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CENTER DISCUSSION PAPER NO. 281

INCOME DISTRIBUTION EFFECTS OF TECHNICAL CHANGE:

SOME ANALYTICAL ISSUES

Hans P. Binswanger

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INCOME DISTRIBUTION EFFECTS OF TECHNICAL CHANGE;
SOME ANALYTICAL ISSUES

Hans P. Binswanger

INTRODUCTION

This paper is a review of partial and general equilibrium approaches to analysis of distributional consequences of technical change. In addition, some existing partial and general equilibrium models are also recast and refined in a way to make them more amenable to empirical analysis, especially by making them consistent with recent developments in econometric parameter estimation techniques.

An earlier version of this paper was prepared for the Workshop on Technology and Factor Markets held recently in Singapore under the auspices of the Agricultural Development Council. That Workshop was convened to see whether economic theory could help in the interpretation of the considerable empirical micro and macro evidence of the distributional impact of agricultural technical changes such as the green revolution. The organizers of the Workshop felt that theoretical advances might help clarify some of the apparently contradictory and confusing picture which is emerging from the empirical studies which sometimes totally lacked a theoretical foundation. The models discussed in this paper have thus been built with agriculture in mind and use agriculture for examples.

The distributional problem associated with technical change in agriculture breaks down into four subproblems.

1) The Distributional Effects among Producers of a Given Region

This is probably the most analyzed and best understood issue. Three determinants are operating here:

First, it is clear that early adoption of a technology provides innovators rents. It is well known that innovators rents are sometimes the only producer benefits from technical change in markets with inelastic final demand where widespread adoption ultimately leads to price reductions. How they are distributed is thus important, despite their transitory nature. It is clear that large producers will usually be among the early adoptors since they have a much stronger incentive to search for information about new technology. The benefits from search are proportional to size while the costs are not, hence

larger producers have a much stronger incentive to search than smaller ones (Welch, 1976).¹

The adoption cycle thus leads to a regressive impact on the income distribution. However, this particular impact is transitory. The empirical evidence on adoption lags is massive and well understood.

Second, technologies may reduce costs for large scale firms more than small scale ones, i.e., have a scale bias. In agriculture much of mechanical technology such as tractors are of this type.² It is clear that any technical change which is biased in favor of large scale firms provides them with benefits while it does so to a lesser extent or not at all for small firms. Since in agriculture the large firms are owned by the wealthier groups, scale biased technology must have a permanent regressive impact.

The third determinant of the distributional impact of a technical change among producers is their relative access to product and factor markets. If access to input and credit markets is unequal prior to the introduction of new technology, any innovation which leads to greater dependence on these markets will lead to a regressive distribution of the gains. This regressive impact is not transitory. To remedy the situation requires institutional changes which will equalize the access of producers to product and factor markets. Blaming the regressive impact on the technology makes little sense unless clearly superior technologies can be developed which do not increase dependence on markets. In agriculture this is highly unlikely. It is interesting to note that the green revolution has led to a much greater realization of the inequalities of access existing in these markets and to a large amount of policy to remedy it.

Analytically the problem of distributional consequences among producers is relatively easy to handle. Microdata on adoption rates, relative productivities and input use levels can provide many insights, although care has to be taken to clearly distinguish the transitory and the more permanent determinants of distributional outcomes.

¹Similarly, extension agents or input salesmen whose performance is judged in terms of acreage of adoption of new techniques or sales of production inputs have an incentive to work with larger producers, because the effort depends on the number of producers visited, while the benefits are proportional to the size of the farms of each producer.

²For a review of these issues, see Hans P. Binswanger (1978).

2) Producers versus Consumers

The conflict about the distribution of gains between agricultural producers and consumers has been the major distributional conflict in Europe and North America. It is usually analyzed in comparative static partial equilibrium models. The basic conclusion of these consumer-producer surplus models is that under perfectly elastic commodity demand producers capture all the gains. But under inelastic demand consumers gain whereas producers may gain or lose. The total gain is captured by consumers, with producers neither gaining nor losing when the elasticity of final demand α is equal to minus 1. Figure 1 shows this clearly. If a technical change shifts the supply curve from S to S' and demand is perfectly elastic (D_2) then producer surplus expands from PAE to PCF and consumer surplus is unaffected. If on the other hand the demand curve is inelastic such as D_1 producer surplus changes from PAE to $P'BF$, which implies the loss of area $PAGP'$ and a gain of the area $EFBA$. Which of these two areas is bigger depends on the elasticity of final demand.¹ Consumers on the other hand gain the area $ABP'P$ which will be the larger the smaller $|\alpha|$. If $|\alpha| < 1$ consumers gain at the expense of real losses to the producers.

Furthermore, it is clear that, whenever gains are captured by consumers the impact of most technical changes in food production on the income distribution is progressive.² Poor people spend a large proportion of their budget on food and the proportional gain in their real income (deflated by a price index using their own consumption weights) is larger than that of rich people who spend proportionately less on food. For a detailed analysis, see Pinstrup-Anderson, et al. (1976).

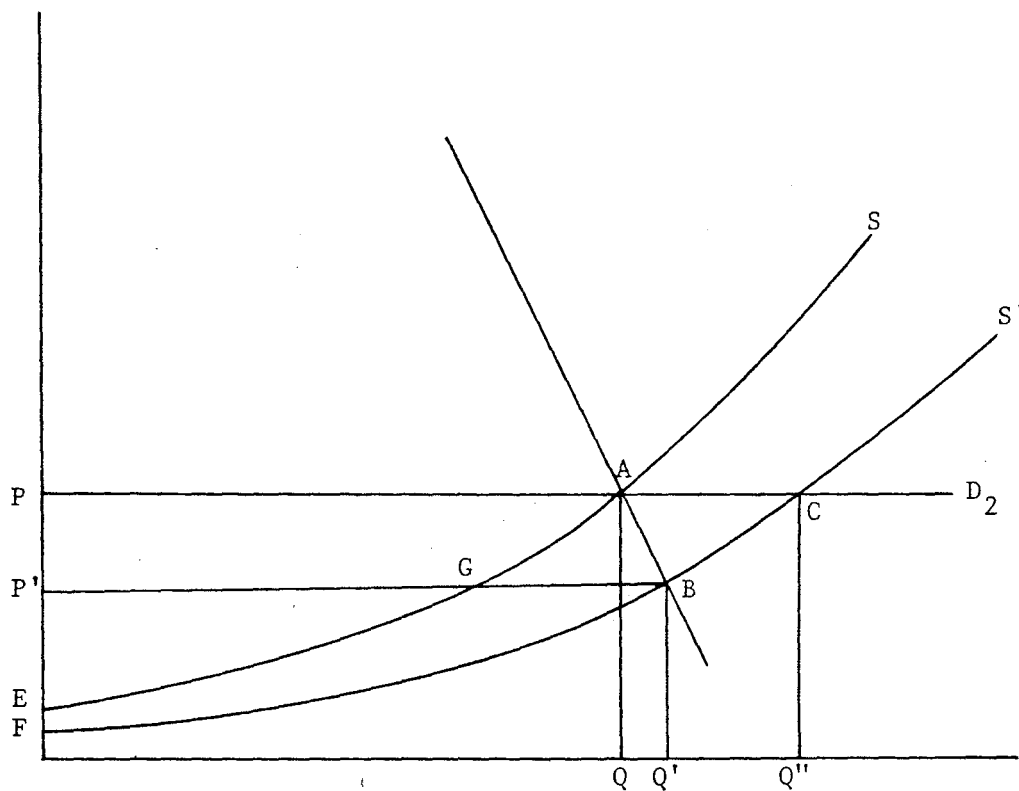
In the context of the green revolution, the issue of consumer gains has received little attention³ because population and income growth have led to shifts in the final demand curve which were often more than sufficient to offset any downward pressure on prices originating from the shifts in the supply curves

¹It also depends on the intercept and the shape of the supply curve through its entire range. For one model of computation, see Hayami (1975), p. 166.

²Exceptions to this are technical changes which are confined to luxury foods.

³Except for analysts who measured the gains from technical change using the consumer-producer surplus techniques.

FIGURE 1: Consumer versus Producer Gains from Technical Change



due to technical changes. However, one can easily reason that the absence of the green revolution might have led to massive adverse consequences on the income distribution via higher food prices.

As we shall see the partial equilibrium models are not always fully adequate to analyze this particular problem, especially when the sectors experiencing technical change are large relative to the economy.

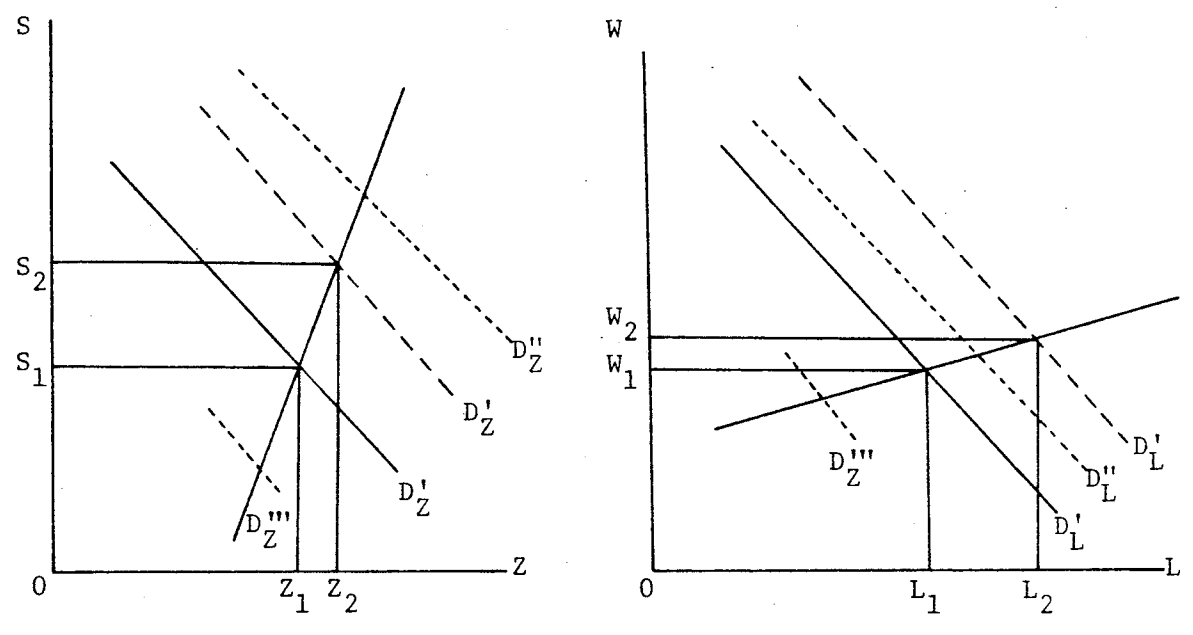
3) Land-owners (or Capitalists) versus Workers

In the wake of the green revolution it has been observed from microstudies that in those areas experiencing the technical change, land rents have been rising faster than wage rates (Hanumantha Rao (1975), Deepak Lal (1976)). Partial equilibrium analysis has a simple explanation for this. The regions experiencing technical changes were faced with elastic final demand because they supplied a national market in which other regions were not substantially expanding supplies. The technical change reduced demand for factors per unit of output, but the expansion in production was more than enough to offset the initial reduction and the demand curves for all factors of production shifted to the right.

Figure 2 shows what happens in these factor markets. (The graphical analysis neglects substitutability among factors, but this will be taken up below.) A neutral technical change with elastic commodity demand leads to an equiproportional outwards shift in the two factor demand curves. This is translated into a large increase in the land rent S because land Z is in inelastic supply. If labor is in elastic supply (for example, because of migration) its wage rises much less, but its total employment increases substantially. The factor price effects are therefore not determined by the technology alone but by the nature of supply in the markets for the factors which it uses. The technology characteristic are also important. If the technical change is labor-saving (and the output demand elastic), this results in a disproportionately large shift in the land demand such as D''_Z relative to the labor demand D''_L and wages rise even less relative to land rents. In this case total employment is also lower relative to a neutral technical change.

When final demand is inelastic the increase in demand is not sufficient to offset the factor savings made possible by the technical change. Factor demands shift backwards (equiproportionally for neutral technical change) to D'''_Z . The factor in inelastic supply is now the biggest loser although all

FIGURE 2: Gains of Workers versus Gains of Capitalists



factors of production loose from the technical change.

Later in the paper we shall see that in certain circumstances, partial equilibrium analysis may not be sufficient to fully analyze this problem, especially when technical change occurs in an entire large sector.

In the case of the green revolution most evidence suggests that the technical change was neutral but also that landowners gained disproportionately relative to labor. For a review of the empirical literature, see Mellor (1976) or Binswanger and Ruttan (1978, Chapter 13).

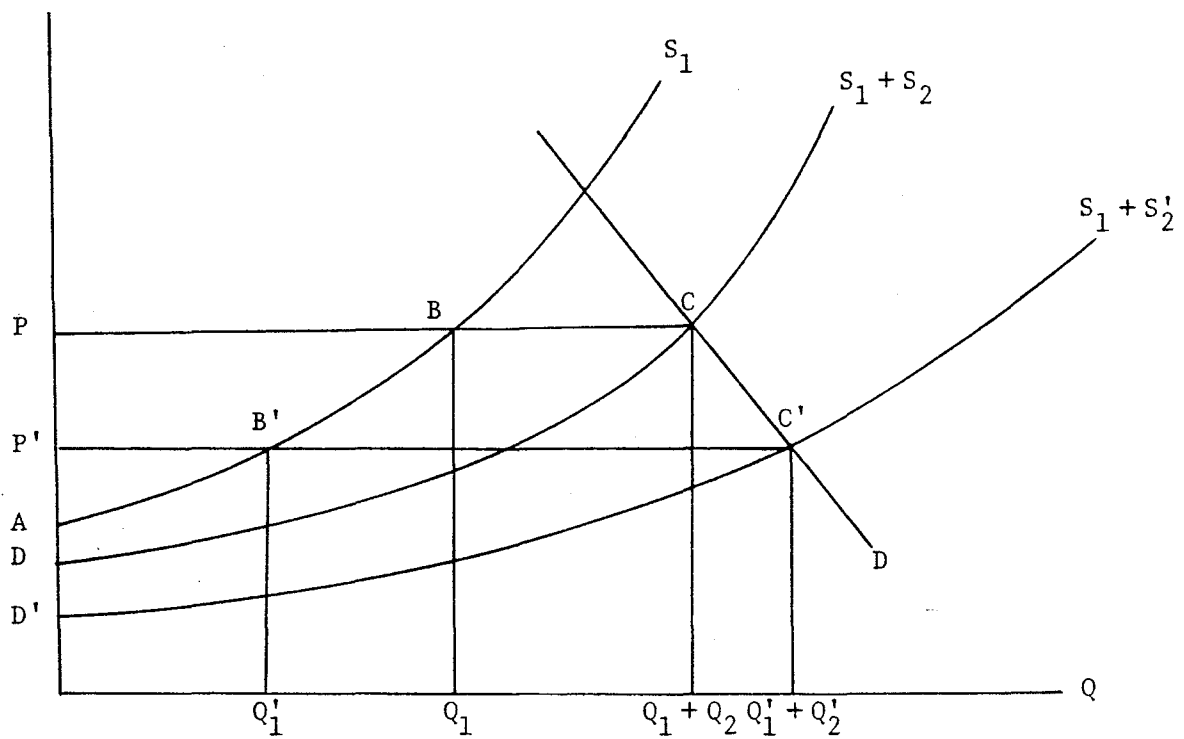
4) Distributional Consequences Among Regions¹

In agriculture in particular, but also in other industries, technical change is often confined to certain regions because of environmental or economic location specificity. In particular the green revolution has largely been confined to irrigated zones with good water control. Partial equilibrium analysis of the distributional consequences of this unequal region access is again straightforward: In Figure 3, two regions supply a national market with an inelastic demand curve D . The supply curve of region 1 is S_1 . Prior to the technical change the total supply curve is $S_1 + S_2$, which is found by adding the supply of region 2 to the supply of region 1 horizontally at each price. In this situation producer surplus in region 1 is ABP and $ABCD$ in region 2. Now the supply curve in region 1 stays constant but region 2 experiences a technical change which shifts the overall supply curve to $S_1 + S_2'$. Output in region 1 is reduced from Q_1 to Q_1' and producer surplus is reduced to $AB'P'$. The region 1 experiences a real loss from the technical change in region 2. The latter, despite inelastic commodity demand increases its output by $(Q_1' + Q_2') - (Q_1 + Q_2)$ along the final demand curve, and, at the expense of the region 2, by $Q_1 - Q_1'$. As long as the combined elasticity of the final demand curve and of the supply curve of region 1 exceeds unity (with appropriate signs), the producer surplus in region 2 increases. After the technical change it is the area $AB'C'D'$.

We already know how the gains in region 1 will be distributed among landowners and workers. In the losing region the largest share of the losses will

¹This section follows closely a paper by Evenson (1976).

FIGURE 3: The Distributional Impact of Technical Change Among Regions



be borne by the factors in most inelastic supply, or in other words, by the immobile factors of production. Land prices will decline more than wage rates because some labor will migrate to the gaining region (and contain the rise in the wage rate there). Note that this model accords well with what is known about regional wage rate changes in India since 1965.

Partial equilibrium analysis, as outlined above, seems to have an ability to explain observed income distribution changes fairly well. The next section discusses the Evenson-Welch partial equilibrium model which integrates the distributional problems 2, 3 and 4 into single framework and makes it possible to consider distributional impacts of technical changes when the demand curve for final output and the factor supply curves are shifting simultaneously. A simple general equilibrium model is considered next. Unfortunately this general equilibrium extension leads to a considerable loss in simplicity and clarity of the picture just sketched. The concluding section will be devoted to a discussion of the conditions under which it makes sense to shift to the general equilibrium approach.

THE EVENSON-WELCH MODEL

The distributional model presented here has initially been developed by Robert E. Evenson and Finis Welch. It has been further refined by Evenson (1978) who extended it to take into account the problems of technology access restricted to certain regions of a country. These versions of the model were based on a production function. Binswanger then reformulated the model in terms of cost functions which makes it consistent with estimation techniques derived from profit or cost functions and allows straightforward extension of the model to more than two factors or more than one sector. The two-factor version of the model will be presented here in its cost function form.

The predominant approach to analyzing biased technical change has been to restrict it to factor augmenting technical change. Here, however, we start from a cost function dual to a linear homogeneous production process with technical change of an arbitrary nature.

$$C = Y \cdot U = Y \cdot U(W, R, t) \quad (1)$$

where C = total cost,

Y = output level,

U = unit cost,

W, R = wage rate and capital rental rate, respectively,

t = technology index or time.

Shepherd's lemma gives the factor demand curves per unit of output.

$$\left. \begin{aligned} \frac{\partial U}{\partial W} &= \ell = g^1(W, R, t) \\ \frac{\partial U}{\partial R} &= k = g^2(W, R, t) \end{aligned} \right\} \quad (2)$$

where $\ell = L/Y$ = labor input per unit of output,

$k = K/Y$ = capital input per unit of output.

Differentiate totally as follows:

$$dL = d(Y\ell) = \ell dY + Y \left[\frac{\partial \ell}{\partial W} dW + \frac{\partial \ell}{\partial R} dR + \frac{\partial \ell}{\partial t} dt \right] \quad (3)$$

and transform into logarithmic changes or time rates of change (i.e., $X' = (1/X) \cdot (\partial X / \partial t) = (\partial \log X) / \partial t$) we find rates of changes for labor and capital

$$\left. \begin{aligned} L' &= Y' + \eta_{LL}W' + \eta_{LK}R' - A'_L \\ K' &= Y' + \eta_{KL}W' + \eta_{KK}R' - A'_K \end{aligned} \right\} \quad (4)$$

where

$$\left. \begin{aligned} A'_L &= - \frac{1}{\ell} \frac{\partial \ell}{\partial t} dt \\ A'_K &= - \frac{1}{k} \frac{\partial k}{\partial t} dt \end{aligned} \right\} \text{Factoral rates of technical change.}$$

The factoral rates of technical change are the negative shifts of the labor and capital demand curves respectively. They are defined negatively so that a technical advance corresponds to positive A'_L and A'_K .

Since unit costs $U = \ell W + kR$ and since the rate of technical change T' is equal to the negative rate of unit cost reduction $-U'$, it follows that

$$T' = -U' \Big|_{W,R} = s_L A'_L + s_K A'_K \quad (5)$$

where s_L = share of labor and s_K = share of capital. This shows that the rate of technical change is the share weighted sum of the factoral rates of technical change.

The bias of technical change is defined as

$$Q_{LK} \Big|_{W,R} = \frac{d(L/K)}{dt} \frac{1}{(L/K)} = A'_L - A'_K \begin{matrix} \geq 0 \\ = 0 \\ < 0 \end{matrix} \left. \begin{array}{l} \text{Labor saving} \\ \text{Neutral} \\ \text{Capital saving} \end{array} \right\} \quad (6)$$

Hence the bias is simply the difference in the factoral rates of technical change or the difference in the shifts of the per unit factor demand curves caused by the technical change.¹ Factoral rates of technical change can be estimated

¹This is one version of Hicks biased technical change. For its relation to other definitions in terms of marginal products, see Binswanger and Ruttan (1978), Appendix to Chapter 2.

empirically using frameworks such as those of Binswanger (1974a).

Empirical approaches to measuring the factoral rates of technical change and/or factor demand elasticities will require the specification of a functional form of the cost function and the factor demand curves. Diewert's (1971) Generalized Leontief cost function is particularly convenient for estimating factoral rates of technical change. All models which follow will be in terms of elasticities only and not in terms of parameters of the Generalized Leontief function. Transforming back to this particular econometric parameterization is straightforward. It should, however, be noted that factoral rates of technical change, which are simply shifts in factor demand curves, are consistent with any kind of functional form one might choose. The Generalized Leontief function is just a particularly convenient one among many.

The Evenson-Welch model can be written as a six equation model in cost function form. Instead of Evenson's marginal product relationships, the first two equations are now the labor demand and capital demand curves (4). The third equation is the equation for the change in the commodity price P_1 which states that the rate of commodity price change must be equal to the share weighted sum of factor price changes, less the rate of technical change.

$$\begin{aligned} P_1' &= U' = s_L W' + s_K R' - T' \\ &= s_L W' + s_K R' - s_L A'_{LL} - s_K A'_{KK} \end{aligned} \quad (7)$$

Finally we have the output demand and the two factor supply equations which can be written in dynamic form as

$$Y' = \alpha P_1' + D^* \quad (8)$$

$$L' = \epsilon_L W' + L^* \quad (9)$$

$$K' = \epsilon_K R' + K^* \quad (10)$$

where α is the demand elasticity for final output, ϵ_L and ϵ_K are the supply elasticities of labor and capital respectively, and D^* , L^* , and K^* are final demand and input supply shifters.

Equations (8), (9), and (10) can be used to eliminate Y' , L' , and K' from equations (4) and (7) to give the following matrix equations:

$$\begin{bmatrix} W' \\ R' \\ P'_1 \end{bmatrix} = \begin{bmatrix} \eta_{LL} - \epsilon_L & \eta_{LK} & \alpha \\ \eta_{KL} & \eta_{KK} - \epsilon_K & \alpha \\ s_L & s_K & -1 \end{bmatrix}^{-1} \begin{bmatrix} A'_L - D^* + L^* \\ A'_L - D^* + K^* \\ T' \end{bmatrix}. \quad (11)$$

The inverse of the matrix in (15) is¹

$$\frac{1}{\Delta} \begin{bmatrix} + & \pm & - \\ \epsilon_K + s_L \sigma - s_K \alpha & s_K (\sigma + \alpha) & \alpha (\sigma + \epsilon_K) \\ \pm & + & - \\ s_L (\sigma + \alpha) & \epsilon_L + s_K \sigma - s_L \alpha & \alpha (\sigma + \epsilon_L) \\ + & + & + \\ s_L (\sigma + \epsilon_K) & s_K (\sigma + \epsilon_L) & s_K \sigma \epsilon_K + s_L \sigma \epsilon_L + \epsilon_K \epsilon_L \end{bmatrix} \quad (12)$$

where $\Delta = \alpha(\sigma + s_L \epsilon_K + s_K \epsilon_L) - \sigma(s_L \epsilon_L + s_K \epsilon_K) - \epsilon_L \epsilon_K < 0$ because α is less than zero while all other parameters and shares are positive. The signs of each of the elements is given above them.

With a few further manipulations one can get Evenson's expression for the decomposition of the absolute wage rate changes.

$$W' = \frac{1}{\Delta} [(\sigma + \epsilon_K)(\alpha + 1)T' + s_K(\epsilon_K - \alpha)(A'_L - A'_K) - (\epsilon_K + \sigma)D^* + (\epsilon_K + s_L \sigma - s_K \alpha)L^* + s_K(\sigma + \alpha)K^*]. \quad (13)$$

Similar equations can be read off the inverse (12) for R' and P'_1 .

Note that the expression for W' is independent of the supply of elasticity of labor. However, what happens to labor income is not independent of its own supply elasticity. If M_L is equal to the wage rate multiplied by employment in the sector, then $M_L = WL$. Therefore, $M'_L = W' + L'$. Since $L' = \epsilon_L W' + L^*$ the change in labor income (in the absence of labor supply shifts) is

¹This derivation uses the relations $\sum_j \eta_{ij} = 0$; $\eta_{ij} = s_j \sigma_{ij}$ and, in the two factor case, $\eta_{KL} - \eta_{LL} = \sigma$; $\eta_{LK} - \eta_{KK} = \sigma$.

$$M'_L = (1 + \epsilon_L)W' . \quad (14)$$

Expression (14) simply means that the change in labor income is a multiple of the change in the wage rate, the multiple being the larger, the larger the elasticity of supply of labor and the shift in the labor supply curve. In situations where labor gains the gains will be larger, the larger the supply elasticity of labor. Conversely, any losses will also be larger, the larger is ϵ_L .

Equation (14) measures the income change in terms of nonagricultural commodities. Suppose, however, that we are interested in real income changes for individuals whose total expenditures are spent on agricultural and non-agricultural goods in the proportion μ_1 and μ_2 respectively. We should then deflate their income by a price deflator $\bar{P}' = \mu_1 P'_1 + \mu_2 P'_2$.¹ Since P'_2 is equal to zero this will reduce to $\bar{P}' = \mu_1 P'_1$. If we denote real income as M'_L / \bar{P}' , its change can be computed as follows:

$$M'_L - \bar{P}' = (1 + \epsilon_L)W' - \mu_1 P'_1 . \quad (15)$$

The equation for P'_1 can be read from the matrix equation above in the same manner as the equation for W' .

The change in relative factor prices due to technical change alone can be evaluated from the following expression:

$$W' - R' = \frac{1}{\Delta} [(\epsilon_K - \epsilon_L)T' + (\epsilon_K - \alpha)A'_L - (\epsilon_L - \alpha)A'_K] . \quad (16)$$

For each factor the model can therefore be solved for the change in the nominal factor price, in total nominal factor income, in real income and in relative factor prices.

The equilibrium price of a factor in this model is affected as follows according to equations (13) and (16):

1. The sign of the pure effect of neutral technical change on the demand for, and the equilibrium price of each factor depends on whether

¹Such a price deflator can be computed separately for different income groups with weights depending on their consumption mix. This is another solution to the problem of computing the benefits from technical change to an agricultural producer who is also a consumer of the commodity, addressed by Hayami and Herdt (1976).

aggregate demand is inelastic or not. If aggregate demand is inelastic the impact of technical change is to reduce the demand for each factor.

2. The effect of a positive shift in aggregate demand is to increase the demand for both factors.
3. A positive shift in the supply function of labor (capital) will lower the equilibrium price of labor (capital).
4. A positive shift in the supply function of capital (through a World Bank subsidy program for example) will affect the labor market according to whether the elasticity of substitution (σ) exceeds the aggregate demand elasticity (α) or not. If $\sigma > |\alpha|$ the impact will be to reduce the demand for labor.
5. For any set of feasible parameter values, labor-saving technical change always tends to reduce the wage rate in terms of goods of the other sector (and employment) when compared with an equal neutral rate of technical change.
6. The relative position of labor as against capital--when both gain or both lose absolutely from technical change--depends on the elasticity of supply of the two factors. In situations of absolute gain for both factors, the factor in relatively inelastic supply will gain relative to the factor in elastic supply. Conversely, in situations of absolute loss due to technical change (inelastic demand for output) the inelastic factor will be the larger loser.
7. A large elasticity of substitution between factors acts as a buffer between them by reducing discrepancies in their relative price movements. (Because the absolute value of the determinant in (14) rises as σ rises.)

These are the comparative static effects of single change in exogenous variables. However, the biggest advantage of the equations (13) to (16) is that they allow the simultaneous consideration of changes in all exogenous variables, the rates of technical change as well as shifts in output demand due to population growth and the concurrent shift in labor supply or in capital supply, once one knows the relevant elasticities.

GENERAL EQUILIBRIUM MODELS

In moving to general equilibrium models, the forces which influence the distributional outcome change. Findlay and Grubert (1959) investigated the standard open economy model with two commodities and two factors (with infinitely elastic commodity demand). They found that, if neutral technical change occurs in one sector alone, the factor being used intensively in that sector will gain absolutely while the other factor will lose absolutely. This is because, given fixed factor endowments, a sector can obtain additional factors only by withdrawing them from the other sector. Technical change in, say, the labor intensive sector, shifts comparative advantage in its favor, and it expands by more than the additional output which could be produced by the factors saved through the technical change. But in releasing labor, the capital intensive sector has to release disproportionately large amounts of capital, which the labor intensive sector only needs in small quantities. In the aggregate the labor markets gets tighter while the capital market suffers from excess supply, pushing down the capital rental rates. Note that the conclusion that one factor loses absolutely while the other gains is totally contradictory to the partial equilibrium prediction which says that both factors either gain or lose together, with relative gains depending on factor supply elasticities.

However, general equilibrium trade theory does not lead us much farther: Kemp (1975) shows that when the open economy model is extended to many factors and many products, technical change in one sector will make at least one factor better off while making at least another one worse off. But we cannot say which factor gains and which one loses. Furthermore, in cases when international demand is not infinitely elastic and technical change is not neutral, trade theory cannot offer any guidance as to possible distributional consequences at all.

We nevertheless have to come to grips with the distributional problems of technical change and to understand why, and in which cases, partial and general equilibrium answers will differ. This can only be done by building general equilibrium models for which parameter values can be estimated empirically. The inability of trade theory to provide answers stems from the fact that it has been couched in generalized terms with no attempt to incorporate an empirical content which enables answers to be given under specific situations.

A SIMPLE TWO SECTOR MODEL

With Evenson's one sector model much insight can be gained if for one sector we know the nature of technical change, the demand conditions for its output and the supply conditions of its factors. One can also extend the model to consider consequences of technical changes in certain sectors or regions on other sectors if one knows the consequences of these technical changes for output demand and factor supply curves of the latter sectors. However, the model neglects general equilibrium effects such as the effect of technical change in one sector on the demand for output (and hence inputs) of other sectors via price and income effects. Similarly, any effects of a sectoral technical change on investment demand is neglected. It is impossible to evaluate these general equilibrium consequences without explicitly building a general equilibrium model. Neglecting general equilibrium implications is unimportant if a sector or region is very small, but may become unsatisfactory when we consider large sectors.

It is straightforward to extend the Evenson model using the cost function formulation. For extension to many factors we simply add the corresponding factor demand curves and for extending to more sectors we add the factor demand curves of the additional sectors. When the economy is open and the country (or region) is small, commodity prices are given from the outside. The addition of full employment and factor mobility conditions is thus sufficient to close the model. When the economy is closed or a substantial partner in international transactions of certain of its commodities, the demand side needs to be modeled explicitly.

For illustration purposes I will convert the two sector model of Yamaguchi and Binswanger (1975, YB model) into the cost function notation with biased technical change. Before that model is used empirically, however, I would rather like to extend it considerably farther along the lines suggested in the last section. However, we have parameter values from Japan for the YB model so it is convenient to use it for illustrative purposes.

The YB model contains a production function for agriculture (sector 1) and nonagriculture (sector 2). The agricultural production function contains land, labor, and capital while nonagricultural output is a function of capital and labor only. Rates of return to capital are assumed equal in both sectors,

but agricultural wage rates are taken to be lower than those in nonagriculture: migration will only occur if the nonagricultural wage exceeds the agricultural one by a certain fraction t :

$$\left. \begin{aligned} R_1 &= R_2 \\ W_1 &= tW_2 \end{aligned} \right\} \quad (17)$$

Note that $W_1' = t' + W_2'$. As long as the market distortion is constant, the rate of increase of agriculture's wage rates is equal to that of nonagriculture. Or if the rate of change of the distortion is known, the two wage rate changes are related in a one-to-one fashion. Hence we need not always keep track of both wage rates.

Land supply is exogenous, i.e.

$$Z' = Z^* \quad (18)$$

where Z^* is the exogenous rate of growth of land. Capital and labor grow at the exogenous rates K^* and L^* . For the small country case this leads to the following model in terms of rates of change:

$$\left. \begin{aligned} L_1' &= Y_1' + \eta_{LL}^1 W' + \eta_{LK}^1 R' + \eta_{LZ}^1 S' - A_L' + \eta_{LL}^1 t' \\ K_1' &= Y_1' + \eta_{KL}^1 W' + \eta_{KK}^1 R' + \eta_{KZ}^1 S' - A_K' + \eta_{KL}^1 t' \\ Z^* &= Y_1' + \eta_{ZL}^1 W' + \eta_{ZK}^1 R' + \eta_{ZZ}^1 S' - A_Z' + \eta_{ZL}^1 t' \\ L_2' &= Y_2' + \eta_{LL}^2 W' + \eta_{LK}^2 R' - B_L' \\ K_2' &= Y_2' + \eta_{KL}^2 W' + \eta_{KK}^2 R' - B_K' \\ 0 &= P_1' = s_L^1 W' + s_K^1 R' + s_Z^1 S' - T_1' + s_L^1 t' \\ 0 &= P_2' = s_L^2 W' + s_K^2 R' + s_Z^2 S' - T_2' \end{aligned} \right\} \quad (19)$$

where B_K' and B_L' are the factoral rates of technical change in the nonagricultural sector and S is the land rent. The model is given in matrix notation in Table 1 where the open economy model is the enclosed upper left 9×9 matrix

TABLE 1. THE OPEN AND THE CLOSED VERSION OF THE SIMPLE TWO SECTOR MODEL

L'_1	K'_1	Y'_1	L'_2	K'_2	Y'_2	W'	R'	S'	P'_1	P'_2	M'	Endogenous Variable	Exogenous Variable
-1	0	1	0	0	0	$s_L^1 - 1$	s_K^1	s_Z^1	0	0	0	L'_1	$A'_1 - (s_L^1 - 1)t'$
0	-1	1	0	0	0	s_L^1	$s_K^1 - 1$	s_Z^1	0	0	0	K'_L	$A'_2 - s_L^1 t'$
0	0	1	0	0	0	s_L^1	s_K^1	$s_Z^1 - 1$	0	0	0	Y'_1	$A'_3 + Z^* - s_L^1 t'$
0	0	0	-1	0	1	$-s_K^2$	s_K^2	0	0	0	0	L'_2	B'_1
0	0	0	0	-1	1	s_L^2	$-s_L^2$	0	0	0	0	K'_2	B'_2
λ_1	0	0	λ_2	0	0	0	0	0	0	0	0	Y'_2	L^*
0	ξ_1	0	0	ξ_2	0	0	0	0	0	0	0	W'	K^*
0	0	0	0	0	0	s_L^1	s_K^1	s_Z^1	-1	0	0	R'	$s_L^1 A'_L + s_K^1 A'_K + s_Z^1 A'_Z + s_L^1 t'$
0	0	0	0	0	0	s_L^2	s_K^2	0	0	-1	0	S'	$s_L^2 B'_L + s_K^2 B'_K$
0	0	1	0	0	0	0	0	0	$-\alpha_{11}$	$-\alpha_{12}$	$-\alpha_{1M}$	P'_1	$N^* + D^*_1$
0	0	0	0	0	1	0	0	0	$-\alpha_{21}$	$-\alpha_{22}$	$-\alpha_{2M}$	P'_2	$N^* + D^*_2$
0	0	μ_1	0	0	μ_2	0	0	0	0	0	0	M'	N^*

with the corresponding variables in the two column vectors.

For the closed economy equivalent we have to add a final demand structure as follows:

$$Y_i = N \cdot G^i(P_1, P_2, M) \quad (20)$$

where N is population and G^i is the per capita demand function for the i^{th} good which depends on the prices and per capita national product M . In terms of rates of changes this demand structure can be written as

$$\left. \begin{aligned} Y_1' &= N' + \alpha_{11}P_1' + \alpha_{12}P_2' + \alpha_{1M}M' + D_1^* \\ Y_2' &= N' + \alpha_{21}P_1' + \alpha_{22}P_2' + \alpha_{2M}M' + D_2^* \end{aligned} \right\} \quad (21)$$

where α_{ij} are the price elasticities and α_{iM} are the income elasticities.¹ Per capita product is defined as follows: $M = (P_1Y_1 + P_2Y_2)/N$. The rate of change of real per capita product is:

$$M' = \mu_1Y_1' + \mu_2Y_2' - N' \quad (22)$$

where μ_i are the income weights of commodity 1 and 2, which in the closed economy case are equal to expenditure weights.

Instead of using either of the goods as a numeraire equations (21) and (22) set $\bar{P}' = \mu_1P_1' + \mu_2P_2' = 0$, i.e. the change in the GNP deflator is set to zero. Thus all goods and factor price changes will be in real terms.

Note that in this model capital formation is exogenous, a simplification which should be dispensed in further applications. The general equilibrium effects considered are thus only those which operate via the demand structure and the input constraints of the economy as a whole.

¹The following constraints must be imposed on these elasticities to make them consistent with consumer demand theory:

$$\alpha_{iM} = -\sum_j \alpha_{ij} ; \quad \sum_i \mu_i \alpha_{iM} = 1 ; \quad -\mu_j = \sum_i \mu_i \alpha_{ij} \quad (21)$$

where μ_i are the shares of commodities in expenditures. This does not make the equations (21) and (22) singular because (22) relates to real income changes, i.e., the term $\mu_1P_1' + \mu_2P_2'$ has already been set equal to zero.

The closed economy model is summarized as the full matrix equation in Table 1. The closed and open form of the model have distinct advantages over the original YB model:

1. The model explicitly derives real factor rewards, including land rents, thus allowing a much richer distributional analysis.¹
2. Technical change can be biased as well as neutral.
3. The model can be parameterized for any kind of twice differential functional form of a cost function (and hence of a production function) since factor demand curves can always be derived from such a cost function.²
4. More sectors can be added without disturbing the basic framework of the model.

¹In this example the price deflators used are national income deflators. If one is interested in particular income groups with different deflators, their real income changes can be computed from data on the shares of income accruing to them from different factor services and from their consumption weights.

²In a production function approach only very simple functional forms will lead to closed form solutions for factor demand curves. Therefore the YB model has only been parameterized for Cobb-Douglas and CES functions, which are both quite restrictive. It would also be fairly straightforward to write a similar model for profit functions if the econometric specification of the corresponding factor demand and output supply curves were to demand this.

GROWTH RATE MULTIPLIERS FOR SELECTED PARAMETER VALUES

The parameter values used in the following pages are taken from Yamaguchi and Binswanger (1975) and are given in Table 2. The demand function parameters are based on estimates of agricultural demand elasticities reported by Kaneda (1968). The corresponding nonagricultural demand elasticities are derived by imposing the usual homogeneity constraint on output demand functions and are consistent with utility maximizing behavior. The income and output shares of the different sectors come from national income statistics as reported in the LTES (1966) studies.

Finally, the factor demand elasticities in the two sectors are derived by assuming that both cost functions (and hence production functions) are Cobb-Douglas and that the output elasticities correspond to expenditure shares of the factors.

Before commenting on the results I would like to introduce a major qualification of the data and hence of the results. The data used imply a much larger productivity of resources in the nonagricultural sector than the agricultural one. In 1880 agriculture produced 47 percent of national income but apparently used 75 percent of the labor force and 63 percent of the reproducible capital stock and the total amount of agricultural land. This implies that resources in this sector are only about half as productive as in the nonagricultural sector. In the appendix this problem is discussed. I have serious doubts about the correctness of the productivity picture implied in these figures (see also Nakamura (1966)). The productivity differential implies that any shift of resources from agriculture to the nonagricultural sector will drastically increase national product whereas shifts in the other direction will reduce it. Hence technical changes or endowment changes which result in relative expansion of the agricultural sector will result in less growth than otherwise similar changes which result in transfer of resources to the nonagricultural one. Some of the conclusions reported below are the result of the productivity differential and must be taken with caution.

Tables 3 to 5 represent growth rate multipliers for various years and various forms of technical change. These growth rate multipliers show how much the rate of change of the endogenous variables would change after an increase in the sectoral or overall rate of technical change. For example the entry of the first line and 5th column of Table 3 indicate that wage rates

TABLE 2. PARAMETER VALUES FOR STRUCTURAL PARAMETERS

Description of the Parameters	Notation Used	Year		
		1880	1930	1960
Income Elasticity of Agricultural Demand	α_{1M}	-.4	.35	.45
Income Elasticity of Nonagricultural Demand	α_{2M}	1.53	1.15	1.08
Price Elasticities of Demand	α_{11}	-.6	-.6	-.6
	α_{12}	.2	.25	.15
	α_{21}	-.35	-.09	-.06
	α_{22}	-1.18	-1.06	-1.02
Labor's Share in Agricultural Output	s_L^1	.58	.61	.57
Capital's Share in Agricultural Output	s_K^1	.12	.12	.13
Labor's Share in Nonagricultural Output	s_L^2	.7	.7	.75
Capital's Share in Nonagricultural Output	s_K^2	.3	.3	.25
Share of Income Produced by Agriculture	μ_1	.47	.19	.13
Share of Income Produced by Nonagriculture	μ_2	.53	.81	.87
Proportion of Labor in Agriculture	λ_1	.75	.47	.3
Proportion of Capital in Agriculture	ξ_2	.63	.16	.08

Source: Yamaguchi and Binswanger (1975).

TABLE 3. GROWTH RATE MULTIPLIERS FOR TECHNICAL CHANGES OCCURRING IN DIFFERENT SECTORS AND WITH DIFFERENT FACTOR SAVING CHARACTERISTICS (1880)

	Agri-cultural Labor L'_1	Agri-cultural Capital K'_1	Agri-cultural Output Y'_1	Nonagri-cultural Output Y'_2	Wage Rates W'	Capital Rent R'	Land Rent S'	Agri-cultural Price P'_1	Nonagri-cultural Price P'_2	Per Capita Product M'
<u>SMALL COUNTRY CASE</u>										
1. Neutral Sector 1	2.59	3.83	2.96	-7.39	0.37	-0.87	2.96			
2. Neutral Sector 2	-2.59	-3.83	-1.96	8.39	0.63	1.87	-1.96			
3. Neutral both Sectors	0	0	1	1	1	1	1			
4. Labor Savings Sector 1	1.75	3.23	2.41	-5.34	-0.07	0.17	3.41			
5. Labor Savings Sector 2	-2.34	-3.99	-1.84	7.96	0.50	2.16	-1.84			
6. Labor Savings both Sectors	-0.59	-0.76	0.57	2.62	0.43	2.33	1.57			
<u>CLOSED ECONOMY CASE</u>										
1. Neutral Sector 1	-0.29	-0.43	0.78	0.83	0.48	0.62	0.19	-0.59	0.52	0.80
2. Neutral Sector 2	-0.14	-0.21	-0.11	1.41	0.54	0.61	0.39	0.50	-0.44	0.70
3. Neutral both Sectors	-0.43	-0.64	0.67	2.24	1.02	1.23	0.58	-0.09	0.08	1.50
4. Labor Savings Sector 1	-0.48	-0.07	0.71	1.04	0.01	1.33	1.25	-0.46	0.40	0.89
5. Labor Savings Sector 2	-0.04	-0.59	-0.09	1.38	0.42	0.96	0.38	0.47	-0.41	0.69
6. Labor Savings both Sectors	-0.52	-0.66	0.62	2.42	0.43	2.29	1.63	0.01	-0.01	1.58

NOTE: Sector 1 = Agriculture; Sector 2 = Nonagriculture.

Each figure represents the change in the rate of growth of the variable listed on top of the table due to a one percent increase in the rate of technical change either in Sector 1, Sector 2 or both Sectors.

TABLE 4. GROWTH RATE MULTIPLIERS FOR TECHNICAL CHANGES OCCURRING IN DIFFERENT SECTORS AND WITH DIFFERENT FACTOR SAVING CHARACTERISTICS (1930)

	Agri- cultural Labor L'_1	Agri- cultural Capital K'_1	Agri- cultural Output Y'_1	Agri- cultural Output Y'_2	Wage Rates W'	Capital Rent R'	Land Rent S'	Agri- cultural Price P'_1	Agri- cultural Price P'_2	Per Capita Product M'
<u>SMALL COUNTRY CASE</u>										
1. Neutral Sector 1	2.66	4.22	3.13	-1.89	0.47	-1.09	3.13			
2. Neutral Sector 2	-2.66	-4.22	-2.13	2.89	0.53	2.09	-2.13			
3. Neutral both Sectors	0	0	1	1	1	1	1			
4. Labor Savings Sector 1	1.61	3.93	2.45	-1.22	0.20	-0.48	3.45			
5. Labor Savings Sector 2	-2.09	-4.51	-1.81	2.55	0.27	2.69	-1.81			
6. Labor Savings both Sectors	-0.48	-0.58	0.64	1.33	0.47	2.21	1.64			
<u>CLOSED ECONOMY CASE</u>										
1. Neutral Sector 1	-0.35	-0.55	0.72	0.25	0.15	0.35	-0.20	-0.92	0.21	0.34
2. Neutral Sector 2	-0.22	-0.34	-0.17	1.15	0.79	0.92	0.57	0.74	-0.17	0.90
3. Neutral both Sectors	-0.57	-0.89	0.55	1.40	0.94	1.27	0.37	-0.18	0.04	1.24
4. Labor Savings Sector 1	-0.68	0.29	0.62	0.41	-0.04	0.62	0.92	-0.70	0.16	0.45
5. Labor Savings Sector 2	0.02	-1.17	-0.13	1.06	0.49	1.68	0.51	0.64	-0.15	0.83
6. Labor Savings both Sectors	-0.66	-0.88	0.49	1.47	0.45	2.30	1.43	-0.06	0.01	1.28

NOTE: Sector 1 = Agriculture; Sector 2 = Nonagriculture.
Each figure represents the change in the rate of growth of the variable listed on top of the table due to a one percent increase in the rate of technical change either in Sector 1, Sector 2 or both Sectors.

TABLE 5. GROWTH RATE MULTIPLIERS FOR TECHNICAL CHANGES OCCURRING IN DIFFERENT SECTORS AND WITH DIFFERENT FACTOR SAVING CHARACTERISTICS (1960)

	Agri-cultural Labor L'_1	Agri-cultural Capital K'_1	Agri-cultural Output Y'_1	Agri-cultural Output Y'_2	Wage Rates W'	Capital Rent R'	Land Rent S'	Agri-cultural Price P'_1	Agri-cultural Price P'_2	Per Capita Product M'
<u>SMALL COUNTRY CASE</u>										
1. Neutral Sector 1	2.96	3.89	3.19	-1.04	0.23	-0.7	3.19			
2. Neutral Sector 2	-2.96	-3.89	-2.19	2.04	0.77	1.7	-2.19			
3. Neutral both Sectors	0	0	1	1	1	1	1			
4. Labor Savings Sector 1	1.45	3.52	2.29	-0.54	-0.08	-0.24	3.28			
5. Labor Savings Sector 2	-2.52	-4.54	-2.03	1.91	0.49	2.51	-2.03			
6. Labor Savings both Sectors	-1.07	-1.02	0.26	1.37	0.41	2.27	1.25			
<u>CLOSED ECONOMY CASE</u>										
1. Neutral Sector 1	-0.39	-0.52	0.71	0.14	0.12	0.24	-0.28	-0.98	0.15	0.21
2. Neutral Sector 2	-0.15	-0.19	-0.11	1.05	0.86	0.91	0.72	0.82	-0.12	0.90
3. Neutral both Sectors	-0.54	-0.71	0.60	1.19	0.98	1.15	0.44	-0.16	0.03	1.11
4. Labor Savings Sector 1	-0.87	0.47	0.56	0.27	0	0.41	0.88	-0.68	0.10	0.31
5. Labor Savings Sector 2	0.09	-1.11	-0.09	0.99	0.58	1.78	0.67	0.77	-0.12	0.85
6. Labor Savings both Sectors	-0.78	-0.64	0.47	1.26	0.58	2.19	1.55	0.09	-0.02	1.16

NOTE: Sector 1 = Agriculture; Sector 2 = Nonagriculture.

Each figure represents the change in the rate of growth of the variable listed on top of the table due to a one percent increase in the rate of technical change either in Sector 1, Sector 2 or both Sectors.

would grow at a faster rate by an additional 0.37 percentage points if the rate of neutral technical change in agriculture increased by one percentage point.

The first three rows represent neutral technical changes. Rows 4 to 6 correspond to labor-saving technical changes in which only the labor demand curve shifts whereas capital and land demand per unit of output remain unchanged.¹ The total rate of technical change remains at one percent, which implies that the labor rate of technical change must exceed one percent.²

Neutral Technical Change

The neutral technical change case is the basic reference case and is discussed first. The small country case (first panel of Tables 3 to 5) is the one which has received the most theoretical treatment in the trade literature. In the two-by-two model customarily employed by trade theorists technical change in one sector results in an absolute increase in the factor reward of the factor employed intensively in that sector. The reward of the factor used intensively in the other sector decreases absolutely. However, when more than two goods or two factors are involved one can no longer say which factor will gain or lose after a technical change without specifying parameter values of the production processes.³

Despite theoretical ambiguities it is quite clear that for the parameter values of Table 2 technical change in agriculture leads to the greatest gain for land, a modest gain for labor and a loss for capital. Conversely land, the factor not used in the nonagricultural sector, loses substantially when technical change occurs in the nonagricultural sector and capital, which is intensively used there, gains most. Labor again gains modestly and its gain is about equal for technical changes in both sectors. All this is quite in accordance with an intuitive extension of the well known 2 x 2 result. Note further that technical changes induce large shifts in the commodity mixes and in the uses of mobile factors in the two sectors.⁴

¹This is the orthogonal labor-saving case discussed in Chapter 4 and 5 of Binswanger and Ruttan (1978).

²The labor rate of technical change must be $A'_1 = 1/s_L^1$ or $B'_1 = 1/s_L^2$.

³See Kemp (1975). Trade theory has little to offer for the biased technical change case or for cases of less than perfectly elastic commodity demand.

⁴Note that the shifts in commodity mixes are so large that per capita income actually declines with agricultural technical change.

In comparison to the one sector model discussed previously one major difference emerges: Even with infinitely elastic demand for all commodities, neutral technical change in one sector can inflict absolute losses on one of the factors of production. This is not possible in the one sector model. The loss arises as follows: the shift in the commodity mix towards one sector increases all factor demands there but leads to a more than offsetting reduction in the factor demand in the other sector for all those factors which are not used intensively in the sectors where the technical change occurs. Since in developing countries agriculture is generally labor intensive relative to the other sectors of the economy we can, therefore, expect that rapid and neutral agricultural technical changes will usually not result in absolute losses for labor in small country cases. However, in such cases land owners will be the major gainers, and that is a conclusion which is fairly robust over different models.

In the closed economy case the situation of losers and gainers is drastically changed. Land now can gain when technical change occurs in the nonagricultural sector. Since final demand for agricultural commodities is price inelastic, we would expect all factors of production employed in agriculture to lose when agricultural technical change occurs. However, this is prevented via two general equilibrium loops:

First, the technical change in agriculture implies an income gain for the economy as a whole. This leads to an increase in the demand for both agricultural and nonagricultural commodities and hence to an increase in factor demand in both sectors. Second, agricultural technical change leads to a transfer of resources to the nonagricultural sector because of that sector's higher income and price elasticities. As discussed before, this also leads to an income gain due to the higher resource productivity in the nonagricultural sector and the income increase further stimulates demand for both commodities. This leads to an expanded demand for most factors of production.

In the partial equilibrium model the saving in factors of production made possible by the agricultural technical change cannot be offset by the increase in agricultural demand which occurs due to the relative price drop of agricultural commodities. However, the general equilibrium model implies that, if the demand for agricultural commodities is price and income inelastic, the demand for all other commodities must be elastic. The positive income

elasticity of agricultural commodities will tend to increase the agricultural demand beyond what it would have been if only partial equilibrium price effects were present. Furthermore, the income effect due to the technical change will stimulate an increase in the demand for nonagricultural commodities, which further helps to offset possible negative factor demand effects in agriculture. The high income elasticities of demand in other sectors to some extent offsets the low price elasticity of demand in agriculture. This is not to say that neutral technical change in agriculture could never lead to declines in incomes of mobile factors. Due to the positive resource transfer effects in this model the income effects of technical change are very large which, to some extent, may explain the absence of losses for owners of mobile factors.

Note also that, as the size of the agricultural sector declines over time, the effect of agricultural technical change on factor incomes declines as well as the effect on total income. This is simply caused by the fact that the technical change applies to a smaller and smaller sector of the economy.

In relative terms also the loss position of factors changes as compared to the small country case. The differentials in gains of different factors are not large, the only case with relatively large differences occur with land. Of course commodity mix shifts are much more moderate than in the small country case. Overall in the closed model all distributional and sectoral effects seem to be "buffered" compared with what they would be in the small country case or especially the single sector case.¹

Nonneutral Technical Change

Labor-saving technical change will always worsen the growth rate of labor incomes and improve the rewards of capitalists and landlords, compared to neutral technical change. This is regardless of the sector in which the labor-saving technical change occurs and regardless of whether the economy is open or closed. For example, in 1880 in the small country case, a one percent neutral rate of technical change in both sectors leads to a one percent growth rate in wage rates. If this technical change becomes labor-saving, the benefit of labor declines to 0.43 percent. In the closed economy the implications of overall labor-saving technical change are practically identical. In both

¹That the single sector case leads to the largest distributional shifts was ascertained by numerical experiments with the Evenson model.

the open and closed economy cases labor saving technical change in 1880 has more adverse implications for the wage rate if it occurs in the agricultural sector, which at that time employed 75 percent of the labor force. In 1960, however, 70 percent of the labor force are employed in the nonagricultural sector. Therefore, a one percent rate of labor-saving technical change reduces wage rates by more if it occurs in the nonagricultural sector than the agricultural one.

There is not much difference between partial and general equilibrium analysis and between the open and closed economy with respect to the factor price effects of nonneutral technical change. Any given gain accruing to a factor from neutral technical change is substantially reduced when technical change in either sector tends to save the particular factor. The only difference is that the relative losses and gains under neutral technical change are more extreme in partial than in general equilibrium analyses and more extreme in the open than the closed economy.

In a general equilibrium world technical change leads to less dramatic impacts on factor rewards if it occurs unequally in different sectors,¹ and the buffering is more efficient in the closed economy than in the small country case. However, when technical change affects factors unequally, the distributional implications are not buffered in this way. There is thus no room for taking labor-saving technical change lightly. Its distributional consequences can be dramatic. The Evenson model could be interpreted that under elastic demand conditions a subsidy on tractors might actually help labor because it enables a very large expansion in output. But this interpretation must be carefully qualified. The amount of capital which has to be withdrawn from the nonagricultural sector to enable the tractor investment in agriculture reduces output and employment in the nonagricultural sector. And that reduction affects the whole labor market negatively, even if tractors contribute to employment in agriculture.

One major general equilibrium effect has not been included. The rise in income should also increase savings and investment. And changes in capital rental rates should also affect investment. Building the investment into the model endogenously--making it a positive function of income M and a negative one of R --would have the following effects: Any technical change resulting in a relative increase in R will lead to additional investment and hence

¹ Technical change in a partial equilibrium model is restricted to the sector which is explicitly considered, hence it affects sectors unequally.

thus again cushioning the differential impact of the technical change on factor rewards. In particular in the case of a labor-saving technical change this feedback loop will indeed introduce a buffering effect. Similarly, any technical change resulting in income gains will increase investment, thus pushing down capital rental rates and pushing up wage rates. Hence dependence of investment on incomes should favor labor over and above its situation when capital formation is exogenous.

CONCLUSIONS

The first two parts of the paper were devoted to partial equilibrium models of a relatively simple structure and which seem to be quite consistent with observed trends in income distribution in India and other Asian developing countries such as the Philippines which accompanied the technical changes in agriculture. We then found that general equilibrium models are not only more complicated but also result in conclusions in terms of the factoral income distribution which differ qualitatively from those of the partial equilibrium models. In partial equilibrium models all factors in one sector or one region either gain or all lose, whereas in the general equilibrium world one factor will always lose and another one will always gain.

We should, however, be cautious not to discard entirely the partial equilibrium models because of possible contradictions: First, in the regional context where only some regions experience technical change, it is the partial equilibrium effects which will dominate within each of them. The impact of technical change in a limited number of regions on aggregate income and labor demand will not be sufficient to make the general equilibrium feedback loops the primary determinants of the distributional outcomes between factors of production in the gaining regions.

Second, in the illustration of the green revolution, the partial equilibrium model was applied only to land and labor, leaving out capital. In the two sector open economy models with capital, we concluded that land would be the primary beneficiary of agricultural technical change, followed by labor while capital would lose. This is consistent with the observations on the green revolution, as well as with the partial equilibrium predictions. (Of course, we do not really know what happened to the rate of return on capital nor does the partial equilibrium model include it.) Most Asian developing countries can probably be treated as open with respect to agriculture, since additional production usually substitutes for imports, so that the open economy model needs to be considered here.

Third, we must note that the basis of the general equilibrium mechanism for distribution among factors of production is the assumed fixity of factor endowments (or their growth) rates and their full employment. Also, easy transfer among sectors (or regions) of the economy is assumed. Where unemployment is

large and where sectoral and regional labor and capital transfers require considerable amounts of time, the partial equilibrium models will do better in predicting distributional outcomes for an intermediate run of say 5 to 10 years. But there is no doubt that even in economies with considerable slack and market imperfections the general equilibrium forces of endowments which grow at given rates will tend to dominate distributional outcomes in the very long run.

The question may not be so much of partial versus general equilibrium analysis. The choice will depend on the particular problem at hand, the size of the sectors or regions experiencing the technical change and the final demand conditions (including trade) of the commodities considered. If the choice is for partial equilibrium models, a full understanding of the differences which might arise from general equilibrium models will help avoid mistakes which could result from total neglect of the latter approach.

Finally, one lesson which comes clearly out of this modelling exercise is that one can only learn so much from history. Knowledge of the distributional impact of a past technical change such as the green revolution alone cannot help one predict what would happen if the same kind of technical change occurred elsewhere. The regionally regressive impact of the green revolution stems from its limitation to the already richer regions. If it had occurred in the disadvantaged areas, the regional distributive impact would, on the contrary, have been progressive. The limitation of the technical change to certain areas also accounts for the regressive impact among factors of production. If it had been more widespread, landlords might not have gained as much because they would have faced inelastic commodity demand. If export markets had prevented inelastic commodity demand, the effects on labor demand would have been more vigorous. In considering future technical changes one thus must know the characteristics of the technology, the characteristics of the region where it occurs, and the characteristics of the factor supply and output markets. This is a tall order.

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APPENDIX

PRODUCTIVITY DIFFERENTIAL BETWEEN AGRICULTURE AND NONAGRICULTURE IN JAPAN

We have seen in the text and Table 2 that the published LTES figures (Okhawa *et al.*, 1966) imply that in 1880 Agriculture used 75% of the labor force and 63% of the capital stock but produced only about 47% of national income. These figures imply a total factor productivity in the nonagricultural sector which is about two to three times the one in agriculture. This is difficult to believe. There may be serious errors in the LTES data.

In my Ph.D thesis (1973) I have added up the total value of output and the total value of inputs in 1936 prices of the agricultural sector of Japan according to LTES statistics. Inputs include primary inputs plus inputs purchased from the nonagricultural sector. Two expenditure and output series were constructed, one in which intermediate agricultural inputs were included in both the total input value and the output value series and one in which they were excluded.

The LTES agricultural output statistics were criticized by Nakamura (1966) who maintains that agricultural output at the beginning of Meiji Japan was much larger than that given in LTES. However, he believed that by 1920 the agricultural output statistics of LTES are correct. I thus took Nakamura's estimate of agricultural production and spliced it backwards into the real agricultural output series of LTES starting from the average of 1919 to 1921. This resulted in "Nakamura" real value of output, again computed both with and without agricultural intermediate inputs. I then computed the ratio of the value of agricultural inputs over the value of agricultural outputs for all four output series and the two total factor input series. The inclusion or exclusion of intermediate agricultural inputs did not make much difference. Therefore, I will discuss only the ratio where intermediate agricultural inputs were excluded.

By LTES statistics cost exceeded output in the 5 years 1890 to 1895 by 78%. This excess declined to 14% for the 5 years between 1958-62. Even using the Nakamura assumption about agricultural output still leads to an excess of costs over output value of 38% in 1881 to 1885, an excess which declines only after World War II to 18% in 1958-62.

It seems unlikely that a sector would continue to produce output for

a long time if costs of production exceed value of output by 50% or more. It is also clear that the LTES statistics are not simply wrong but have survived much scrutiny from many angles and Nakamura's rice yield adjustment seems to be excessive (see Hayami, 1975). What is more plausible is that the factors of production in agriculture, in particular labor, were also producing nonagricultural outputs, especially of the service kind. Many of these services, such as transportation, may not have entered national income accounts at all. Others may have been counted as nonagricultural outputs. If this hypothesis was true we would have to adjust the fraction of income produced in agriculture upwards and adjust downwards the fraction of labor engaged in agriculture.

Even if the statistics did reflect production of other than agricultural commodities by the factors assigned to agriculture, the productivity differential between the two sectors would probably not disappear completely. A certain amount of resource productivity differential is always assumed in economic models with dual structure. But how would this differential be maintained in the presence of factor mobility?

Two main possibilities exist: One is that the nonagricultural labor force is more highly qualified than the agricultural one, i.e. having more human capital or a different demographic mix. This could be built into our model by assuming that an agricultural laborer can only replace a k^{th} fraction of a nonagricultural one. A full employment condition could be written as

$$kL_1 + L_2 = L_N \quad (\text{A-1})$$

where L_N is the labor force adjusted to the quality of the nonagricultural labor force. The factor mobility condition would then become

$$\lambda_1 L'_1 + \lambda_2 L'_2 = L'_N - \lambda_1 k'$$

where the λ 's now are proportions of labor in the adjusted labor stock L .

If k and its changes could be estimated, this reason for productivity differences would not be too difficult to introduced into models.

However, this phenomenon cannot be the only reason for the observed

excess of the costs of production in agriculture over the outputs value. Surely such productivity differences in the labor force would be reflected in lower wage rates and hence lower costs of production, and could thus not contribute to such large cost excesses. The existence of a wage differential for equally efficient labor may be another mechanism by which a productivity differential between the sectors can be maintained. From most studies in developing countries it appears that the gains from migration far exceed migration costs, i.e. that a permanent differential between urban and rural wages exists. As long as the nonagricultural sector expands, the wage differential can persist simply because of lags in the migration process. But it could also persist due to higher costs of living in the nonagricultural sector. A third explanation could be that the nonagricultural labor force has less opportunities for self-provisioning type of home production and will want to be compensated for this by a higher wage rate. And finally, union power could push up wages in certain parts of the nonagricultural sector.

One can compute how much higher the average nonagricultural wage rate would have to be if the labor market imperfection were the only mechanisms by which the productivity differential between the sectors are maintained. The ratio of nonagricultural to agricultural wages necessary in 1880 is about 4 to 1, which is totally unrealistic and not supported at all by Japanese economic data. (See Okhawa *et al.*, 1966, Bank of Japan, 1966, Kelly and Williamson, 1974.) The mystery of the apparent factor productivity differential thus remains a puzzle which limits the usefulness of general equilibrium type models for the analyses of early Japanese economic history. Because such models do require very good data on sectoral allocation of factors of production and output and they also require the modeling of factor and goods markets behavior which is consistent with whatever productivity differentials remain after inputs and outputs have been measured correctly.

LIST OF SYMBOLS

- A' , B' : Factoral rates of technical change.
 C : Cost of production.
 D^* : Final demand shifters.
 E : Factor augmentation rates.
 K , K^* : Capital, capital supply shifter.
 L , L^* : Labor, labor supply shifter.
 M : Per capita product or income.
 M_L , M_K , M_Z : Labor, capital, land income.
 N : Population.
 P : Output prices.
 Q : Biases.
 R : Capital rental rate.
 S : Land rent.
 s_i^j : Share of factor i in product j .
 T' : Rates of technical change.
 W : Wage rates (or factor prices in general many factor case).
 Y : Outputs.
 Z : Quantity of land.
 α : Commodity demand elasticities.
 σ : Elasticity of substitution.
 ϵ : Factor supply elasticities.
 η : Factor demand elasticities.
 λ_i : Share of labor force in sector i .
 μ_i : Share of sector i in national product.
 ξ_i : Share of capital in sector i .