engineering-type relationship that can be revealed by econometrics.

The work on production functions has progressed in several directions, determined largely by the objective of the study. The empirically oriented work has searched for algebraic relationships that make economic sense and at the same time can be fitted to the data. The economic sense is judged by requirements that are imposed on the micro functions. The estimation is conducted under the basic, but tacit, assumption that all the observations were generated from the same aggregate relationship, which by itself is allowed to change with time in one way or another. That work alone is very rich, and some aspects of it are reviewed in Chapter 11.

Alternatively, theoretical work on technical change has concentrated on formulations that can be conveniently analyzed. The outcome of such analysis is not the same as the outcome of the empirically oriented literature. The difference between the two approaches can be attributed to the complexity of the subject matter, and more work is needed to integrate the various approaches.

Our interest in the subject covers both aspects. We want to trace the effect of technical change on the behavior of the economy with the purpose, however, of being able to come up with empirically verifiable conclusions. In this we continue with the procedure we have followed thus far. The chapter begins by tracing the effect of technical change on the behavior of our simple economy. For that matter, the convenient conventional formulations of technical change are adopted. Later on, Chapter 6 will take up a somewhat different view of technology that is expected to be more realistic and therefore more pertinent empirically. Basically, that approach recognizes that at any time, the economy employs many techniques, each identified with a production function. Technology is thus identified with the collection of all techniques. This is in contrast to the standard approach, to be followed in this chapter, which assumes that the technology of each sector can be represented by a well-defined production function. The empirical aspects are discussed in Chapters 11 to 14.

A general formulation of technical change is to write the production function with an explicit representation of a technology shifter, t. For a single-output production function with two inputs, this is written as

$$Y = F(K, L, t), \quad \frac{\partial F}{\partial t} \geq 0. \tag{5.1}$$

The essence of technical change is that a given set of inputs gives a larger output, or alternatively, that the same output can be obtained with less inputs The formulation in (5 1) is too general to allow specific results. A common simplification is that of factor-augmenting technical changes (FATC):

$$Y = F[A_L(t)L, A_K(t)K], \tag{5.2}$$

where $A_L(t)$ and $A_K(t)$ are positive functions of the technology index t. Because it is assumed that technology improves with time, we usually identify t with time. Actually, A_L and A_K can be functions of various variables This possibility is further discussed in Chapters 6 and 13. For the present discussion, however, they are assumed to be determined uniquely by the technology, which in turn is monotonic increasing with time As such, the identification of t with time is just a question of language. The essence of (5.2) is that the new technology expresses itself only as a result of an interaction with the inputs Consequently, the products $A_L(t)L$ and $A_K(t)K$ are viewed as effective inputs measured in quality units, often referred to as efficiency units The functions can be standardized so that for any arbitrary technology, designated as $t = 0$, we have $A_L(0) = A_K(0) = 1$. $A_L(t)$ and $A_K(t)$ are referred to here as labor- and capital-augmenting functions respectively.

A special case of this formulation is that of equal augmentation $A_L(t) = A_K(t) = A(t)$ for all t. Since F is homogeneous of degree 1, $A(t)$ can be factored out so that

$$Y = A(t)F(K, L). \tag{5.3}$$

In this case, technical change (TC) is referred to as Hicks neutral (NTC). The neutrality of this concept is related to the invariance of the marginal rate of factor substitution to technical change

Other cases of interest occur when only one input is affected by the TC. The case of $A_L(t) > 1$ and $A_K(t) = 1$ is identical with what is known as Harrod-neutral TC (HNTC), whereas the opposite case of $A_L(t) = 1$ and $A_K(t) > 1$ is known as Solow-neutral TC (SNTC). These concepts of neutrality are discussed below.

There is analytic convenience, as well as economic insight, in dealing separately with NTC and factor augmentation For that purpose (5 2) is rewritten by factoring out one of the A's. For instance

$$Y = A_L(t)F[a_k(t)K, L], \tag{5.4}$$

where $a_k(t) = A_K(t)/A_L(t)$

Note that $a_k(t)$ can now be viewed as a capital-augmenting function, if $a_k(t)$ is larger than 1 If $a_k \le 1$, then, holding K constant, the term $a_k(t)K$ will decline with time. In this case it is more meaningful to factor out A_K Thus for $F(\,)$ to increase with t, the rule for factoring out should be: $\underline{A}(t) = \min(A_L(t), A_K(t))$. The factored function $A(t)$ is the common rate of augmentation of the two factors. This is the neutral component

We now turn to the two-sector economy where we have two production functions. The TC in each sector is decomposed according to (5 4) The analysis of the effect of TC on the economy is first conducted by considering only NTC in the two sectors. This is followed by analyzing only one factor augmentation in each sector. The final outcome of course is obtained by combining the two cases.

Technical change affects the supply side of the economy and consequently the equilibrium position. In tracing the effect on the supply side, we differentiate among various possible effects: allocation, productivity, and cost, to be explained below

Hicks-Neutral Technical Change

The presentation builds up gradually to cover the various possibilities with the aid of graphical presentation, followed by a summary Some readers may prefer to start with the summary and supplement it with the graphical presentation.

General Results

In this section we examine the effect of NTC in the two sectors Incorporating this assumption, we replace the production functions in (2.8) with

$$y_1 = \ell A_1(t) f_1(k_1) \tag{5.5}$$

$$y_2 = (1 - \ell)A_2(t) f_2(k_2). \tag{5.6}$$

The competitive conditions are modified accordingly:

$$r/p_i(\omega, t) = A_i(t) f_i'(k_i) \tag{5.7}$$

$$w/p_i(\omega, t) = A_i(t)[f_i(k_i) - k_i f_i'(k_i)]. \tag{5.8}$$

The supply system is now given by equations (5 5) to (5 8) and the full employment condition, (2.13).

The wage-rental ratios, $\omega_i(k_i)$, are unaffected by $A_i(t)$, and consequently the labor allocation is determined by (2.13). On the other hand, the price and the supply functions depend on the technology and are therefore labeled $p(\omega, t)$; and $y_i(p, k, t)$, or $y_i(p, t)$ when the dependence on k is suppressed

To derive the price equation, we follow the procedure employed in Chapter 2 and evaluate the ratio of the sectoral cost functions. We utilize the fact that $k_i(\omega)$ is unaffected by the NTC. Consider an initial allocation (K_{i0}, L_{i0}) producing output Y_{i0} with technology $A_i(0) = 1$. The average cost is $c_i(w, r, 0)$. Given the *same* input allocation and the new technology $A_i(t)$, *total* cost remains the same, but *average* cost declines: $c_i(w, r, t) = c_i(w, r, 0)/A_i(t)$. Consequently, the price equation at t can be related to that of the base technology:

$$p(\omega, t) = \frac{A_2(t)}{A_1(t)} p(\omega, 0). \tag{5.9}$$

DEFINITION The sector with a larger rate of technical change is referred to as the *progressive sector*.

PROPERTY 5.1 (the price effect of NTC) The relative price of the progressive sector declines.

It is only in the special case of $A_2(t) = A_1(t)$ that $p(\omega, t) = p(\omega, 0)$.

Next we turn to examine the changes in the outputs corresponding to a given allocation. Resources are held constant, and therefore the dependence on k is suppressed in the notation.

Neutral Technical Change of Equal Rates

The assumption here is that $A_1(t) = A_2(t) = A(t)$. Because the $\omega_i(k_i)$ functions are unaffected by the NTC, there is no change in resource allocation for any given ω. The change in outputs corresponding to a given resource allocation is determined by $A(t)$. This is defined as the productivity effect

DEFINITION The *productivity effect of technical change* is the increase in output derived from a constant bundle of resources

By assumption, we deal here with the case where the productivity effect is the same for both sectors. This is illustrated in Figure 5.1 as a shift of the transformation curve. Point A is the initial point, and point B, located on a ray from the origin through A, represents the productivity effect. Equal rates of NTC leave the price function unchanged so that $p_B = p_A$, and the supply functions are augmented by the productivity effect, $y_i(p, t) = A_i(t)y_i(p, 0)$.

On the demand side, the technical change increases income, thereby increasing the consumption possibilities of the economy, and the demand increases accordingly. Let $y(p, t) = A(t)y(p, 0)$ represent the income attained at

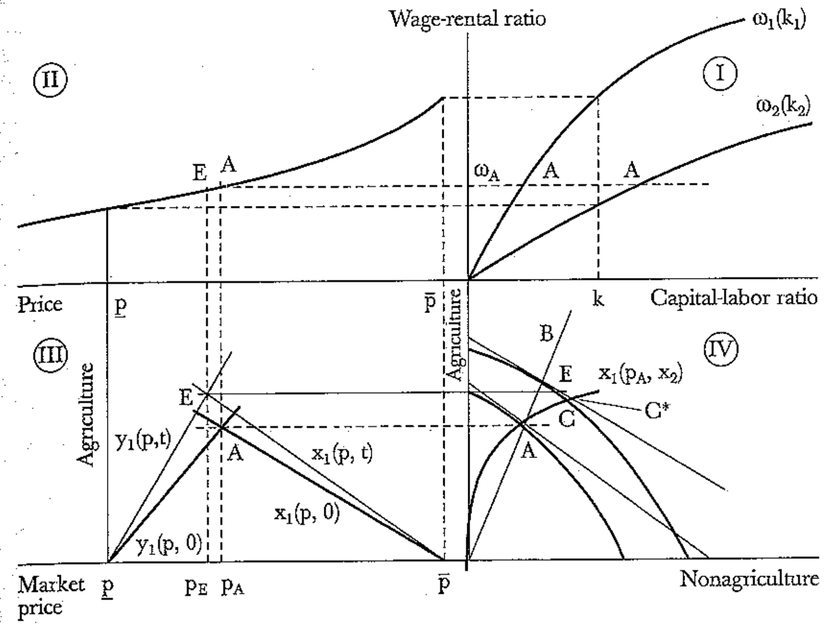

Figure 5.1 Hicks-neutral technical change: Equal rates

price p and technology t. The rate of change of income due to t is $\hat{A}$. This is also the rate of the shift of the supply functions of both products. Thus there is an upward shift in supply and demand, and consequently the outputs and the consumption of the two goods increase. The change in the excess demand depends on the relative rates of growth of supply and demand, the latter depending on the income elasticity. Because the income elasticity for agriculture is less than 1, the demand for agriculture shifts relatively less than the supply, and hence an excess supply of agriculture is likely to occur. As derived from equation (5.13) below, this is true only when the ratio of output to consumption in agriculture, y_1/x_1, is larger than the income elasticity E_{1c}, a condition that is generally met

Small Open Economy

For the small open economy, an increase in excess supply implies an increase in the net export of agriculture. This can be shown in Figure 5.1 where the output changes from A to B. Consumption is at C^*, obtained at the intersection of the new budget line with the demand $x_1(p_A, x_2)$. Initially the country did not trade, and under the new technology it becomes an exporter of agriculture

PROPERTY 5.2 (neutral technical change of equal rates; open economy) In general, neutral technical change of equal rates in the two sectors increases the net export of the income-inelastic product.

The statement is qualified by the term "in general" to account for the case where agricultural production is small relative to consumption, in which case the increase in demand is larger than the increase in production. The condition for this qualification is derived below (equation 5.12).

The foregoing analysis has important implications for possible changes in trade resulting from technical change With equal rates of technical change, the changes in trade reflect the income elasticities and the position of the economy. When import does not constitute a major component of consumption, the technical change increases the excess supply of the income-inelastic product As a consequence, if the country is initially self-sufficient, it will now become an exporter of agriculture. Alternatively, the country can change from importing to exporting food This simple framework can explain a change such as the one that occurred in India, which switched from importing to exporting grain This example emphasizes the crucial role played by the income elasticity. If the income elasticity of food were larger than 1, the situation would be reversed.

Closed Economy

In the case of a closed economy, output is equal to consumption in each sector It is therefore sufficient that the income elasticity for food is less than 1 for the technical change to produce an excess supply of food and for the price of agriculture to decline The change in the equilibrium position is illustrated in Figure 5.1, where the demand at the initial price, p_A, increases to C, not C^* as in the case of the open economy. The new equilibrium point E is located between B and C. It is also shown in panel III, where the initial point A is located on the initial supply function, labeled as $y_1(p, 0)$, whereas E is located on the new supply curve, labeled $y_1(p, t)$. The reader is invited to trace the new equilibrium values in the remaining panels of Figure 5.1 and to show that ω declines to ω_E as p declines from p_A to p_E, and k_i declines correspondingly. The corresponding change in resource allocation takes place under a constant k, and as follows from the discussion in Chapter 2, it requires a shift of resources to the capital-intensive sector Since the productivity effect is the same in the two sectors, the change in resource allocation implies a larger relative increase

in the output of sector 2, which is the capital-intensive and the high income elasticity sector.

The dependence of the solution on income elasticity is illustrated by the location of point C relative to B. In the special case when the demand is homothetic, C and B will coincide, and the price will remain unchanged If the income elasticity of agriculture were larger than 1, point C, and therefore E, would be to the left of B, with $p_E \geq p_A$ and consequently $\omega_E \geq \omega_A$.

PROPERTY 5.3 (neutral technical change of equal rates; closed economy) A neutral technical change of equal rates produces equal productivity effects in the two sectors As a result, outputs increase in the two sectors The relative price of the product whose income elasticity is smaller than 1 declines The wage-rental ratio decreases (increases) when the income-inelastic sector is labor (capital) intensive Prices are unaffected when both income elasticities are unitary or when factor intensities are the same.

The discussion is pertinent to the understanding of the developments in the world market for basic agricultural products For this purpose the world is considered as a closed economy. Initially, this market is postulated to be in equilibrium at A, as shown in Figure 5.1. Technical change moves it to E with a decline in world price. This is consistent with the evidence summarized in Figures 1.1 to 1.4 This discussion is illustrative and not exhaustive, of course, as there are other forms of technical change, considered below and in Chapter 6, which also affect the outcome. However, recall the discussion at the beginning of this chapter, where neutral technical change of equal rates was interpreted as the common rate to all sectors. As such this extracts a considerable portion of the technical change that has taken place

Neutral Technical Change of Unequal Rates

Next we turn to unequal rates of NTC. In dealing with this case it suffices to consider TC in one sector only, because any NTC in the two sectors can be decomposed as follows: label $[\,] = [A_1(t), A_2(t)]$, and define $\underline{A}(t) = \min[\,]$, $\overline{A}(t) = \max[\,]$. The equal rate is given by $\underline{A}(t)$, and the differential rate is $\overline{A}(t) - \underline{A}(t)$.

In what follows we let agriculture be the progressive sector in that $A_1(t) > 1$ and $A_2(t) = 1$. Consequently, the productivity effect is limited to agriculture It is shown in panel IV of Figure 5.2 as a movement from A to B Both of these points are obtained with the resource allocation corresponding to the wage-rental ratio ω_A.

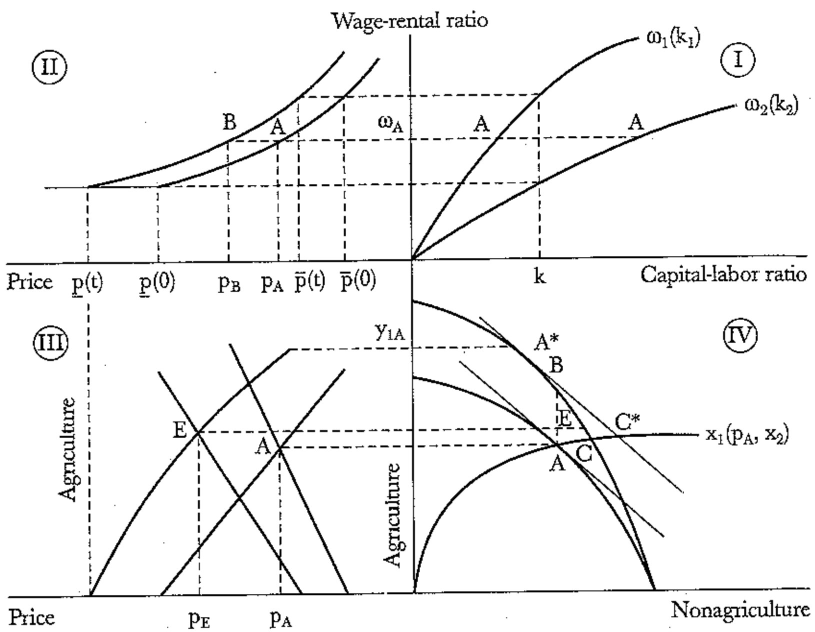

Figure 5.2 Hicks-neutral technical change in agriculture

Unequal rates of technical change affect the price equation, as can be seen from equation (5.9). This is shown in panel II of Figure 5.2, with $p_B < p_A$. The initial price, p_A, can be restored by shifting resources to the progressive sector, resulting in point A^* where $p_{A*} = p_A$. The movement from B to A^* is referred to as the cost effect. More formally, the cost effect is $y_i(p,t) - A_i(t)y_i(p,0), i = 1, 2$.

DEFINITION (cost effect) The *cost effect* of technical change is the shift of supply, over and above the productivity effect, necessary to maintain a constant price.

PROPERTY 5.4 (cost effect) The cost effect of technical change on output is positive for the progressive sector and negative for the passive sector.

Thus, in the progressive sector, the cost effect supplements the productivity effect. In the passive sector, the cost effect reduces output, whereas the productivity effect leaves the output of that sector unchanged. The shift of the supply function of the progressive sector is illustrated in panel III of Figure 5.2.

The technical change has a positive income effect on the demand of both products. Thus, for the passive product, the demand increases, whereas the supply declines; therefore its excess demand increases. For the progressive sector both demand and supply increase, but demand increases less than supply. With the two products being normal, the increase in income is distributed between the two products, and therefore the increase in demand for either product is smaller than the increase in income. The increase in income is equal to the productivity effect, which is smaller than the increase in supply, which also includes the cost effect. Consequently, the excess supply of the progressive sector increases. The open economy case is illustrated in Figure 5.2 where output changes from A to A^* and demand moves to C^*.

PROPERTY 5.5 (technical change in one sector; open economy) A neutral technical change in one sector increases the net export of the progressive sector.

In the closed economy, the increase in the excess supply of the progressive sector results in a decline of its price and an increase in its equilibrium output. If this increase in output is smaller than the productivity effect, resources are released from the progressive sector to increase production in the passive sector. The actual outcome depends on the demand elasticity, as is shown below. Another way of viewing the change is to indicate that in the progressive sector the income and price effects supplement each other, and the equilibrium quantity will increase. For the passive sector the two effects contradict each other, and the direction of the change is ambiguous.

The discussion is illustrated in Figure 5.2, where the demand $x_1(p_A, x_2)$ intersects the new transformation curve at C. At p_A, the excess supply is given by $z_1(p_A, t) = y_{1A*} - x_{1C} > 0$, and the equilibrium price will be lower than p_A. The output of the progressive sector will increase. The equilibrium output of the passive sector depends on the price elasticity of demand. To see this we obtain from (5.9) $\hat{p}(\omega)\,|_{\omega,A_2(t)} = -\hat{A}_1(t)$. That is, with ω and technology in nonagriculture held constant, the rate of change in p is equal to the rate of technical change (with sign reversed). Consequently, $p_B = p_A(1 - \hat{A}_1)$. On the other hand, $y_{1B} = y_{1A}(1 + \hat{A}_1)$. Thus B represents the same proportionate increase in y_1 and decline in p. Therefore the new demand curve will pass through B when the price elasticity of (2.18) is unitary. It will intersect to the left of B when the price elasticity is larger than 1 and to the right of B when the elasticity is smaller than 1.

To trace the implications of the shift in equilibrium for resource allocation, we note that because B represents the same resource allocation as A, $\omega_B = \omega_A$. Let the progressive sector be labor intensive, and p be its relative price. Then points on the transformation curve to the right of B correspond to values of

ω that are lower than ω_A and conversely for points to the left of B. In other words, points to the right of B imply a shift of resources to the passive sector, which in our case is capital intensive, whereas points to the left of B imply a shift of resources away from the passive sector. The discussion can now be summarized:

PROPERTY 5.6 (neutral technical change in one sector; closed economy) A neutral technical change in one sector leads to an increase in the output and a decline of the equilibrium price of the progressive sector. The equilibrium output of the passive sector declines, remains constant, or increases when the absolute value of the demand elasticity for the progressive product is larger, equal, or smaller than 1 respectively. Resources shift in the same direction as the output of the passive sector. The wage-rental ratio moves in the direction of the resource allocation to the labor-intensive sector.

Effect on Trade

The relationships among technical change, growth, and food import have attracted some attention. It has been observed that countries that have enjoyed a fast economic growth have also increased their food import. Such an association is sometimes erroneously interpreted to mean that food import is the source or the cause of growth. It is therefore useful to summarize the foregoing discussion by evaluating the effect of NTC on trade for the open economy and its further consequences on world food prices.

The output of the small open economy is determined by the world price. The technical change causes an increase in output and hence in income and thereby an income effect on demand. The excess demand for agriculture is then affected by the change in demand and supply. The net import in this case is equal to the excess demand. Let

$$z_1(p, t) = x_1[p, y(p, t)] - y_1(p, t). \tag{5.10}$$

Let E_{1c} be the income elasticity of x_1 with respect to y, $S_1 = py_1/y$, and differentiate $y(p, t)$ with respect to t:

$$\frac{\partial \ln y}{\partial t}\Big|_p = S_1\hat{A}_1 + (1 - S_1)\hat{A}_2 \equiv \hat{A}, \quad \text{then}$$

$$\partial z_{1t}/\partial t = x_1(E_{1c}\hat{A} - \frac{y_1}{x_1}\hat{A}_1), \quad \text{substituting for } \hat{A},$$

$$\partial z_{1t}/\partial t = x_1(\hat{A}_1(E_{1c}S_1 - \frac{y_1}{x_1}) + E_{1c}(1 - S_1)\hat{A}_2]. \tag{5.11}$$

Consider leading cases.

Equal rates $\hat{A}_2 = \hat{A}_1$, then

$$\text{sign } \partial z_{1t}/\partial t = \text{sign}(E_{1c} - y_1/x_1). \tag{5.12}$$

For countries that do not import agriculture, $y_1/x_1 \geq 1$, and since $E_{1c} < 1$, $\partial z_{1t}/\partial t < 0$, implying an increase of agricultural export. With the exception of countries where domestic agricultural production covers only a small fraction of consumption, food-importing countries are likely to decrease their import. The exception requires that the fraction of domestic production in consumption should be smaller than the income elasticity. In this case, an increase in output at rate $\hat{A}$ in both sectors increases demand for agriculture by $\hat{A}E_{1c}x_1$, whereas supply increases by $\hat{A}y_1$. When y_1/x_1 is relatively small, excess demand increases. This case is not applicable to most countries.

Agricultural-based growth. In this case agriculture is the progressive sector, $\hat{A}_2 = 0$, then

$$\text{sign } \partial z_1/\partial t = \text{sign}(S_1E_{1c} - y_1/x_1). \tag{5.13}$$

This expression is similar to (5.12), except that now E_{1c} is replaced by S_1E_{1c} because the increase in income originates only in agriculture. In this case the agricultural net export will increase.

Nonagricultural-based growth. Here technical change occurs only in nonagriculture, $\hat{A}_1 = 0$, and (5.11) reduces to

$$\partial z_1/\partial t = x_1E_{1c}(1 - S_1)\hat{A}_2. \tag{5.14}$$

The income effect increases the demand, whereas the cost effect causes a decline of supply. Consequently, *net* agricultural import increases. This is a result of the fact that agriculture is the passive sector.

The effect on the volume of trade depends on whether the country is initially importing or exporting agriculture. In the first case, import increases, and under balanced trade export of nonagriculture increases as well. Thus the nonagricultural growth is the source of financing needed for the growth of agricultural imports. If the country exports agriculture, export declines, and with it, total trade declines.

To conclude, the *net* import of agriculture is positively related to technical change in nonagriculture and, with unimportant exceptions, negatively related to technical change in agriculture.

Closed Economy and the Global Effect

In the closed economy the changes in the excess demand cause price changes. In this case, it is convenient to express the excess demand in terms of a given resource allocation, which we identify by ω, because ω is unaffected by NTC Thus the supply of the ith product conditional on resource allocation is written as $y_i(\omega, A_i)$. As total resources are held constant, k is suppressed. The excess demand for the closed economy is

$$z_1(\omega, t) = x_1(p(\omega), y_2(\omega, A_2)) - y_1(\omega, A_1), \tag{5.15}$$

where A_i are functions of the technology index t. Under NTC, $y_i(\omega, A_i) = A_i y_i(\omega)$. Differentiate $z_1(\omega, t)$ with respect to t and impose $x_2 = y_2(\omega, A_2)$,

$$\frac{\partial z_1}{\partial t}\Big|_{\omega} = \frac{\partial x_1}{\partial p}\frac{\partial p}{\partial t} + \frac{\partial x_1}{\partial x_2}\frac{\partial y_2}{\partial t} - \frac{\partial y_1}{\partial t}.$$

Write the expressions in terms of elasticities, using (5.9):

$$\begin{aligned}\frac{\partial z_1}{\partial t}\Big|_{\omega} &= x_1[\hat{A}_1(E^r_{1p} - 1) + \hat{A}_2(E^r_{1c} - E^r_{1p}] \\ &= x_1[\hat{A}_1(E^r_{1c} - 1) + (\hat{A}_2 - \hat{A}_1)(E^r_{1c} - E^r_{1p})] \end{aligned} \tag{5.16}$$

where E^r_{1c} and $-E^r_{1p}$ are the income and price elasticities for agriculture derived from the demand $x_1(p, x_2)$: $E^r_{1c} = \partial \ln x_1/\partial \ln x_2$, $-E^r_{1p} = \partial \ln x_1/\partial \ln p$.

If we assume that the economy is initially in equilibrium, then the change in price can be signed by utilizing the convergence assumption; for $z_1 \neq 0$, $z_1 dp > 0$. When the technical change generates a positive excess demand, the price will increase accordingly. More generally,

$$\text{sign}\,\frac{\partial p}{\partial t}\Big|_{\text{eq}} = \text{sign}\,\frac{\partial z_1}{\partial t}\Big|_{\omega}$$

Under equal rates,

$$\hat{A}_1 = \hat{A}_2 = \hat{A},\ \text{sign}\ \partial z_1/\partial t = \text{sign}(E^r_{1c} - 1).$$

Agriculture, being income inelastic, will realize a net excess supply and a decline in p. In this case the rate of technical change is the same in both sectors; therefore the price equation remains unchanged, and the change in p is sufficient to determine the change of the other variables in the system. For instance, if agriculture is labor intensive, a decline in p causes a decline in ω and in $k_i(\omega)$ and a move of resources to nonagriculture.

For agricultural-based growth, $\hat{A}_1 > 0$ and $\hat{A}_2 = 0$, and therefore

$$\text{sign}\ \partial z_i/\partial t = \text{sign}(E^r_{1p} - 1).$$

Because the demand for agriculture is price inelastic, the technical change generates excess supply and therefore a decline in p

To evaluate the effect on the rest of the system, note that in this case the price equation changes, and the change in p cannot characterize the changes in the other variables. Instead, such changes are better characterized in terms of the output of the passive sector.

For nonagricultural-based growth, $\hat{A}_2 > 0$ and $\hat{A}_1 = 0$, hence

$$\frac{\partial z_1}{\partial t}\Big|_{\omega} = x_1\hat{A}_2(E^r_{1c} - E^r_{1p}).$$

The direction of the change in the excess demand is determined by the magnitudes of the income effect and the substitution effect in demand away from agriculture. When the income effect is dominating, the excess demand increases, as does the price of agriculture When the income effect is relatively weak, the demand for agriculture declines because the price of nonagriculture declines due to the technical change, and therefore the production of the initial level of agriculture is now more costly

Note that under unequal rates of NTC, the importance of the difference $\hat{A}_2 - \hat{A}_1$ depends on the relative strength of the income and price elasticities

The Contribution of Agriculture to Economic Growth

This is a good place to return to the remark in Chapter 1 on the contribution of agriculture to economic growth, a subject often discussed in the literature. This subject makes sense only in an environment of changes, and the most important source for change is technology. In the case of nonagricultural-, or manufacturing-, based growth, the excess demand generated for food is met by agriculture, and the stronger the response of agriculture, the less food prices will increase. This is a straightforward, and perhaps natural, role one would expect of agriculture. In the other cases considered above, equal rates of change or a greater rate in agriculture, food prices decline, and resources move away from agriculture to nonagriculture The contribution of agriculture is in lower food prices and in labor and possibly capital. Thus, regardless of the case, agriculture is contributing, but so is nonagriculture. This comment is intended to indicate that in an economy with active trade between sectors, the question of contribution has a limited meaning. It is more meaningful to evaluate the changes themselves

Factor-Augmenting Technical Change

The specification of the technology in equation (5.2) does not indicate whether the augmentation is factor specific or sector specific. It is factor specific when quality factors are homogeneous, and it is immaterial in which sector the technical change takes place. For instance, if we assume $A_{2L} = 1$ and $A_{1L} > 1$, then moving a unit of labor from agriculture to nonagriculture implies moving A_{1L} quality units, and the labor force in nonagriculture after this move will be $L_2 + A_{1L}$. Think of A_{1L} as the years of schooling of agricultural labor, where the units are standardized so that A_{1L} has a value of 1 in a base year. The size of the quality-labor force is the total school years, and the factor augmentation increases the total factor supply measured in quality units. In this case the economy can be viewed as operating in terms of quality factors; factor augmentation increases the labor supply.[1]

When the augmentation is sector specific, the change in the factor productivity depends on the sector of employment. Given the above assumption on the augmentation, when a unit of labor moves from agriculture to nonagriculture, the quality-labor in nonagriculture will be $L_2 + 1$ rather than $L_2 + A_{1L}$ as in the previous case. In this case, it is simpler to think about the factor markets for physical rather than quality inputs. The full employment conditions are stated in terms of the physical inputs and are unaffected by the augmentation. Still, factor augmentation can be viewed as a change of factor supply.

Thinking about factor-augmenting technical change as a change in factor supply makes it possible to draw an analogy to the discussion in Chapter 4. However, there is one modification: the change in the augmentation function immediately disturbs the competitive conditions in that it affects the wage-rental ratio in the progressive sector. This is the new effect introduced here. The other two effects, productivity and cost, are similar in nature to those considered under NTC.

The discussion begins with the evaluation of the effect of FATC on resource allocation at a given wage-rental ratio. The sector-specific FATC is less obvious than that of the factor-specific, and therefore the discussion deals with this case. The required modification for analyzing factor-specific FATC is straightforward. The productivity and cost effects are then added to the allocation effect, and the change in the equilibrium position is evaluated.

The Response of the $\omega(k)$ Function

We begin by examining some general properties related to factor-augmenting technical change. For that purpose there is no need, at this point, to use sectoral notations. Consider the production function: $Y = F(K^e, L^e)$, where $K^e = A_K K$ and $L^e = A_L L$ are capital and labor measured in terms of quality units, respectively. $F(\cdot)$ is a CRS, concave, and twice differentiable function in K^e and L^e. We can thus write the average labor productivity for physical labor, $y = Y/L$, $y = A_L f(k^e)$, where k^e is the quality capital-labor ratio, $k^e = ak$, $a = A_K/A_L$. As the function is defined in terms of quality units, the marginal productivities are also defined in terms of quality units, and those can be expressed in terms of quality prices:

$$F_{K^e} = f'(k^e) = r^e/p \tag{5.17}$$

$$F_{L^e} = f(k^e) - k^e f'(k^e) = w^e/p. \tag{5.18}$$

The quality price indicates the unit value of a quality input. But when the augmentation is sector specific, there is no economywide market for quality inputs and thus the quality prices are unobserved. We therefore turn to physical inputs. The marginal productivity of physical inputs are $F_K = F_{K^e} A_K$ and $F_L = F_{L^e} A_L$. The competitive conditions require that $r/p = F_K$ and $w/p = F_L$. Combining this with (5.17) and (5.18), we obtain the relationships among factor prices in physical and quality units:

$$r = A_K r^e; \quad w = A_L w^e, \tag{5.19}$$

and consequently,

$$\omega(k) = (1/a)\omega^e(ak). \tag{5.20}$$

The FATC affects differently the input ratios and their marginal productivities, which are functions of the input ratios. This implies a rotation of the isoquants for any value of k or equivalently, a change of the $\omega(k)$ function. To evaluate this change, we note that the production function is defined in terms of the quality factors, and therefore σ is the elasticity of substitution of that function. Consequently we can write $\sigma\, d \ln \omega^e = d \ln k^e$. But by definition, $d \ln \omega^e = d \ln \omega + d \ln a$ and $d \ln k^e = d \ln k + d \ln a$. Hence, using rates of change notation,

$$\sigma(\hat{\omega} + \hat{a}) = (\hat{k} + \hat{a}) \tag{5.21}$$

$$\frac{\partial \ln \omega}{\partial \ln a}\Big|_k = \frac{1}{\sigma} - 1, \quad \text{and} \quad \frac{\partial \ln k}{\partial \ln a}\Big|_\omega = \sigma - 1 \tag{5.22}$$

This change is illustrated graphically in Figure 5.3, where we derive $\omega(k)$ from $\omega^e(k^e)$. We begin with an arbitrary point k_0 and set $a(0) = 1$ for the initial technology. Thus $\omega(k_0 \mid a = 1) = \omega^e(k^e \mid a = 1)$, as represented by point C. Now introduce technical change, and without a loss in generality, let $a > 1$, so that the value of k_0 in terms of quality units becomes $k_1^e = ak_0$. Then, by (5.20), we have $\omega(k_0 \mid a) = (1/a)\omega^e(k_1^e \mid k_1^e = ak_0)$. We can add to the right-hand side of this equation the term $[1 - (1/a)]0$ and express $\omega[k_0 \mid a(t)]$ as a weighted average of $\omega^e(k_1^e)$ and the origin. Consequently, when $\omega^e(k^e)$ is

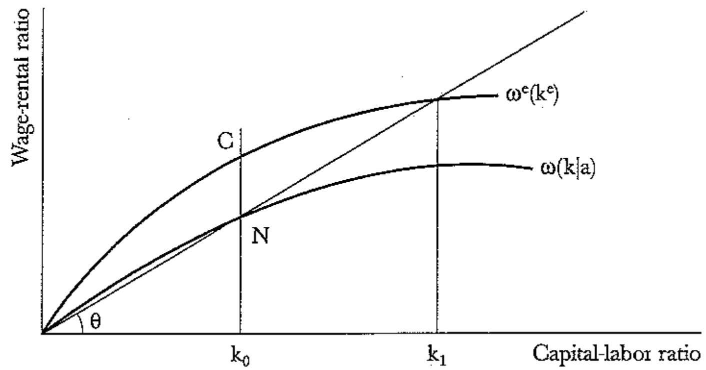

Figure 5.3 Factor-augmenting technical change

concave, $\omega(k_0 \mid a > 1)$ will be below point C, say at point N. We can now repeat the procedure for other initial values instead of k_0 and thereby generate the function $\omega(k \mid a > 1)$. The graph of this function will go through points like N and thus will be below and to the right of $\omega^e(k^e)$ when the function is strictly concave, above and to the left of $\omega^e(k^e)$ when the function is strictly convex, and identical with $\omega^e(k^e)$ when that function is a straight line through the origin. Those three possibilities correspond to σ larger, smaller, or equal to 1, respectively.

Having established the geometry, we can turn to the economic explanation. The question asked here is what price adjustment is needed to absorb an increase in the supply of quality inputs. To answer, assume capital-augmenting technical change, so that $a = A_K$, and the supply of quality capital increases. When σ is large, this increment is absorbed with little change in the marginal rate of substitution of the quality factors, namely ω^e. In the extreme case of $\sigma \to \infty$, ω^e remains unchanged. On the other hand, the rate of return to physical capital increases by a, and therefore $\omega = \omega^e/a$ declines. The situation is reversed when σ is small, in which case ω^e has to increase considerably in order to absorb the change in k. This change in ω^e is larger than the change in A_K, and therefore ω increases. The two effects are equal when $\sigma = 1$. The discussion is concluded with the following proposition.

PROPERTY 5.7 (factor intensity) Factor-augmenting technical change in favor of one factor increases (decreases) the intensity of that factor, under constant wage-rental ratio, if and only if σ is larger (smaller) than 1. When $\sigma = 1$, the intensity is constant.

A change in the function $\omega(k)$ leads to a change in the income distribution as measured by the ratio of the two factor shares, $wL/rK = \omega/k$. At any point we have $\omega/k = \omega^e/k^e$, but a change in a affects ω^e/k^e and therefore also affects ω/k. In terms of Figure 5.3 this ratio is equal to $\tan\theta$. Consequently, the movement from C to N reduces the labor share in output. This change in the factor shares is used as a measure of factor saving.

DEFINITION (factor saving) An exogenous change is said to be *factor saving* if it reduces the share of this factor in value output. The change is *factor using* if it increases the factor share in output.

In this discussion, the changes in the factor shares are evaluated for constant ω, and as such are sometimes referred to as factor saving in the Hicks sense (Binswanger, 1978). Returning to our example, note that the decline in the labor share is obtained by capital-augmenting technical change and elasticity of substitution larger than 1. The logic of it is clear; an increase in quality capital and the "ease" of its absorption results in a substitution of capital for labor to the extent that the share of labor in total output is reduced. It should be emphasized that the classification of a particular factor augmentation as a factor saver depends not only on the factor that is augmented but also on the elasticity of substitution. We can then state the following corollary to Property 5.7.

PROPERTY 5.8 (factor saving) The share of the augmented factor in total output, with the wage-rental ratio held constant, increases, remains constant, or declines if and only if σ is larger, equal, or smaller than 1, respectively.

Allocation and Productivity Effects

In a full employment economy, a change in factor intensity in one sector, with resources held constant, requires a change in resource allocation, otherwise the full employment conditions are violated. An increase in $k_i(\omega)$ in either sector, regardless of capital intensity, can take place only if the shares of the capital-intensive sector in the employment of both resources decline. This follows from the full employment condition as stated in equation (2.13), which is rewritten in the following form:

$$\frac{\ell(\omega, t)}{1 - \ell(\omega, t)} = \frac{k_2(\omega, t) - k}{k - k_1(\omega, t)}$$

Thus $\ell(\omega, t)$, which in this case is interpreted as the share of the labor-intensive sector in total employment, is positively related to either $k_1(\omega, t)$ or $k_2(\omega, t)$. Since we deal here with a FATC in one sector only, $k_i(\omega)$ remains constant in the passive sector. For this ratio to remain constant in the passive sector, the change in the share of the passive sector in the total use of capital, $\rho(\omega, t)$, should follow the same pattern as that of labor, $\ell(\omega, t)$. We thus have

PROPERTY 5.9 (resource allocation) Labor (capital)-saving technical change in either sector increases the relative share in factor employment of the labor (capital)-intensive sector.

Note the similarity of this proposition to the Rybczynski proposition. Labor-saving technical change can be viewed as an increase in the supply of quality labor. The production function is defined in terms of quality labor. Thus, following the Rybczynski proposition, the technical change should increase the share of the labor-intensive sector in both resources. Holding ω constant implies k_i are constant, but since ℓ increases, so must ρ increase. This is the essence of Property 5.9.

The change in factor allocation that takes place at a constant ω causes a change in sectoral output not realized under NTC. We therefore give it a name.

DEFINITION (allocation effect) The change in outputs necessary to maintain a constant wage-rental ratio under FATC is defined as the *allocation effect*.

The analogy of the allocation effect to that of a change in resources provides an insight to Property 5.10

PROPERTY 5.10 (allocation effect) The allocation effect is positive (negative) for the progressive sector when that sector is intensive (extensive) in the factor saved. The sign of the allocation effect of the passive sector is opposite to that of the progressive sector.

The allocation effect may supplement or contradict the productivity effect. The allocation and productivity effects of a capital-augmenting technical change in sector 1 are illustrated in Figure 5.4. Panel I shows the change in $\omega_1(k_1) : \omega_B = \omega_1(k_{1A}, t) \neq \omega_1(k_{1A}, 0) = \omega_2(k_{2A})$. Consequently, the initial allocation represented by (k_{1A}, k_{2A}) becomes inefficient under technology $t > 0$. With the new technology, the capital-labor ratio in the progressive sector evaluated at ω_A is $k_1(\omega_A, t) = k_{1C}$, and consequently, the share of the labor-intensive sector in total labor is $\ell(\omega_A, t) > \ell(\omega_A, 0)$. This is simply an illustration of Property 5.9 for the case where the technical change is labor saving. The implied impact of this change on outputs is given by point C on the transformation curve. This represents the combined productivity and allocation effects. The productivity effect alone is represented by B, which is not on the transformation curve under the new technology. It is dominated by points like B^* corresponding to $\omega_{B*} < \omega_A$.

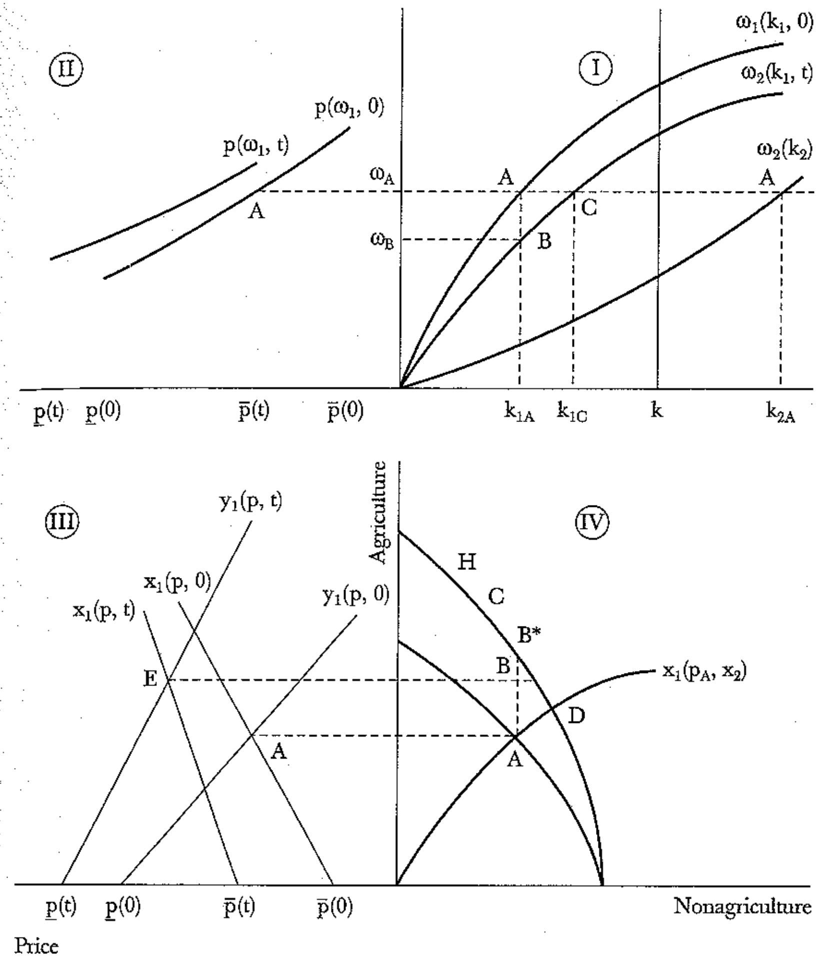

Figure 5.4 Factor-augmenting technical change in agriculture

The Cost Effect

To obtain the total shift of supply, we have to add the cost effect. For this we need the price equation. Since the production function is defined in terms of quality inputs, the dual cost functions are defined in terms of quality prices. Thus we have for the average cost function in sector i: $c_i(w^e, r^e) = c_i(w/A_{iL}, r/A_{iK})$, and consequently

$$p(\omega, t) = c_1(w^e, r^e)/c_2(w^e, r^e). \tag{5.23}$$

The cost function is increasing in factor prices; therefore, if technology in sector 2 is kept constant, any increase in A_{1L} or A_{1K} or both decreases the relative price of the output of sector 1.

PROPERTY 5.11 The supply price of the progressive sector declines.

Thus the change in price depends on the origin and the degree of augmentation and not on the direction of factor saving. Returning to the case under consideration, $p(\omega, t) < p(\omega, 0)$, and therefore, the change in output necessary to restore the original price calls for a shift of resources to the progressive sector. Thus the cost effect supplements the productivity effect. In terms of Figure 5.4, the cost effect is represented by the move from C to H.

Equilibrium

The qualitative difference in the dislocation of supply between FATC and NTC is in the allocation effect. Consequently when the allocation effect supplements the cost and productivity effects, the nature of the displacement caused by the FATC will be similar to that analyzed for NTC in one sector. In Figure 5.4, the supply at the initial price moves from A to H. The new equilibrium point of a closed economy will be located between the following two points: (1) The intersection of the demand curve, corresponding to the initial price, with the new transformation curve. That point gives the quantity demanded at the original price, and thereby it represents the income effect alone. It is represented by a movement from A to D in Figure 5.4. (2) The new product mix at the original price, H, also the equilibrium production of a small open economy.

When the allocation effect is contradicting the productivity and cost effects, it pulls the supply downward, and there is no a priori reason why the supply cannot decline so that H would be to the right of point B^*.

With the equilibrium price of the progressive sector declining, its output increases. The question is what happens to the output of the passive sector. Does it increase as well? The answer depends on the relative strength of the price and income effects generated by technical change and on the price and income elasticities.

The dependence of the solution on demand elasticities is intuitively clear. If the income and price elasticities for the product of the progressive sector were very high, then the increase in income and the decline in its price caused by technical change might cause a big shift of demand in the direction of the progressive sector and cause a decline in the output of the passive sector. It is indeed the case for perfectly elastic demand, as for the small open economy, that the output of the passive sector will shrink. In that case, H will represent the equilibrium output. The consumption will be determined by the intersection of demand functions with the income line corresponding to output H.

Factor-augmenting Technical Change in Two Sectors

The foregoing analysis was conducted for the special case where the FATC occurred in one sector. With two sectors and two factors, there are various possible scenarios. Those, however, can be reduced to the situations analyzed above plus an additional one to be outlined here, FATC in two sectors.

Our foregoing discussion dealt with four factor-augmenting functions: $\hat{A}_{1L}$, $\hat{A}_{1K}$, $\hat{A}_{2L}$, and $\hat{A}_{2K}$. For each sector this is reduced to $\hat{A}_i$, $\hat{a}_i$, where $\hat{A}_i = \min(\hat{A}_{iL}, \hat{A}_{iK})$, and $\hat{a}_i = \max(\hat{A}_{iL} - \hat{A}_i, \hat{A}_{iK} - \hat{A}_i)$. The case of $\hat{a}_i = 0$ for $i = 1, 2$ was dealt with under the NTC. The case of $\hat{a}_i \neq 0$ for one sector was dealt with above. To complete the discussion we thus have to consider the case of $\hat{a}_1 \hat{a}_2 \neq 0$.

Productivity Effects

By definition, the productivity effects in both sectors are positive. The strength of the effects depends on the values of a_i and on the factor shares of the augmented factors.

Allocation Effect

If the technical change in both sectors is saving the same factor, then the allocation effect is uniquely determined–it increases the output of the sector that is intensive in the saved factor. This situation, covered by Property 5.9, is of particular interest. As we will see in Chapter 6, there is a reason to expect technical change to be on the whole labor saving. Thus this process has the partial effect of transferring resources to the labor-intensive sector. The relative strength of this effect depends on the difference in factor intensity, on the rates of factor augmentation, and on the values of σ_i. Specifically, recall that if $\sigma_i = 1$ for $i = 1, 2$, there are no allocation effects.

Cost Effect

While the allocation effect depends on the factors that are saved, the cost effect depends on the factors that are *augmented* and on their shares in total output (factor shares). To concentrate on the case under consideration, assume $\hat{A}_{1K} > 0$, $\hat{A}_{2K} > 0$, $\hat{A}_{1L} = \hat{A}_{2L} = 0$. In the special case where the rate of factor augmentation is the same ($\hat{A}_{1K} = \hat{A}_{2K}$), we obtain

$$\hat{p}(\omega, t)\,|_{\omega} = (S_{1L} - S_{2L})\hat{A}_{iK}$$

That is, capital-augmenting technical change of equal rates in both sectors reduces cost more in the capital-cost-intensive sector and thereby increases the price of the labor-cost-intensive product corresponding to any given wage-rental ratio.

Income Distribution

In general factor-augmenting technical change leads to changes in the factor distribution of income, as measured by the ratio of factor shares. Rearranging (5.21) we obtain

$$d\ln(\omega/k) = \left(\frac{1}{\sigma} - 1\right) d\ln(ka) \qquad (5.24)$$

There are three conditions under which the factor shares are unaffected by technical change:

1. $\hat{a} = 0$. This is Hicks-neutral technical change, where ω/k is constant when k is constant.
2. $\sigma = 1$. This is equivalent to a Cobb-Douglas production function where the factor shares are constant everywhere.
3. $\hat{k} = -\hat{a}$. This implies that the quality-capital-labor ratio is constant and so is $f(ak)$. As a matter of definition,

$$Y/L^e = f(k^e). \qquad (5.25)$$

When k^e is held constant, the factor prices in quality units are constant as well. Two cases have been widely discussed in the literature. First, Harrod-neutral technical change,[2] where the technology is labor augmenting; it is characterized by $A_K = 1$ and $a = A_L^{-1}$. Rewrite (5.25) and divide through by $k^e = K/A_L L$ to obtain

$$\frac{Y}{K} = \frac{f(ak)}{ak}, \quad \text{which is constant.} \qquad (5.26)$$

Thus, with labor-augmenting technical change, the factor shares remain constant along expansion paths that maintain constant Y/K. In this case $r^e = r$, and because the quality prices are constant, r is constant as well.[3] While Y/K is constant, the average labor productivity, $Y/L = A_L f(ak)$ is an increasing function of A_L, and the wage rate is increasing accordingly: $w = w^e A_L$.

By a similar argument, we can examine the consequences of capital-augmenting technical change where $A_L = 1$ and $A_K > 1$. From the definition, $y = f(ak)$, and hence the factor shares are constant along expansion paths that maintain Y/L constant. This is Solow neutrality. Here the wage rate is constant along Y/L, whereas the rate of return is increasing with A_K.

These concepts of neutrality generate corresponding classifications of factor saving. For instance, technical change is labor saving in the Harrod sense if the labor share declines along a given output-capital ratio.

The Real Rate of Exchange: Long-Run Aspects

Discussions of the real exchange rate deal generally with short-term variations in external terms of trade and macro policies. However, the real exchange rate is also affected by long-run changes in supply and demand. Long-run changes on the supply side emerge from capital accumulation and technical change. If the nontradable product is labor intensive, its price increases along the equilibrium path generated by capital deepening, and therefore the real rate of exchange declines. This is true as long as the two products are normal. The degree of this effect depends on the difference in factor intensities and in income elasticities.

Less can be said on the supply effect that comes from technical change without knowing the nature of the change. It has been argued (Balassa, 1964; Samuelson, 1964) that technical change is faster in the production of commodities, which are largely tradable, than in nontradables. In this case, there is a downward trend in the real exchange rate. This is a very plausible argument; nevertheless, its underlying premise calls for a quantitative perspective. This qualifier is always true, but it is particularly important in this case. Much of the nontradable product is produced in the public sector, so the output is measured by the cost of production. Technical change is measured by comparing the changes in output with the changes in the cost of inputs; therefore when the measure of output is the same as that of the input, no technical change can be detected. This is also true for some services produced in the private sector whose output is measured by cost, for instance, medicine. The increase in life expectancy, as well as in the (physical) quality of life, is not captured in the measurement of output, and therefore we obtain a distorted view of the changes in productivity in the nontradable sector.

If we turn to the demand side, we note that capital deepening and technical change generate an increase in income that in turn generates an increase in demand. At the private level, beyond a certain income, the demand for services increases faster than the demand for commodities. Since commodities are largely tradable and services are largely nontradable, an increase in income results in an increase in the relative price of nontradables, or a decline in the real exchange rate. The public sector demand for nontradables may also have a strong positive income response; social and welfare programs are developed as the economy becomes more affluent. The net effect of such programs depends on two factors: first, the extent that they constitute a net addition to spending over and above what the private sector would have spent on these programs, and second, the form of finance. For instance, if the programs are financed by a progressive income tax that generates a more equal income distribution, and if the income elasticity of nontradables is larger than 1, then the net effect may be a decline in the demand for nontradables and therefore an increase in the real exchange rate. On the other hand, if the programs reduce the price of nontradables, such as health and education, then their demand will increase, and the real exchange rate will decline

To conclude, this discussion indicates that as an economy develops, the real exchange rate is likely to decline. This is structural change that should not be attributed to short-run policy or other shocks. The quantitative effect of the various considerations discussed here is a subject for empirical analysis.

Empirical Implications

The discussion in this chapter is empirically oriented in that it derives the comparative static implications for growth paths of various forms of technical change. Clearly, the range of possible outcomes is wide. Still, some empirical generalizations applicable to agricultural growth can be made. Such generalizations are derived from the low income and price elasticities for agriculture, and as such they are fairly robust to the possible variations in the orders of magnitudes of the various forms of technical change.

We now turn to review trends in agricultural prices and in sectoral outputs. Such trends are determined, of course, by various other variables in addition to demand and technical change. Furthermore, they are generated under market conditions that violate our assumptions and which are introduced into the analysis as we go along Nevertheless, with all these qualifications, it is instructive to refer to the data at this stage and to highlight some of the important processes.

Agricultural Prices

Changes in productivity lead to changes in excess demand and thereby affect agricultural prices. For countries that trade in agricultural products, such changes in excess demand are transmitted to the world market, where world supply and demand determine world prices. The world is then viewed as a closed economy Countries that do not trade in agriculture are, by definition, also analyzed within a closed economy framework. Consequently, we can begin the discussion by referring to equation (5.16), which summarizes the effects of neutral technical change. Obviously, technical change of equal rates generates an excess supply for agriculture Similarly, the excess supply increases when the technical change in agriculture exceeds that in nonagriculture. Can the excess supply decline? Yes, but for this to occur the technical change in nonagriculture must exceed *considerably* that in agriculture, and the income elasticity of agriculture must be larger than its price elasticity. As we saw even in the crude evidence presented in Chapter 1, however, technical change in agriculture, if anything, exceeded that of nonagriculture, and this accounts for the excess supply Thus for the excess demand in agriculture to rise, technology in agriculture must stagnate. There is no empirical evidence that leads us to expect such an event in the foreseeable future

An increase in excess supply leads to a decline in prices. Hence an efficient way to examine the importance of technical change is to examine the trends in world agricultural prices. The country story is presented in Figure 1.2. A view of the global situation is obtained from Table 5.1, which presents estimates of the average annual percentage change in prices of some primary agricultural commodities. The prices are deflated by the index of U.S. wholesale prices These estimates were obtained from semilogarithmic trend regressions Two facts immediately emerge First, there has been a deterioration at an average annual rate of 0.5–0.7 percent in most of the relative prices of agriculture. This implies a deterioration by a factor of one-half over the period 1900–1983. Second, the degree of fit of the trend regressions, as measured by R^2, is relatively low. This reflects wide annual variations in supply and demand conditions over this period, which includes two world wars, energy crises, and other shocks As such, the trend is a poor predictor for *short-term* price variations. Yet, considering the length of the period, these numbers are suggestive with regard to the long-term trend.

Over this period world population increased by a factor of 3, from 1.6 billion in 1900 to nearly 5 billion in 1984. Add to this the increase in per capita income, and we obtain an increase in food demand by a factor of 4 or more. The decline in world prices indicates that production increased more than demand. Since the supply function is positively sloped, it is clear, as is well known, that there were large changes in supply that made it profitable to expand production in spite of the decline in the relative price If we take such a long-term view, changes in supply make it possible to identify the demand function empirically. That is, the deterioration in prices implies that the growth in supply could only be absorbed at some price decline. In turn, the decline in

Table 5.1 Time-trend of agricultural prices deflated by U.S. wholesale prices, 1900–1983

Commodity	Coefficient	*t*-ratio	R^2
Sugar	−0.7	(3.7)	0.14
Wheat	−0.7	(7.2)	0.39
Maize	−0.6	(7.1)	0.31
Rice	−0.6	(5.5)	0.27
Cotton	−0.5	(5.4)	0.26
Wool	−0.1	(8.9)	0.49

Source: Binswanger et al. (1985).

Note: The coefficients are obtained from the semilogarithmic regression: $\ln p_t = a + bt$. The slope, b, indicating the rate of growth, is multiplied by 100 to be expressed in percent. The numbers in parentheses are the ratios of the coefficients to their standard errors (t-ratios).

price had a depressing effect on the growth of output. This implies that demand has acted as one of the determinants of agricultural growth. Thus the results are in line with the predictions that can be drawn from equation (5.16).

How should equation (5.16) be modified if the technical change has a factor-augmenting component? As indicated, technical change on the whole tends to be labor saving, and as such it tends to increase the output of the labor-intensive sector. This then supplements the effect derived under neutral technical change. On the other hand, under the present framework where the technology is exogenous, capital accumulation tends to increase the price of the labor-intensive product. To the extent that such an effect prevailed, it was not sufficient to offset the effect of technical change.

On Sectoral Growth

Technical change and capital accumulation increase real income, and therefore, with prices held constant, consumption of the two products should increase. At the global level, consumption of each of the two products is nearly equal to output. The difference between consumption and production reflects a change in inventories that is a small fraction of production in any given year and more so when longer periods are considered. Thus, under constant prices, the relative change in production reflects income elasticities. Because agriculture is income inelastic, its growth is constrained by income elasticity. It is also constrained by the low price elasticity that contains the substitution effect on demand expansion in response to the price decline.

The foregoing discussion has dealt with a closed economy. In an open economy, output need not equal consumption, and therefore the growth pattern of output need not follow that of demand. Therefore, the patterns of sectoral growth in individual countries are expected to differ in accordance with their trade patterns. This is well illustrated in Figure 1.4, which shows the spread in the ratio of growth rates of agriculture to that of total output. In only 19 percent of the countries did the rate of growth of agriculture exceed that of total output, but these countries accounted for only 4 percent of world agricultural production.

At this point it is useful to go back and review the mechanism that determines sectoral growth. Consider the typical case where technical change creates an excess supply of agriculture. This presses agricultural prices down, and value output declines. Value output is distributed to labor and capital, and therefore there is now less to be distributed. Consequently labor and capital find their way to nonagriculture, where the remuneration is higher. This shift of resources contributes to output in nonagriculture.

To summarize, the determinants of the process of agricultural growth are low income elasticity for agriculture and the desire of individuals to increase, whenever possible, the returns for their services. The process moves on with less friction when competitive markets exist. However, as we shall see in subsequent discussion, the process takes place under less favorable conditions as well. All that is required is that individuals be able to improve their position by reallocating the resources at their command.

Technical Change and Land Expansion

We now continue the discussion in Chapter 4 of land expansion by considering three natural forms of technical change. We begin with the case where agriculture is a price taker and thereby obtain the supply response under constant prices. The nature of the results changes when a capital constraint is introduced. The investigation concentrates on agriculture and therefore avoids sectoral notations.

Neutral Technical Change

The production function is $\tau F[qA(q), K(q)] = \tau qA(q) f[k(q)/q]$. The role of the technology index τ is the same as the price p in the constant technology model of Chapter 4, and the results of this model are immediately applicable. Specifically, neutral technical change causes the two margins to expand.

Land-augmenting Technical Change

The production function is

$$F(\tau q A(q), K(tq)) = \tau q A(q) f(k(\tau q)/\tau q) \tag{5.27}$$

The optimization problem is

$$\max_{k(\tau q), z} L(k(\tau q), z)) = \int_z^\infty [\tau q f(k(\tau q)/\tau q) - rk(\tau q) - c] A(q) dq \tag{5.28}$$

The first-order conditions are

$$L_1 = f'[k(\tau q)/\tau q] - r = 0, \tag{5.29}$$

$$L_2 = \tau z f[k(\tau z)/\tau z] - rk(\tau z) - c = 0. \tag{5.30}$$

Differentiating equation (5.29) and rearranging to obtain

$$\frac{\partial k(\tau q)}{\partial \tau}\Big|_r = \frac{k(\tau q)}{\tau} > 0 \tag{5.31}$$

Differentiating equation (5.30) and rearranging to obtain

$$\frac{\partial z}{\partial \tau}\Big|_r = -\frac{z}{\tau} < 0, \tag{5.32}$$

or $E(z, \tau) = -1$. To interpret this result, differentiate the rent,

$$\frac{\partial R(\tau q)}{\partial \tau} = \frac{R(\tau q) + c}{\tau} > 0.$$

Hence, as τ increases, the rent increases for all q; therefore the margin is moved, and z declines.

PROPERTY 5.12 When agriculture is a price taker, land-augmenting technical change causes the expansion of land, the capital-land ratio, and total output.

Capital-augmenting Technical Change

The production function is

$$F(qA(q), \tau K(q)) = qA(q) f[\tau k(q)/q] \tag{5.33}$$

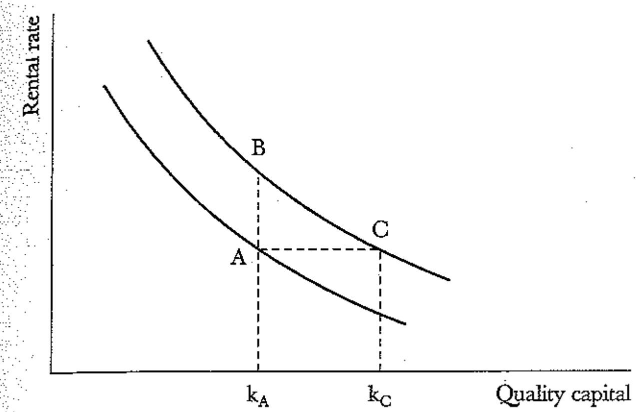

Figure 5.5 Demand for quality capital

The optimization problem is

$$\max_{k(q), z} L[k(q), z] = \int_z^\infty [qf(\tau k(q)/q) - rk(q) - c] A(q) dq \tag{5.34}$$

The first-order conditions are

$$L_1 = \tau f'[\tau k(q)/q] - r = 0, \tag{5.35}$$

$$L_2 = zf[\tau k(z)/z] - rk(z) - c = 0. \tag{5.36}$$

Differentiating $L_2(\cdot)$ to obtain

$$E(z, \tau) = -\frac{S(k; z)}{S(c; z)} < 0. \tag{5.37}$$

Next, differentiating L_1 and rearranging to obtain[4]

$$\frac{d \ln k(q)}{d \ln \tau} = \sigma - 1 \tag{5.38}$$

We can interpret this result with the aid of Figure 5.5. An examination of equation (5.38) shows that the technical change has two effects. First, it shifts the marginal productivity of capital so that the initial point A, with quality-capital k_A, shifts to B. This shift disturbs the first-order condition, and to restore it, the quality-capital increases to k_C that corresponds to point C. The proportional change in the marginal productivity between A and B is $\hat{\tau}$, and the movement from C to B is along the curve whose elasticity in absolute value is σ so that the relative change of quality-capital between A and C is $\sigma\hat{\tau}$. The larger the numerical value of this elasticity, the larger the relative difference between k_C and k_A. Second, to translate the rate of change in quality-capital to that of physical capital, we subtract $\hat{\tau}$. The new level of physical capital is the net outcome of these two effects as equation (5.38) indicates. When the demand for capital is inelastic, the retraction dominates, and the capital intensity declines. In this case, land augmentation and land saving move in opposite directions. But this is not an interesting case empirically because it calls for the expansion of land and a decline in the capital-land ratio.

The discussion is summarized by

PROPERTY 5.13 When agriculture is a price taker, capital-augmenting technical change reduces the marginal quality land and thereby increases the cultivated area. The corresponding change in capital intensity depends on the elasticity of capital demand; it increases (decreases) when the demand is elastic (inelastic).

Of the three cases of technical change analyzed here, this is the only case in which land expansion and augmentation can take different directions, but as indicated, it is not an interesting case from an empirical point of view. A different result is obtained when the supply of capital is not perfectly elastic. To deal with this case, we take up the extreme version of perfectly inelastic supply of capital, examined in Chapter 4, together with land-augmenting technical change.

Land-augmenting Technical Change and Capital Constraint

The production function is given by (5.27), and the optimization problem is

$$\max_{k(q),z,r} L(k(q),z,r) = \int_z^\infty [\tau q f(k(\tau q)/\tau q) - c]A(q)dq - r[\int_z^\infty A(q)k(\tau q)dq - K] \tag{5.39}$$

The first-order conditions are

$$L_1 = f'[k(\tau q)/\tau q] - r = 0, \tag{5.40}$$

$$L_2 = \tau z f[k(\tau z)/\tau z] - r k(\tau z) - c = 0, \tag{5.41}$$

$$L_3(\,) = \int_z^\infty A(q)k(\tau q)dq - K = 0. \tag{5.42}$$

Differentiating L_1, we obtain[5]

$$1 - \sigma\frac{d\ln r}{d\ln\tau} = \frac{d\ln k(\cdot)}{d\ln\tau}. \tag{5.43}$$

When agriculture is a price taker, r does not change and equation (5.43) reduces to equation (5.31), which states that the relative increase in k is equal to the rate of the technical change. When the supply of capital is not perfectly elastic, the increase in r will reduce the relative increase in k by σ.

Differentiating L_2, simplifying and imposing $dc = 0$,

$$(\tau/c)k(\tau z)dr - \tau dz/z = d\tau. \tag{5.44}$$

To differentiate L_3 we modify (4.23),

$$\tau\Phi(r)Q = K. \tag{5.45}$$

Then,[6]

$$\tau z A(z)/Q\; dz + \tau\sigma/r\; dr = d\tau. \tag{5.46}$$

To solve for $dr/d\tau$ and $dz/d\tau$, write equations (5.44) and (5.46) in matrix notations:

$$\begin{bmatrix} -1 & rk(\,)c \\ z^2A(z)/Q & \sigma \end{bmatrix}\begin{bmatrix} d\ln z \\ d\ln r \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \end{bmatrix} d\ln\tau \tag{5.47}$$

Except for the element in the (1,1) position, all the elements are positive; hence the determinant (det) is negative. The solution is

$$d\ln z/d\ln\tau = (1/\det)[\sigma - rk(\,)/c] \quad \text{The sign is ambiguous} \tag{5.48}$$

$$d\ln r/d\ln\tau = (1/\det)[-1 - z^2A(z)/Q] > 0. \tag{5.49}$$

The technical change shifts to the right the demand for capital; therefore its shadow price rises, and the rent declines. On the other hand, the rent increases as a result of the technical change. The net effect of the technical change depends on the magnitude of these two effects. When the elasticity is large, the increase in r reduces k, and capital is freed to allow the expansion of cultivated land; consequently z declines. On the other hand, when the elasticity is small, the increase in r causes an increase in z, the area declines, and the capital freed by the reduction in the cultivated area is used to satisfy the increase in the demand for capital triggered by the technical change.

Empirical Analysis

To apply the foregoing analysis to the data, we have to differentiate between short-term fluctuations in land use and changes of a more permanent nature

Because the necessary data for such an analysis are lacking, this is not an easy task. Alternatively, we can look at a situation where permanent expansion was dominating, such as Thailand. It was examined in Mundlak (1993), and some of the results of that analysis are summarized here.

Thailand's agricultural growth has been impressive. During the period 1961–1990, world agricultural production grew at an average annual rate of 2.3 percent, whereas that of Thailand grew at a 4 percent rate. If we reduce the output to three major components, crops, fruits (tree crops), and livestock, we find that Thailand excelled in all three. The growth in fruit production was faster than that of crops, and this indicates an intensification in the use of capital. Still, crops form the major subsector of agriculture, accounting for about three-quarters of total agricultural value added. Thailand's performance is even more impressive when viewed on a per capita basis: its output increased at an average annual rate of 1.6 percent compared with 0.6 percent for the world as a whole. Thailand could achieve such a performance by maintaining strong exports, which in the last four decades, on average, made up from 13 to 17 percent of agricultural output; at the same time, its imports fluctuated from 1.9 to 5.4 percent. Cultivated land increased from 8.3 million hectares in 1950 to 23.6 million in 1990. This new land was obtained by clearing forests. The annual average growth rate of land amounted to 2.84 percent, implying that the output-land ratio increased at an annual average rate of about 1.2 percent. Agricultural labor increased over the period from 1954 to 1990 from 9.0 million to 20.1 million, an average annual growth rate of 2.1 percent. Data for other inputs are available only for the period beginning in 1961, and therefore subsequent analysis covers only the years 1961–1990. During this period the average annual growth rates of inputs per hectare, in percent, are: agricultural labor, –0.42; fertilizers, 9.5; irrigation, 2.2; tractors, 14.8. These developments cannot be explained by attributing them to more favorable prices, because the price ratio of agriculture to that of nonagriculture trended downward over the period, particularly from the mid-1970s. It is clear that the drastic expansion in cultivated land was accompanied by a considerable intensification in the use of capital as measured by the increase in the application per hectare of fertilizers, tractors, and irrigation. The labor use per hectare declined but at a relatively slow rate.

The land expansion that took place in Thailand was largely an initiative of the private sector (Siamwalla, Setboonsarng, and Patamasiriwat, 1993). As for the future, analysts note: "Thai agriculture is now at a crossroads. The two factors that fueled its past growth–surplus land and buoyant foreign market–cannot sustain it in the future ... These developments ... present a

set of delicate problems for the government. First, the factor intensity of Thai agriculture will change .... At the same time, domestic demand will dictate that the more capital-intensive and technology-intensive horticultural sector must expand" (ibid., p. 116).

From these comments it is clear that past behavior was the outcome of farmers' decisions; the question what will happen in the future–and the role of government in it–is focused on issues related to the extensive-intensive margins. With this background, we turn to the analysis.

Our discussion suggests that land expansion can be explained by capital accumulation, the cost of reclamation, the terms of trade of agriculture, and technology. Land expansion is also expected to be positively correlated with land augmentation, measured by the increase of other inputs. Table 5.2 presents correlation coefficients between land and other variables. The correlation between land and the other agricultural inputs is obviously very high, and this is also the case on a per hectare basis. The third panel of the table shows the high positive correlation between land, length of roads, and the investment in road maintenance and the low negative values between land and cost of road construction. This cost is taken as a partial indicator of the cost of clearing land for agricultural production.

The relationships between the size of agricultural land and these variables are summarized by regressions presented in Table 5.3. The investment variable is for the economy as whole, and it represents a measure of resource availability. The table presents four empirical equations. The first and the third were obtained by ordinary least squares (OLS); the second and the fourth were obtained by instrumental variables. The last two equations were corrected for serial correlations. These regressions clearly indicate the strong positive relationships between land and capital accumulation, the terms of trade of agriculture, and roads and the negative or zero relationships with the cost of construction.

Can this model account for the main developments of Thai agriculture? The joint expansion of land and capital-land ratio required considerable resources. The question is, what induced this big expansion? The terms of trade of agriculture were deteriorating over time, and this should have discouraged expansion. The answer is capital accumulation, improvement in the infrastructure, and technical change in agriculture. However, the major technological event in this area was the green revolution, the introduction of modern cereal varieties. This began in Thailand only in the late 1960s, whereas land had been expanding rapidly even before then. The empirical analysis suggests that capital availability and the decline in the cost of reclamation were important factors in this expansion.

Table 5.2 Thailand: Correlation coefficients, 1961–1990

Total inputs

	Agricultural land	Irrigation	Fertilizer	Tractor	Investment
Agricultural land	1	0.95	0.92	0.89	0.89
Irrigation		1	0.95	0.98	0.9
Fertilizer			1	0.95	0.97
Tractor				1	0.89
Investment					1

Inputs per hectare

	Irrigation	Fertilizer	Tractor	Investment
Irrigation	1	0.88	0.96	0.79
Fertilizer		1	0.93	0.95
Tractor			1	0.86
Investment				1

Variables related to land regression

	Agric. land	State highways: length	Provincial roads: length	State highways: construction costs	State highways: maintenance costs	Provincial roads: total cost*
Agric. land	1	0.98	0.94	−0.084	0.83	−0.147
State highways: length		1	0.96			
Provincial roads: length			1			
State highways: construction costs				1	−0.042	0.56
State highways: maintenance costs					1	−0.22

Source: Mundlak (1993).
*Series is from 1975 to 1990 only.

Table 5.3 Thailand: Agricultural land expansion, regression analysis, 1961–1990

Regression	Constant	Capital	Price of agriculture	Cost of highways	Length of roads	$AR(1)$	R^2	D.W.	Obs.
1	5.198	0.107	0.275	−0.004	0.277		0.990	0.874	30
	(10.15)	(8.45)	(4.59)	(0.34)	(9.30)				
2	7.004	0.171	0.163	−0.038	0.159		0.991	1.115	29
	(7.18)	(5.57)	(2.12)	(1.74)	(2.74)				
3	6.531	0.189	0.213	−0.009	0.133	0.484	0.993	1.800	29
	(8.68)	(3.98)	(3.25)	(0.66)	(1.63)	(3.28)			
4	6.751	0.197	0.197	−0.011	0.118	0.497	0.992	1.770	28
	(7.22)	(3.65)	(2.62)	(0.46)	(1.26)	(3.19)			

Source: Mundlak (1993).
Note: Regressions 1 and 3 were estimated using ordinary least squares. Regressions 2 and 4 were estimated using two-stage least squares, using as instruments, price of agriculture, capital, PEAK, relative price of rice to fertilizer, and as inputs, agricultural labor lagged one year, tractors, fertilizer, and irrigation. $AR(1)$–auto regression of the first degree; D.W.–Durbin Watson statistics.

Exercises

5 1 In Chapter 4 we signed the changes in demand for sectoral inputs in response to resource change, taking into account the various effects. Do the same for technical change, where the change to be evaluated is between two equilibrium points ("original" and "new"). Do it systematically for the following cases:

(a) NTC of equal rates in both sectors.
(b) NTC in agriculture alone.
(c) Capital-augmenting TC in agriculture.
(d) Labor-augmenting technical change in agriculture.
(e) The introduction of a modern cereal variety in agriculture that is more productive and more capital intensive than the traditional variety

Solve first for the small open economy and second for the closed economy.

Which of these cases (or what combinations of them) will yield results which are consistent with the data on agricultural capital summarized in Chapter 10? Do we do better if we combine these results with those on capital accumulation presented in Chapter 4?

Make the following assumptions:

Factor prices are equal across sectors
Agriculture is the labor-intensive sector.
Demand elasticities of $x_1(p, x_2)$ and income elasticities, using class notations, are restricted by $\sigma_D < 1, \eta < 1$.
The elasticities of substitution in both sectors are smaller than 1

6

Heterogeneous Technology

So far we have assumed that the technology in each sector consists of a single technique. When there is an improvement in technology, producers are expected to replace the old technique with the new one Within this framework, there is no reason to use the old technique, and only the new, more productive technique should be employed. This conclusion, however, is inconsistent with the data, which show that the process of transition from old to new techniques takes time, often a long time, during which different techniques coexist This observation is important for understanding the process of the implementation of new techniques, which is the main vehicle for economic growth. This chapter examines two issues related to this process. First, we consider the reasons for the coexistence of techniques with an emphasis on the relationships between resource constraints, specifically capital accumulation, and the implementation of new techniques Second, we analyze the effect of the appearance of a new technique on the equilibrium position of the economy This discussion is continued in subsequent chapters, particularly in Chapter 13, where we also take up the implications of this framework for the empirical analysis of productivity and growth.

This discussion draws on the experience of the introduction of modern cereal varieties, known as the green revolution, which began in the mid-1960s An empirical study of food grain growth in India based on district data provides empirical evidence for some of the propositions developed here (Bhalla and Khan, 1979). In comparing production changes from the period 1962–1965 (pre–green revolution) to 1970–1973, a period when the new technology in Indian agriculture was well established, the study concludes that the introduction of modern varieties:

1. represents technical change in that yields are increased and the productivity of all inputs is increased, including that of labor, whose factor share declines,
2. has required capital inputs,