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,

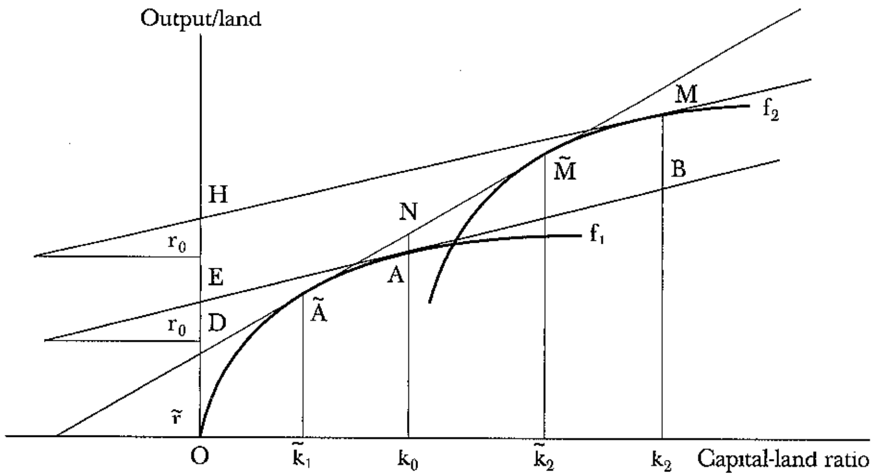


Figure 6.1 Resource constraint and the choice of technique

3. is capital intensive in the sense that it increases the share of capital inputs in total output, and
4. most important, has taken a long time to implement and after twenty years is far from being completed. The transition period is characterized by the coexistence of traditional and modern techniques.

Points 1–3 are consistent with the institution of labor-saving technical change generated by factor augmentation that, with given prices, results in higher capital-labor ratios. This is demonstrated in Figure 6.1, where f_1 and f_2 describe the production functions of the traditional and modern varieties respectively. Let k in this example be the ratio of capital to land, ignoring labor for the time being, and f_j be the output per unit of land of technique j. When the technology consists of the traditional variety alone, producers produce at point A, with capital-land ratio k_0 and a rate of return, or marginal productivity of capital, $r_0 = f_1'(k_0)$. The appearance of a modern technique, f_2, opens up new possibilities. With a perfectly elastic supply of capital at rental rate of capital r_0, producers move to point M, where $f_2'(k_2) = r_0$, and the return to land is higher than at A. In this case there is no scope for coexistence of the traditional and modern varieties, and the traditional variety should disappear.

The coexistence of techniques indicates that either the supply of capital is not perfectly elastic at the going rate or else that there are other reasons not taken into account in the analysis. Often the reason given for the coexistence is

that producers have imperfect knowledge about the new technique. Although this explanation appears reasonable, it cannot by itself account for the length of time that it has required to introduce the modern varieties (MV) nor can it explain the geographical variability in the pattern of their use. The green revolution is considered here as an example, indeed a very important one. Another example is the mechanization of agriculture, which has also taken a long time to be implemented.

The explanation given here for the delayed response is the scarcity of capital needed for full implementation of the modern technique. We illustrate it in terms of Figure 6.1 where, by assumption, the initial capital-land ratio is k_0. With k_0 given, the traditional variety dominates the modern one because it produces a higher yield. Under the new technology, however, it is possible to obtain higher output by allocating the scarce resource to the two varieties. For such an allocation to be optimal, it should produce equal marginal productivity of capital for the two varieties; otherwise some producers could gain by reallocating the capital among the varieties. The optimal allocation is shown by the line tangent to the two production functions at the points $\tilde{A}$ and $\tilde{M}$ with a slope $\tilde{r} = f_j'(\tilde{k}_j)$, where $j = 1, 2$. The average yield with capital-land ratio k_0 is now given by point N, which dominates the yield at A.

To increase the share of land allocated to the MV it is necessary to increase the available capital-land ratio. The increase in capital is prompted by the appearance of the MV, which causes the rate of return to capital to increase from r_0 to $\tilde{r}$, thereby attracting capital. But this process takes time. It is in this sense that the pace of the transition is related to the scarcity of capital, which cannot be mobilized within a short period. All this is discussed in greater detail below.

The foregoing analysis is somewhat simplified in order to enable graphical illustration. Nevertheless it brings forward the important points for our subsequent discussion. We begin the discussion by reviewing empirical evidence that will help us to place the discussion within an appropriate perspective. This is then followed by constructing the choice of technique framework, which considers the choice to be endogenous within the economic system. The discussion generates a direct link between capital accumulation and technical change.

Underlying the choice of the implemented technology is the available technology, which changes with the appearance of new techniques. The new techniques are not entered into the economy exogenously. Some agents invest resources in the production of new techniques. Thus economic considerations must also have an effect on the flow of new techniques. Hence both the supply and the demand of new techniques are endogenous, and in this sense the technology is endogenous.

The Transformation of Punjab Agriculture

The application of this framework to Indian Punjab agriculture was studied by McGuirk and Mundlak (1991), and their results are pertinent for our discussion. The study seeks to determine the level and pace of the implementation of the modern wheat and rice varieties, as well as new varieties of cotton and maize, introduced in Punjab during 1960–1979. The implementation of these new varieties resulted in a dramatic growth in crop production. The techniques that are included in the analysis, described in Table 6.1, constitute the most important crops, accounting for about 67 to 80 percent of the sown area in the period under consideration. The analysis considers three levels of decisions–area allocation, yield determination, and finally, investment-type decisions (to be explained below)–and is based on district-level data.

We turn immediately to the results, providing only necessary details here and postponing the explicit formulation to subsequent discussion, particularly in Chapter 13. At each stage of the analysis the state variables, those variables that affect the decisions, are grouped into three categories: incentives, constraints, and environment. Our immediate interest is in the role of the constraints in the pacing of implementation of the new varieties. The degree of implementation is measured in terms of the area allocated to the MV. Table 6.2 reports results for the empirical equations that explain the *shares* of wheat and rice varieties, the most important crops, in total area. The constraints consist of

Table 6.1 Punjab: Cropping alternatives

	Rabi	Kharif
Irrigated	Modern variety wheat Traditional wheat	Modern variety rice Traditional rice
	Gram Other	Irrigated maize* Cotton (American and Desi) Other
Dry	Wheat Gram Other	Rice Maize Cotton Other

Source: McGuirk and Mundlak (1991).
Note: Rabi and Kharif are two different seasons. Gram is a well-known legume in Asia.
*The irrigated maize category includes both improved and traditional varieties.

areas irrigated from private sources, mainly tube wells, and from government sources, mainly canals, the quantity of fertilizers *expected* to be available for the planting season, and roads. The results show that an increase in irrigation (mainly private), fertilizers, and roads was associated with an increase in the share of the MV of wheat in the total area and at the same time in a decrease in the area of traditional irrigated wheat.

For rice, fertilizers and roads were associated with an increase in the share of the MV in total acreage, but irrigation was associated with a decline in their share. This is consistent with the view that the irrigation favored wheat, and that therefore the *share* of rice declined. Note, however, that the table reports shares and not total area. Total area sown in MV of rice increased. Without going into further detail at this stage, we can say that the results indicate that with prices (or more generally the level of incentives) held constant, the transition to the MV was associated with an increase in the level of these quasi-fixed, capital inputs.

The results for the equations that explain the yield variations are reported in Table 6.3. The dependent variable in this equation is the average crop yield, which can be written as $y = (1 - S)y_1 + Sy_2$, where S is the share of the modern variety in the total area. The incentives were empirically irrelevant and therefore are not included in the equations. What is interesting is that the fertilizer variable, which in this equation is the actual quantity applied rather than the expected quantity used in the area equation, is not significantly different from zero. Thus, the only variable that matters is the proportion of the MV in total area, or simply S. The coefficient of this variable indicates the yield difference of the traditional and modern varieties,

$$\frac{\partial y}{\partial S} = \frac{\partial[(1 - S)y_1 + Sy_2]}{\partial S} = y_2 - y_1.$$

The empirical results are consistent with Figure 6.1, which shows the effect of a change in the level of the constraint. The proportion of the MV in total area changes as the constraint, k, changes, whereas the input ratio of each technique is kept constant at a level that equates the shadow price of the constraint over all the implemented techniques.

The results indeed indicate that the pace and level of the transition to the MV were determined to a large degree by the availability of the quasi-fixed inputs. The expansion of their supply required resources that had to be taken from other productive uses. But resources, of course, are finite, and if the implementation of a new technique requires resources, it cannot move faster than the necessary change in the supply of such resources.[1]

Table 6.2 Estimates of area allocation equations

	Irrigated wheat				Irrigated rice		
Variables	MV	Trad.	Dry wheat	Variables	MV	Trad.	Dry rice
Incentives				*Incentives*			
MV wheat	0.00123	−0.00089		MV rice	0.00020	−0.00012	
	(6.15)	(−6.20)			(3.36)	(−2.80)	
IT wheat	−0.00089	0.00041		IT rice	−0.00012	0.00011	
	(−6.20)	(2.81)			(−2.80)	(1.64)	
I gram	−0.00005	−0.00008		I maize	−0.00004	0.00001	
	(−1.12)	(−1.59)			(−1.24)	(0.21)	
D wheat			−0.00077	I cotton	0.000085	−0.00002	
			(−3.04)		(3.35)	(−0.89)	
D gram			0.00009	D rice			0.00021
			(0.53)				(3.79)
				D maize			0.00003
							(0.97)
				D cotton			0.00004
							(2.05)
Constraints				*Constraints*			
IRR priv.	0.74701	−0.73056	0.12686	IRR priv.	−0.17733	0.03924	0.04272
	(6.24)	(−8.59)	(1.68)		(−3.06)	(0.91)	(1.68)
IRR govt.	0.23259	−0.17860	0.88662	IRR govt.	−0.11958	−0.13078	−0.00294
	(1.55)	(−1.63)	(7.28)		(−1.79)	(−2.69)	(−0.09)
E fert.	0.00125	−0.00090	−0.00177	E fert.	0.00053	0.00018	0.00010
	(3.3)	(−3.08)	(−4.57)		(3.55)	(1.49)	(0.96)
Roads	0.02376	−0.00590	−0.00272	Roads	0.05195	−0.01477	−0.00097
	(2.35)	(−0.75)	(−0.33)		(11.16)	(−3.69)	(−0.45)
Environment				*Environment*			
June–Sept	0.00123	−0.00095	0.000749	May	−0.00083	0.00014	−0.00007
	(3.16)	(−3.30)	(2.58)		(−1.00)	(0.23)	(−0.14)
				June	−0.00051	0.00093	0.00067
					(−1.13)	(2.64)	(2.49)
R^2	0.949	0.8097	0.9261	R^2	0.9621	0.8759	0.9058

Source: Based on McGuirk and Mundlak (1991), table 7.

Note: The incentive variables are expected revenues per thousand hectares deflated by wage for the indicated variety. MV, IT, I, and D indicate whether the particular crop variety is modern, irrigated traditional, irrigated, or dry. IRR priv. and IRR govt. are net irrigated area by private and government sources deflated by net cropped area (in thousands of ha.). E fert. is expected fertilizer available (nutrient kgs. per 1,000 ha. of net cropped area available in previous year). Roads measures km. of roads in district/1,000 ha. June-September, May, and June are preplanting rainfall variables (.01 mm.) District intercept shifters and a pre-green revolution intercept shifter are included in the estimated equations but are not included in the table. The Kharif irrigated and dry area equations (including rice) are all adjusted to correct for positive first-order autocorrelation following Parks (1967). T-statistics are in parentheses.

Table 6.3 Punjab: Estimates of yield equations

Explanatory variable	Dependent variable: Yield				
	Wheat	Gram	Rice	Maize	Cotton
Technology					
MV wheat	1.19928 (12.12)				
Irrigated gram		0.2215 (0.64)			
MV rice			1.32789 (7.18)		
Irrigated maize				2.07472 (4.66)	
Irrigated cotton					0.41771 (3.15)
American cotton					0.11413 (4.49)
Constraints					
Fertilizer	0.00316 (1.30)	0.00141 (1.66)	0.00189 (1.00)	0.00201 (1.46)	0.00116 (2.2)
Fertilizer technology	−0.00301 (−1.27)	−0.00314 (−1.69)	0.00115 (0.59)	−0.00121 (−0.74)	−0.00135 (−2.45)
Environment					
Rain	−0.00955 (−2.12)	−0.00437 (−0.64)	0.00212 (0.94)	−0.00118 (−0.36)	0.002306 (1.58)
Rain technology	0.00342 (0.53)	0.00622 (0.35)	0.00183 (0.59)	−0.01200 (−2.82)	−0.002679 (−1.69)
R^2	0.831	0.172	0.833	0.539	0.716

Source: Based on McGuirk and Mundlak (1991), tables 15 and 16.
Note: The numbers in parentheses are *t*-statistics. The district effects are not reported here.
The technology variables are:
Irrigated cotton, gram, and maize–proportion of area irrigated.
MV rice and wheat–proportion of MV in rice and wheat areas respectively.
American cotton–proportion of American cotton in cotton area.
The rain variables are:
Cotton–district rainfall, June–September.
Maize and rice–district rainfall, July–September.
Wheat and gram–district rainfall, October–April.

By the very nature of the fact that k is a constraint, the introduction of the MV increases its marginal value productivity, referred to as its shadow price. This can be seen in Figure 6.1, where the rate of return changes due to the appearance of the new technique from r_0 to $\tilde{r}$. With time, this increase in the rate of return will attract more capital and thereby facilitate further implementation of the new techniques. This is indeed what actually happened: the Punjab experienced a dramatic increase in the supply of fertilizers, tube wells, electricity, and roads as well as other variables that provide the infrastructure conducive for the adaptation of the modern varieties. Some of these variables are plotted in Figure 6.2. The most dramatic change is in the use of fertilizers, which increased from 46 thousand tons in 1965 to 1,199 thousand tons in 1992, a 26-fold increase that amounts to an average annual growth rate of 13 percent. The rate was even higher, 17 percent, for the twenty-year period from 1965 to 1985. For most of the period, the total supply of fertilizers and its expansion was controlled by the Indian government, which gave priority to the development of domestic production and restricted imports. Thus the growth rate of fertilizer supply, and thereby the shift to the new varieties, largely reflects the pace at which resources were allocated to domestic production. With this background we turn to formulate the process just described.

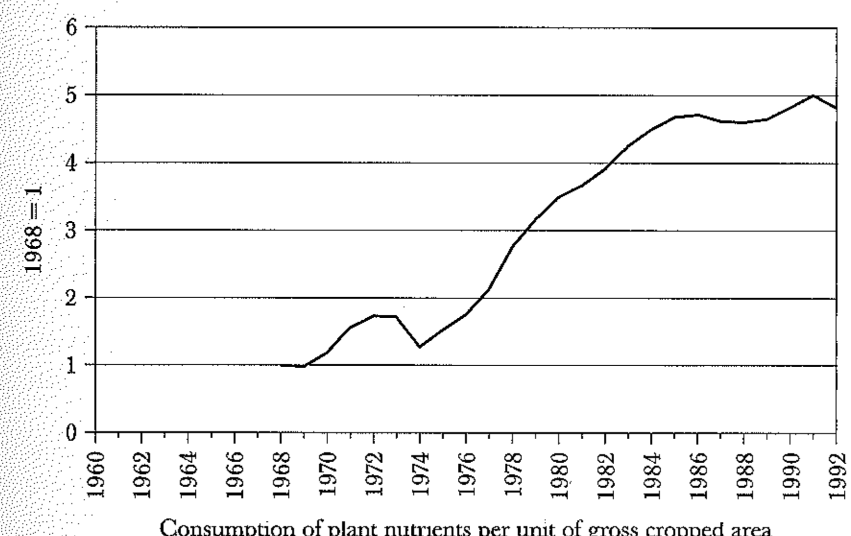
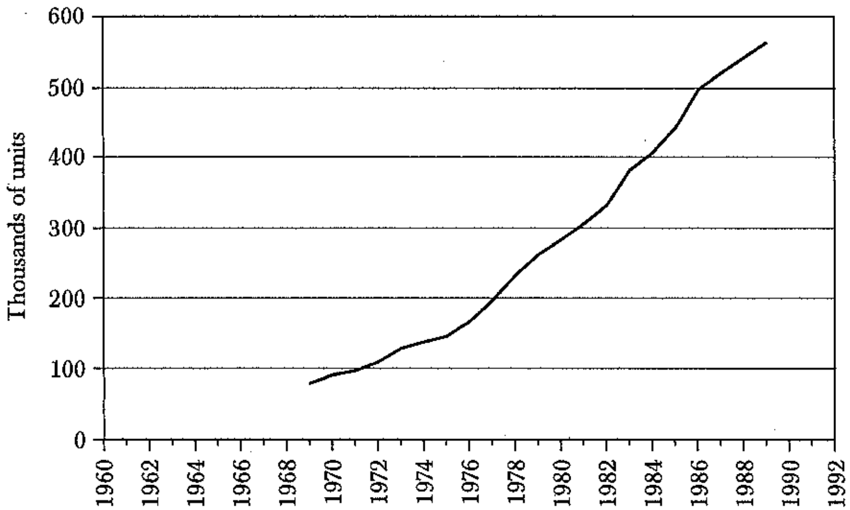
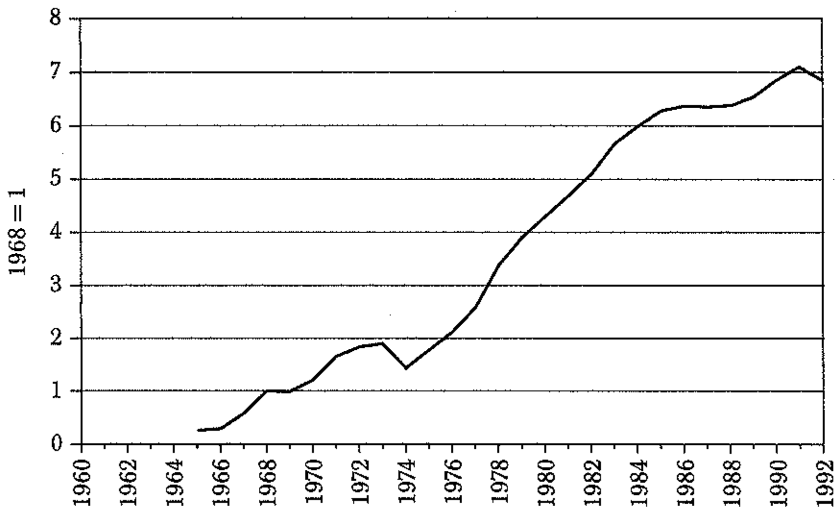


Figure 6.2 Punjab: Selected inputs. (From *Statistical Abstracts of Punjab*, Chandigarh: Economic and Statistical Organization, various years.)

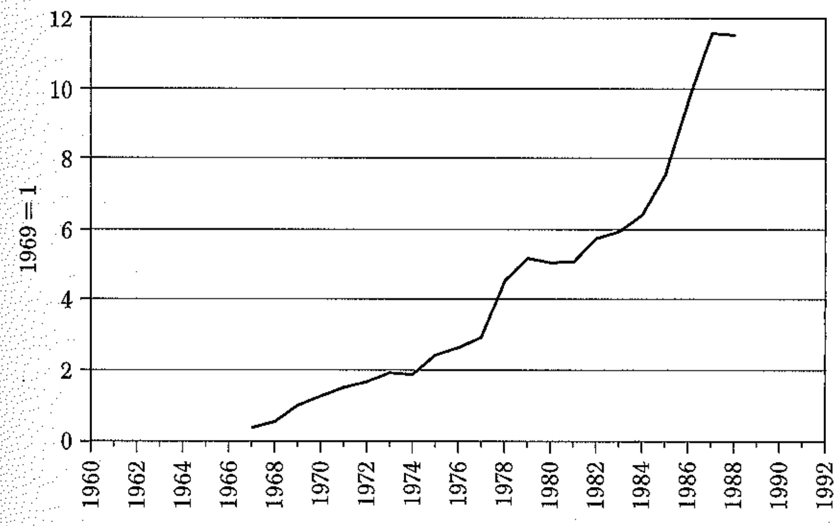


Number of electric tubewells and pumping sets



Use of fertilizers

Figure 6.2 *(continued)*



Electricity sales to irrigation and agriculture

Figure 6.2 *(continued)*

The Production Structure

General

At this point it is helpful to broaden our discussion of the production structure.[2] For this we need the concept of the input requirement set.

DEFINITION The *input requirement set,* $V(Y)$, is the set of all inputs that can possibly produce a given output Y.

It is assumed that $V(Y)$ is nonempty, containing nonnegative inputs, closed, convex, and monotone in the sense that if $x \in V(Y)$, $x^* > x$, then $x^* \in V(Y)$ also. $V(Y)$ is bounded from below by the isoquant that also belongs to $V(Y)$. With this structure it is possible to derive the production function associated with $V(Y)$.[3]

The model is now extended to allow for more than one production function in each sector. We examine in detail the simplest case, two production functions in one sector, say in agriculture. Since a production function is associated with an input requirement set, there are now two such sets, as shown in Figure 6.3. Some input combinations belong only to one input requirement set; others are common to both. This suggests that we can now broaden the concept of technology to allow for more than one production function. For instance,

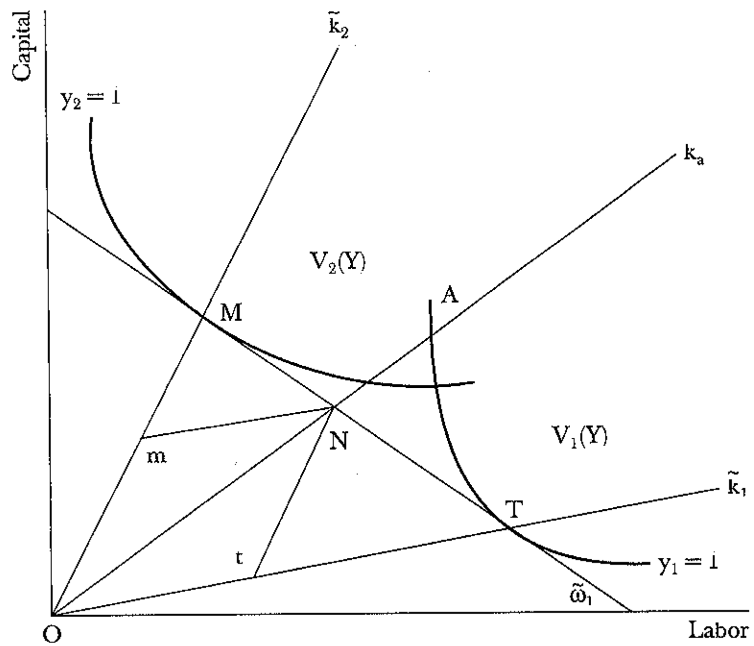


Figure 6.3 Input constraint and the composition of techniques

the first production function associated with $V_1(Y)$ is assumed to describe a traditional grain variety, whereas the second function, associated with $V_2(Y)$, is assumed to describe a modern grain variety. A technique is a method of production that can be described by a production function. It can be defined as narrow or as disaggregated, as desired. The basic assumption made here is that the technology is convex, so that it is possible to use the two techniques simultaneously. This means that some of the land can be used for the modern variety and some of the land can be used for the traditional variety. To assist the discussion, some terminology needs to be introduced.

DEFINITION The *available technology (AT)* is the collection of all available techniques.

Let $F_j(x)$ be the production function associated with the jth techniques; then the available technology is

$$T = \{F_j(x); j = 1, \ldots, J\}. \tag{6.1}$$

In our example, the technology, T, consists of the two varieties. Since each

which is the union of $V_1(Y)$ and $V_2(Y)$. Under the assumption that the technology is convex, it consists of all convex combinations of $V_1(Y)$ and $V_2(Y)$. The isoquant of $V(Y)$, or the efficiency frontier of $V(Y)$, is identical with that of the traditional variety for capital-labor ratios smaller or equal to $\tilde{k}_1$ that corresponds to point T in Figure 6.3. It is associated with the isoquant of the modern variety for capital-labor ratios larger than $\tilde{k}_2$ that corresponds to point M. For $\tilde{k}_1 \leq k \leq \tilde{k}_2$, the isoquant consists of the segment MT. The introduction of modern techniques opens up efficient production plans that were not feasible under the traditional variety. This motivates the definition of technical change.

DEFINITION *Technical change* is a change in the technology set T.

The appearance of the modern variety, or any new technique for that matter, implies technical change. This change is of *potential* consequence only if it changes the frontier of T. It is of *actual* relevance only if it is implemented. In terms of our illustration, the technical change occurs in the form of the appearance of the modern variety. The degree of its implementation depends on the available resources. If $k \leq \tilde{k}_1$, the economy does not have sufficient capital to implement the new technique. Consequently, the empirical observations will be of the traditional technique alone. It is therefore important to distinguish between available technology and implemented technology.

DEFINITION *Implemented technology (IT)* is a subset of the available technology containing all the techniques that are actually implemented.

The Composite Production Function

We turn now to specify the production structure in one sector, say agriculture, where the technology is made up of two techniques represented by production functions homogeneous of degree 1, twice differentiable, and concave. Let L_j and K_j be the labor and capital assigned to technique j, $j = 1, 2$, and L_a, K_a be the labor and capital available to agriculture. Define $\ell = L_1/L_a$ and $k_j = K_j/L_j$, then the technology and full employment conditions in agriculture are

$$\ell k_1 + (1 - \ell)k_2 = k_a \tag{6.2}$$

$$Y_1/L_a = \ell f_1(k_1) \tag{6.3}$$

$$Y_2/L_a = (1 - \ell) f_2(k_2) \tag{6.4}$$

$$k_2(\omega) > k_1(\omega) \quad \text{for all admissible } \omega.$$

If we add the competitive conditions, we get a system that describes a two-with different techniques. Because the product is the same, the price ratio is 1, and the price function dictates a constant wage-rental ratio.

PROPERTY 6.1 (technique coexistence and factor prices) Factor prices are constant under the coexistence of techniques.

As the capital-labor ratio increases, the economy moves along the Rybczynski path in the direction of the capital-intensive technique until the labor-intensive technique disappears. Throughout the domain of coexistence of the two techniques, the wage-rental ratio is constant, and therefore the sectoral capital-labor ratios are also constant. These factor ratios are the threshold values. Figure 6.4 describes the relationship between the available resources in agriculture, k_a, and output and its composition by techniques. At point A, $k_a = \tilde{k}_1$ and only technique 1 is employed, therefore at this point $y_a = y_1$. At point B, $k_a = \tilde{k}_2$ and only technique 2 is employed, therefore at this point $y_a = y_2$. The pair $(\tilde{k}_1, \tilde{k}_2)$ makes up the threshold values.

DEFINITION (threshold values) The capital-labor ratios that define the domain of coexistence of the two techniques are referred to as *threshold values*.

PROPERTY 6.2 The threshold values of the capital-labor ratio are determined by the technology.

As k_a increases from $k_a = \tilde{k}_1$ to $k_a = \tilde{k}_2$, the Rybczynski path, connecting points A and B, is generated. Because the price is 1, the output level at any point on the path is the sum of the two coordinates of that point.

PROPERTY 6.3 (composition of techniques) Under coexistence of techniques, the relative importance of the labor-intensive technique declines with capital deepening.

When k_a is not bounded by the threshold values, only one technique is used. We have basically outlined the composite production function for agriculture. For future reference, we develop the results analytically. Agricultural output, Y_a, is the sum of outputs produced by the individual techniques: $Y_a = Y_1 + Y_2$. Using (6.2) and (6.3), the average labor productivity in agriculture is

$$Y_a/L_a \equiv f_a(k_a) = \ell f_1(k_1) + (1 - \ell) f_2(k_2). \qquad (6.5)$$

The optimization problem is to maximize output under the resource constraint. This is the same as maximizing the output-labor ratio, Y_a/L_a.

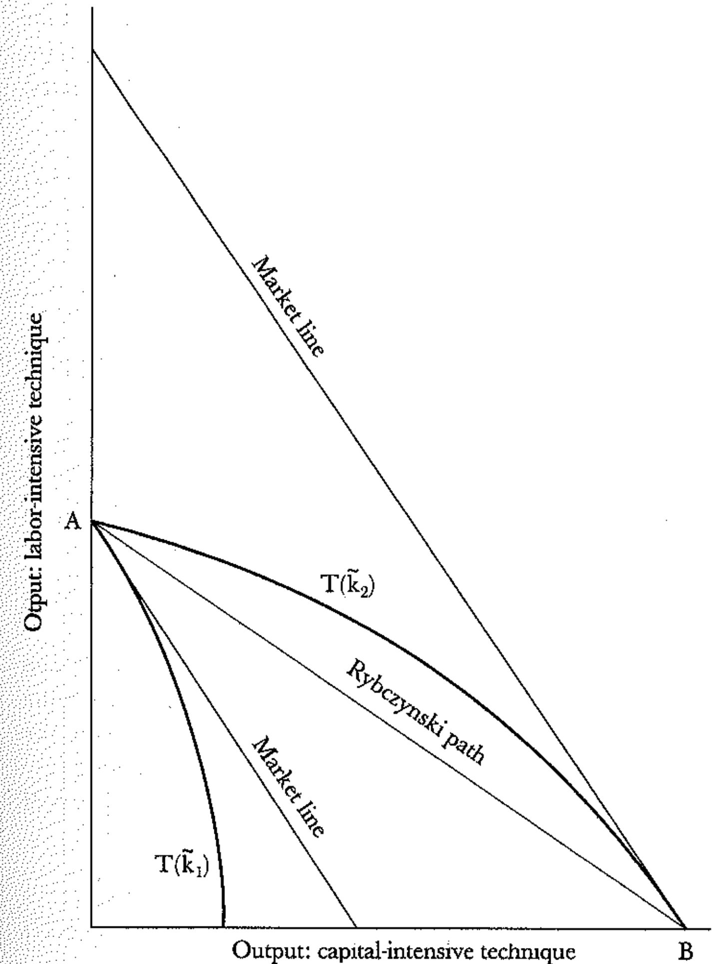


Figure 6.4 Construction of a composite production function

$$\max_{k_j \geq 0, \ell_j \geq 0} G(k_a, L_a) = \sum_j \ell_j f_j(k_j) + r(k_a - \sum_j \ell_j k_j) + w(1 - \sum_j \ell_j). \qquad (6.6a)$$

The Kuhn-Tucker conditions require that

$$\begin{aligned} &[f_j'(k_j) - r]k_j = 0 \quad [f_j(k_j) - rk_j - w]\ell_j = 0 \\ &f_j'(k_j) - r \leq 0 \qquad f_j(k_j) - rk_j - w \leq 0. \end{aligned} \qquad (6.6b)$$

A technique is implemented when the marginal productivity of each of the inputs is equal to its shadow price. Hence, for the two techniques to coexist, the marginal productivity of each factor should be the same across techniques. To derive the domain of coexistence, we solve for the threshold values:

$$f_1'(\tilde{k}_1) = f_2'(\tilde{k}_2) \tag{6.7}$$

$$f_1(\tilde{k}_1) - \tilde{k}_1 f_1'(\tilde{k}_1) = f_2(\tilde{k}_2) - \tilde{k}_2 f_2'(\tilde{k}_2). \tag{6.8}$$

The labor allocation among the techniques is determined by

$$\ell(\tilde{\omega}, k_a) = \frac{\tilde{k}_2 - k_a}{\tilde{k}_2 - \tilde{k}_1} \tag{6.9}$$

The real factor prices, $\tilde{w}$ and $\tilde{r}$ are given by the marginal productivity of labor and capital derived from the composite function, $f_a(\cdot)$, respectively. Those can be obtained by differentiation and to do so, write $f_j(\tilde{k}_j) = \tilde{w} + \tilde{r}\tilde{k}_j$ and substitute it in (6.5) to obtain

$$f_a(k_a) = \tilde{w} + \tilde{r}k_a. \tag{6.10}$$

The marginal productivity of capital, $\tilde{r}$, is derived directly from (6.10). When k_a is outside the domain bounded by the threshold values, only one technique is used. This follows from the full employment condition. In this case the composite production function is identical to that of the active technique.

The discussion may be summarized by giving a complete description of the composite production function.

$$\text{For} \quad k_a \le \tilde{k}_1, \quad \text{or} \quad k_a \ge \tilde{k}_2, \; f_a(k_a) = f_j(k_a), \quad j = 1, 2, \; \text{respectively.} \tag{6.11}$$
$$\text{For} \quad k_a \in [\tilde{k}_1, \tilde{k}_2], \quad f_a(\tilde{k}_a) = \tilde{w} + \tilde{r}k_a, \quad f_a'(k_a) = \tilde{r}, \quad \omega_a(k_a) = \tilde{\omega}.$$

PROPERTY 6.4 (composite production function) The composite production function obtained under the coexistence of techniques, characterized by differentiable concave production functions, is also differentiable and concave.

The composite production function is illustrated in Figure 6.5. The upper panel shows the wage-rental ratio as a function of k_a where $k_j(\tilde{\omega})$ are fixed at $\tilde{k}_j$. The lower panel shows $f(k_a)$; it starts at the origin along f_1 until $\tilde{A}$, from there on it moves along the segment $\tilde{A}\tilde{M}$ and thereafter continues along f_2. Note that for any value of $k_a \in k_a(\tilde{\omega})$, the average productivity of labor, $f_a[k_a(\tilde{\omega})]$ and the marginal productivity of capital, $f_a'[k_a(\tilde{\omega})]$, are uniquely defined. For any

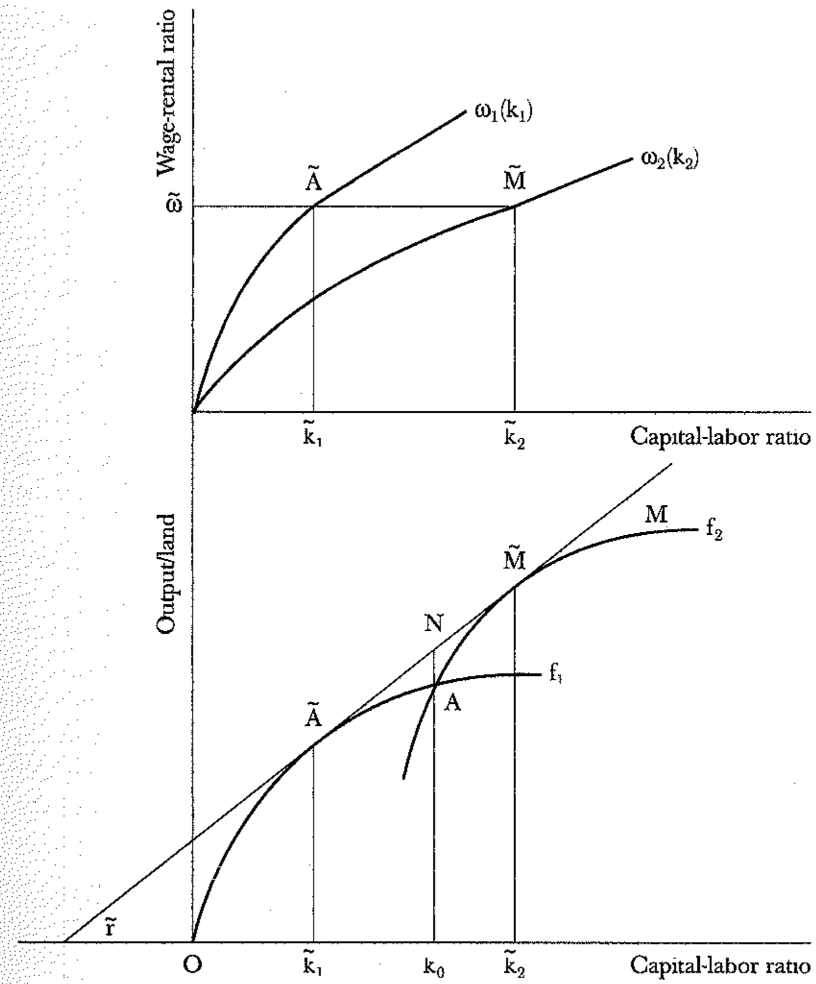


Figure 6.5 The composite production function

other value of k_a only one technique is used, and because $k_j(\omega)$ is monotonic in ω, the solution can again be expressed in terms of k_a.

The Economy

Having derived the production structure in agriculture, we turn to examine the effect of the introduction of the modern technique on the economy as a whole. This we do under the assumption that the technology in nonagriculture consists of a single technique. We rewrite the relevant part of the system with the obvious change of notation:

$$\ell_a k_a + (1 - \ell_a)k_n = k \tag{6.12}$$

$$Y_a/L = \ell_a f_a(k_a) \tag{6.13}$$

$$Y_n/L = (1 - \ell_a) f_n(k_n) \tag{6.14}$$

$$k_n(\omega) > k_a(\omega) \quad \text{for all admissible } \omega.$$

Because the agricultural production function maintains all the properties of the production function assumed in Chapter 2, the results of that chapter are immediately applicable. There is only one difference: the method of solving the system is modified to allow for the fact that k_a is not uniquely defined in terms of ω. As $\omega(k_a)$ is uniquely determined, however, so is $k_n(\omega)$. Hence the system can be solved in terms of k_a.

The solution is demonstrated in Figure 6.6. At levels of k_a below the threshold value of the traditional technique, $k_a \leq \tilde{k}_1$, only technique 1 is used, and the corresponding segment of the transformation curve displays an upward-sloping supply, which we write as $p'(y_a) > 0$. Similarly for $k_a \geq \tilde{k}_2$ only technique 2 is used, and again $p'(y_a) > 0$. In both cases, $\omega(k_a)$ is monotonically increasing. The new results are obtained for the case of coexistence, where ω is constant at $\tilde{\omega}$, as is $k_n(\tilde{\omega})$ as well as the marginal productivity in the two sectors. Consequently, p is constant and the corresponding segment of the transformation curve is a straight line.

PROPERTY 6.5 (technique coexistence and product price) When two techniques coexist, the product price is constant and is unaffected by capital deepening.

As k_a varies within the domain of coexistence, the resource allocation changes in order to maintain the full employment condition. Recall that in this domain $k_n(\omega)$ is constant, let $\ell_a = L_a/L$, and rewrite the full employment condition as

$$\frac{1 - \ell_a}{\ell_a} = \frac{k - k_a}{k_n(\omega) - k} \tag{6.15}$$

Equation (6.15) is solved for varying values of k_a:

$$\text{sign}\, \frac{d\ell_a}{dk_a}\Big|_{k_n} = \text{sign}[k_n(\omega) - k].$$

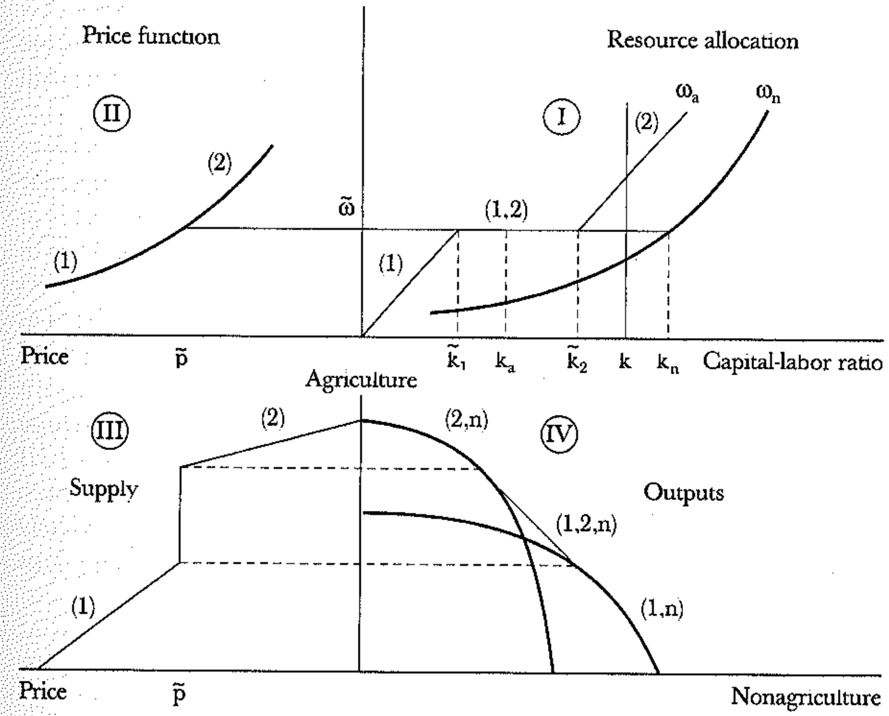


Figure 6.6 Coexistence of techniques: Supply side

This is simply a property discussed in Chapter 2 for the case where agriculture employs only one technique. This result applies independently of the factor intensity. To generalize the result, however, we may consider k_a to be the capital-labor ratio in the sector with the heterogeneous technology. We note that the relative importance of the labor-intensive sector grows with k_a. The importance of k_a is derived in Property 6.2, which highlights the fact that the degree of utilization of the new, more productive, and capital-intensive technique is through capital deepening. This can now be summarized.

PROPERTY 6.6 (resource allocation) The transition to a capital-intensive *technique* under fixed resources requires an increase in the share of the labor-intensive *sector* in resources and output. The result is independent of the sector in which the new technique is introduced.

It is important to note that in this discussion, it is the direct measure of factor intensity, rather than the factor-cost intensity, which matters, and as such capital does not include land. This discussion is general and applies equally well to the case of human capital. When the application of the new technique requires a special skill whose total endowment is given, the extent of its implementation depends on the ability to mobilize workers with this skill from other occupations.

Returning to the illustration in Figure 6.6, the numbers in parentheses identify the implemented techniques. Panel II presents the corresponding price function. The function is monotone and continuous but not differentiable at $\tilde{p} = p(\tilde{\omega})$. The transformation curve is given in panel IV. As agriculture in this case is the labor-intensive sector, the increase in its output requires an increase in its capital-labor ratio. But by Property 6.2, such an increase leads to a shift toward the capital-intensive technique. Therefore, with high agricultural production, only technique 2 is used in agriculture. The middle segment represents the coexistence of the two techniques. Finally, when agricultural output is relatively low, only technique 1 is used in agriculture. Panel III portrays the corresponding agricultural supply relationship. It is important to note that when the two techniques coexist, the agricultural supply is infinitely elastic. This result is of great importance and we will discuss its ramifications at a later stage.

PROPERTY 6.7 (supply elasticity) When the two techniques coexist, the supply is perfectly elastic.

The discussion was conducted under the assumption that agriculture is labor intensive. When agriculture is capital intensive so that $k_a > k > k_n$, some of the results are modified. In this case, the only way to increase k_a is to initiate the changes within agriculture itself. This can be done by shifting labor to nonagriculture, but because the capital-labor ratio of nonagriculture is fixed within the area of coexistence, the shift of labor has to be accompanied by a shift of capital. The result is a decline of the share of agriculture in total resources. However, this does not mean a decline in total agricultural output. The new technique is more productive and therefore produces higher output with less resources. This is illustrated in Figure 6.6, where the movement along the line of technique-coexistence represents a higher production frontier than that given by the use of single techniques. The case where agriculture is capital intensive is more applicable to high-income countries, and indeed in these countries the share of agriculture in total resources is relatively small.

COROLLARY TO PROPERTY 6.6. When agriculture is capital intensive, the introduction of capital-intensive techniques is likely to reduce the share of agriculture in total resources even though output increases.

The reversal of the relationship between the use of the techniques and the relative importance of agricultural production is also reflected in the reversal of the relationship between the use of the techniques and p. However, what has not changed is the relationship between the choice of a technique and the wage-rental ratio or the capital-labor ratio in agriculture. This is the essence of the process.

PROPERTY 6.8 (technique choice and factor prices) An increase in the wage-rental ratio leads to the replacement of labor-intensive techniques by capital-intensive techniques.

The Effect of Capital Accumulation

Bringing in the demand functions, we can determine the short-run equilibrium. From the point of view of the present discussion it is desirable to distinguish between two cases: $p = \tilde{p}$ and $p \neq \tilde{p}$. The latter case is identical to that discussed in Chapter 4 and need not be repeated here. Thus we turn to the case where the two techniques coexist and prices are constant. In this case, an increase in k shifts the transformation curve and income increases. As p is fixed in the region of coexistence, the new equilibrium solution reflects only income effect on demand.

When the technology of each sector consists of a single technique, the supply effect of a change in k is signed by the Rybczynski proposition. When techniques coexist, however, this proposition cannot be applied because $y_i(\tilde{p})$ does not have a single value. We can still sign the supply effect of capital accumulation by modifying the Rybczynski proposition. What drives the proposition is the fact that constant prices fix the value of the sectoral factor ratios. We can state this result as the condition of the proposition and turn to the full employment condition in (6.15) to derive the proposition. Thus an increase in k, with k_a and k_n held constant, increases the proportion of the capital-intensive sector in total resources. Under the assumption of $k_n > k_a$, $\partial \ell_a / \partial k \,|_{k_a,k_n} < 0$. Since $y_i = \ell_i f_i(k_i)$, $i = a, n$, any output plan obtained under constant k_i is shifted by capital accumulation so that the output of the capital-intensive sector increases and that of the labor-intensive sector declines. This is illustrated in Figure 6.7 where point B^* is southeast of B and the two points are obtained for the same values of k_a and k_n.

Bringing the changes in demand and supply together, and maintaining $p = \tilde{p}$ an increase in k leads to a new equilibrium point, E. The equilibrium quantities of the two sectors increase at rates proportional to their income

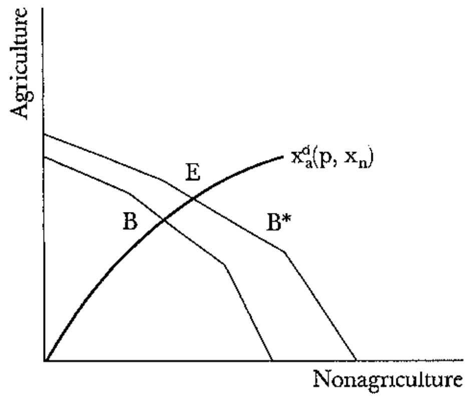


Figure 6.7 Equilibrium: Capital accumulation and a composite production function

elasticities. The movement from B to E is decomposed to an expansion effect, a movement from B to B^*, and to a movement along the new transformation curve, from B^* to E. Both effects take place at a constant ω, and therefore k_n is also constant. Hence, the total movement from B to E implies an increase of y_n at a constant k_n. This requires an increase of ℓ_n, which in turn implies a decrease in ℓ_a. Increasing ℓ_n while k_n is constant implies a shift of capital and labor to the n-sector. But at the same time y_a also goes up in spite of the decline in ℓ_a, and this can only be accomplished by increasing k_a. This in turn implies substituting the modern technique for the traditional technique and thereby supplying the labor to the n-sector. The discussion is now summarized:

PROPERTY 6.9 (technique choice and capital accumulation) An increase in the overall capital-labor ratio that maintains the state of coexistence of the two techniques generates only an income effect on demand. The change in demand is met by a shift of resources to the capital-intensive sector and by a rise of the relative importance of the capital-intensive technique.

The Rate of Implementation of New Techniques

The foregoing discussion highlighted the fact that the rate of adoption of new capital-intensive techniques is subject to a capital constraint, and therefore it depends on the rate of capital accumulation. For this reason, when dealing with an important sector of the economy, the introduction of a new technique may take time to accomplish. If we refer to Figures 6.1 and 6.3, this long-

run problem can be described as movement of point N on the frontier of the composite production function.

In addition, there is the short-run problem of a movement to the new frontier with the existing capital stock. When a new technique is introduced, the initial point becomes inefficient in that it is not on the frontier of the new composite function as illustrated by point A in Figure 6.1. The question is whether the movement from A to N, which does not require more overall capital, is immediate. This is obviously an empirical question, but it is reasonable to assume that in many cases this movement is not instantaneous. The determinants of the pace of such a movement often given in the literature can be classified into two groups, those related to heterogeneity of capital and those related to uncertainty and imperfect knowledge.

Heterogeneous capital

In the foregoing discussion, it was implicitly assumed that capital goods are homogeneous, so that horses and tractors are the same thing. They both represent foregone consumption, and as such they are the "same." This sameness is historical, however, and at present, the two capital goods do not serve the same function. The recognition that capital goods are heterogeneous introduces another dimension into the discussion. If the two techniques in question require different forms of capital, then the pace of moving from A to N will be determined by the pace of changing the composition of the capital stock so as to relieve the bottleneck generated by the capital components in which the new techniques are intensive. In general, the disappearance of the capital good associated with the traditional technique is determined by obsolescence or discard, and the introduction of the capital good associated with the new technique is determined by gross investment. Consequently, the rate of implementation of the new technique will be determined by the rate of *gross investment*, whereas the decline in the traditional technique will depend on the rate of disappearance of the capital good associated with it. Thus, the movement from A to N would imply a gradual reduction of the capital-labor ratio in the traditional technique from k_a to $\tilde{k}_1$. In this process ω will gradually decline from its level at A, as determined by the traditional technique, to $\tilde{\omega}$.

The essence of the argument on heterogeneity of capital is that the two techniques may require different compositions of the various capital goods. If this is the case, then the change in the composition of the two techniques will depend on the necessary change in the composition of the various capital goods. This process may require time, and the pace of convergence of the economy to the new frontier will depend on the rate of *gross investment*.

PROPERTY 6.10 When capital is heterogeneous and the new technique requires a different composition of capital goods, the pace of the movement to the new efficiency frontier generated by the technique depends on the pace of *gross investment,* whereas the movement to a new equilibrium point on the new frontier depends on the pace of *net investment.*

So far we have treated the modern technique as a new entity completely unrelated to the traditional technique. However, from a strictly formal point of view, once the new technique is available, it can be expressed as if it were obtained by some parametric change of the existing production function. Of special interest is the case where the modern technique can be described as a Hicks-neutral technical change in the traditional technique. In this case, the $\omega(k)$ function is unaffected by the technical change, so that the threshold values of the two techniques are identical. The new technique completely dominates the old technique, and it is therefore inefficient to employ the two techniques simultaneously. One reason for the coexistence of techniques in this case is that the two techniques use different capital goods. This is the case of the embodiment hypothesis developed by Solow (1962). Under this hypothesis, the new technique is embodied in a new capital good, say a machine, and it cannot be applied with the old machine. Consequently the pace of introduction of the new technique will depend on the flow of new machines, which depends on the rate of *gross investment,* rather than *net investment.* In this case, the traditional technique will disappear eventually, even if there is no net investment.

The situation is different when the modern technique can be expressed as a factor-augmenting technical change of the traditional technique so that the $\omega(k)$ function changes. In contrast to the previous case, factor-augmenting technical change generates a difference in the threshold value so that $\tilde{k}_2 > \tilde{k}_1$. In this case, if the new threshold value exceeds the available capital-labor ratio, the rate of implementation will eventually depend on *net investment.* Thus, if the economy does not accumulate capital, it will not discard the traditional technique. This is the difference between this model and that of embodied technical change. It follows

PROPERTY 6.11 The pace of the implementation of embodied technical change that does not change the capital-labor ratio depends on the pace of *gross investment.* When the new techniques are more capital intensive, the pace of adoption depends on *net investment.*

Human capital

The foregoing discussion has dealt with physical capital, but it is equally appli-

discussion. First is the actual appearance of new techniques, which will be treated in a subsequent section. Second is the specific knowledge needed to take advantage of the new techniques. From the point of view of our presentation, this element can be considered as a component of k in the above illustration. Thus Property 6.10 also applies to the case of skill accumulation. It also follows that when a new technique requires a new skill for its operation, the pace of implementation will depend on the pace of investment in the needed skill. This suggests that a low level of human capital will be associated with low per capita output and that an increase in the rate of investment in human capital will increase the growth rate of per capita output. It sounds so simple; why then don't low-income countries speed up the accumulation of their human capital? The mere fact that we have to raise this question suggests that perhaps things are somewhat more complicated. To deal with this question, we draw an analogy between the two types of capital. Basically, human capital, like physical capital, is endogenously determined. The appearance of a new technique increases the rate of return to the specific knowledge or skill associated with this technique, and this in turn is expected to stimulate learning. For example, the appearance of computers generated demand for programmers, and this was reflected in their returns. However, the implementation of the new techniques may be constrained by other factors, such as physical capital. When the capital stock is too low for the implementation of the new technique, there is no point in investing in the knowledge needed for its implementation, because it will remain unutilized for a long time to come. It follows that low-income countries with a low level of physical capital will not invest in acquiring knowledge needed for the operation of techniques that they cannot afford to acquire. Low-income countries do not invest in space research, for example, because they do not have the resources needed to make use of such knowledge. This brings us back to the important role played by physical capital in the implementation of new techniques.

Information

The foregoing discussion dealt with the question of knowledge needed to operate the new technique. There is another kind of knowledge that affects the implementation, knowledge about the performance of the new technique. Farmers know how to grow wheat, but they may lack knowledge about the potential performance of a new variety. The new technique may be superior, but farmers do not know it and may require time to sample it. A flow of new techniques generates a process of search that requires resources. At the farm level, the amount of resources devoted to the search depends on their cost (Feder and Slade, 1984). Such cost depends on the time allocated to the search and the level of education. Hence the speed of implementation that reflects imperfect knowledge is also positively related to capital in the form of human capital.

Another reason for uncertainty is related to the stochastic nature of the production process associated with the various techniques. Some techniques may have a higher variance in their performance than others. For instance, it has been debated whether or not the yields of the modern varieties have a higher variance than that of the traditional varieties. It is in this sense that the degree of implementation will depend on the stochastic performance of the techniques and the attitude of producers toward risk (Just and Zilberman, 1983). The importance of this source needs empirical quantification.

Sustainable Technology and Learning by Doing

The dependence of the implemented technology on resource endowment implies that if for any reason there is a decline in the capital-labor ratio, the economy will retreat to labor-intensive techniques, and with those there may be a loss in productivity. To dramatize the case, consider a major destruction of physical capital due to an earthquake or a war. The question is in what way would the reduction of capital affect the performance of the economy. The answer depends largely on what part of the technology is sustainable in the sense that it does not diminish with the reduction of the capital stock. This component represents cumulative experience, which is similar in nature to Arrow's "learning by doing." That may include knowledge that initially required capital to acquire but which, once acquired, does not depreciate and is not susceptible to destruction. In this we can also include changes in market organizations or economic policies that result in higher productivity, which might have been costly to implement, but once implemented, will continue without additional capital requirements. This also includes the introduction of new varieties or other elements of new knowledge. It is expected that these elements would be increasing with positive gross investment but would not be eliminated with negative investment.

In recent literature, learning by doing plays a more explicit role in the determination of technological progress. We return to this subject in the next chapter and also in Chapter 15.

Choice of Techniques and Land Expansion

The appearance of new techniques affects our analysis of land expansion. When a new technique is more capital intensive than the existing one, the

response of agriculture depends on the availability of capital. The subject can be illustrated in terms of Figure 6.1, which we now assume to represent the production function for quality q land. When capital is not constrained and agriculture is a price taker, the capital-land ratio will change with the introduction of the new technique from k_0 to k_2. The rent on the marginal land increases due to the higher productivity of the new technique from OE to OH, and more land will come under production. The actual increment will depend on the thickness of the margin, as was discussed in Chapters 4 and 5. We also note that the appearance of the new technique increases the capital-land ratio.

PROPERTY 6.12 When agriculture is a price taker, the appearance of a more productive and more capital-intensive technique will result in an increase in total capital, land, and output in agriculture.

In the case of a capital constraint, the appearance of the new technique increases the demand for capital; therefore its shadow price increases, and the marginal productivity of land declines. In this case, the decline in the marginal productivity of land is from OE to OD in Figure 6.1. If the tax, c, is larger than OD, then the rent becomes negative, and this land will go out of production. If this land was initially marginal, then by definition c is equal to OE and the land will be set idle. The capital released by the exit of the marginal land will be distributed to higher-quality land, and this will make it possible to increase the capital intensity on this land, thereby increasing the share of the new technique on it. Recall from Figure 4.8 that $k(q)$ increases with q to conclude

PROPERTY 6.13 When agriculture is subject to a capital constraint, the appearance of a more productive and more capital-intensive technique will increase the quality of the marginal land, and land will go out of production. The degree of implementation of the new technique will increase with the land quality.

A comparison of Properties 6.12 and 6.13 shows that the *same* technical change can be classified as land expanding under unconstrained capital and land substituting under a capital constraint. The outcome under a capital constraint can be viewed as the short-run effect, whereas the long-term effect is achieved under no resource constraint. Thus if the introduction of a modern, capital-intensive technique causes land to go out of production, this can be viewed as a temporary outcome.

New Techniques and Income Distribution

New techniques are generated by firms, private or public, that spend resources on research and development. Given the state of science, there is generally a choice to be made in determining the research strategy. For the purpose of our discussion, the key variable is the capital intensity of the new techniques. The foregoing discussions indicated that capital accumulation causes a shift of resources to capital-intensive techniques and thus generates demand for them. It is no surprise then that new techniques are often capital intensive. However, overshooting is counterproductive. The demand for the new techniques depends on the expected rate of their implementation, which in turn depends on capital availability. For the new techniques to be implemented, therefore, their threshold level should not be too high.

This story can be told by looking at the firm level. In the absence of a new capital-intensive technique, capital accumulation increases capital-labor ratios, thereby causing a rise in wage and a decline in the rental rate. Consequently, the owners of capital will be interested in investing their capital in techniques that prevent the rate of return from falling. This generates the demand for the capital-intensive techniques.

By its very nature, this process leads to a decline in the labor share, S_L, and as such can be considered labor saving. This can be illustrated by observing changes in $\theta = \omega/k = S_L/(1 - S_L)$. Note that θ is monotonically increasing with S_L. If we refer to Figure 6.3, we see that the movement from T to N increases k with ω held constant. Consequently θ, and therefore S_L, decline. The transition from A to N implies a decline in ω under a constant k, which again results in a decline of the labor share.

With technology consisting of more than one technique, Hicks-neutral technical change (NTC) in one technique has the effect of factor-saving technical change for the sector as a whole. Of special interest is NTC of the capital-intensive technique that generates an overall effect of labor-saving technical change. An improvement in the productivity of the capital-intensive technique increases the shadow price of capital, or equivalently causes a decline in ω. The threshold values of the various techniques decline accordingly, from $\tilde{k}_j(0)$ to $\tilde{k}_j(t)$. Let ℓ be the share of the labor-intensive technique in employment and use (6.9) to write

$$\frac{1-\ell}{\ell} = \frac{k - \tilde{k}_1}{\tilde{k}_2 - k} \tag{6.16}$$

This ratio rises as $\tilde{k}_j$ declines, implying a decline in the relative importance of

of a Hicks-neutral technical change in the capital-intensive technique is labor saving. The details of this argument are assigned as an exercise. Indeed, as we saw in Chapter 1, labor share in agriculture has declined.

In this illustration, the modern technique is the subject of the NTC for a purpose. If, as has been argued, the process of capital accumulation causes a shift in the direction toward capital-intensive techniques, then—other things being equal—the demand will call for development of the NTC to be implemented on the modern techniques. In a more detailed framework, the cost of producing and changing techniques, as well as the required research time, should be introduced. If the required time is significant, by the time the research is completed, the traditional technique may not be of any importance. Therefore, efforts will be directed at increasing the productivity of the modern technique. This consideration has a dynamic aspect. With time, the modern techniques become traditional. They have already been worked on so that the easy gains have already been made, and additional gains may be subject to increasing cost. Thus from both the demand side and the supply side, it is likely that the effort of improving an existing technique will be aimed at modern techniques.

Total Factor Productivity

What is the rate of technical change? This subject is an important one in empirical analysis, and in practice there is more than one answer, depending on the method of measurement. To begin with, there is the difference between partial and total factor productivity (TFP). Partial productivity measures are measures of average factor productivity, such as average labor productivity. Changes in this measure reflect changes in the amount of inputs used per worker in addition to changes in technology. The same holds true for average land productivity, or simply yields. To measure the net effect of changes in technology, it is necessary to allow for the effect of changes in all inputs. The outcome gives the total factor productivity. To illustrate, consider a differentiable production function $Y = F(X, t)$, where X is a vector of inputs and t is a measure of technology. Then the rate of growth of output is obtained by logarithmic differentiation:

$$\hat{Y} = \sum_j \beta_j \hat{X}_j + \widehat{\mathrm{TFP}},$$

where β_j is the production elasticity of factor j. The first term on the right-hand side is a measure of the aggregate input. This equation defines the relative change in TFP. Using discrete time measures, the TFP in year t is

To estimate the changes in the TFP, it is necessary to obtain estimates of the production elasticities. Those are obtained by estimating the production function, or by replacing them with factor shares, assuming that the production function is linear homogeneous and that the competitive conditions are met. The various aspects of obtaining empirical production functions are discussed in Part III. Our present interest is conceptual in nature, and it is related to the question of what function to estimate.

To illustrate the question, refer to Figure 6.1. Initially, only the traditional technique is available, and output is at point A with input ratio k_0. As the discussion indicated, the response to the introduction of the modern technique may take various forms. Under a resource constraint, the movement is to point N, and this movement generates a relative change in TFP of Y_N/Y_A. As more resources become available, the movement will be along the tangent line from N to $\tilde{M}$ and thereafter along the function f_2 to M. This movement from point N on will show no TFP, because it is all explained by the input change. Alternatively, if the sector is a price taker, the movement is from point A to point M with an input ratio of k_2. Here the change in the TFP is obtained by first calculating the effect of the input change by extending the line tangent to the production function at point A to point B and then computing the ratio Y_M/Y_B. The result is different from that obtained in the first case above. The conclusion is that the outcome is path dependent. This discussion abstracts from the question of time needed to travel in each path. Actual calculations are made for data collected for calendar time, mostly annual data. The annual results will differ with the changes in the pace of the yearly movement. When the annual results are integrated, however, the final outcome will depend on the path followed by the economy. Obviously, the path taken under a resource constraint will give a smaller value to the TFP because the potential of the technical change is not fully utilized. We will see in Chapter 13 the empirical implication of this discussion.

Exercises

6.1 Assume a two-sector economy where the agricultural technology consists of two techniques; the modern technique (MV) is more capital intensive than the traditional technique (TV).

(i) The composite production function of agriculture derived in the chapter is

$$Y_a/L_a \equiv f_a(k_a) = \ell f_1(k_1) + (1-\ell) f_2(k_2).$$

Derive the marginal productivity of capital in the domain of coexistence of techniques.

(ii) Assume that total resources (k) are given and that agriculture is capital intensive. Answer the following questions with the aid of the four-panel diagram (Figure 6.6).

(a) What is the relationship between the level of agricultural output, the implemented techniques, the agricultural price, and the wage-rental ratio?

(b) What happens to sectoral outputs, prices (p and ω), and the use of techniques when k increases?

(c) In evaluating this process, which concept of agricultural capital is more adequate: with or without land included?

6.2 Write the optimization problem to show that when the technology consists of two techniques, Hicks-neutral technical change in the capital-intensive technique has the net effect of labor-saving technical change for the sector as a whole.

6.3 Can a technical change in one sector affect the measure of TFP in the other sector?