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Biased Technological Change and Factor Demand in Postwar Japanese Agriculture

by

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August 1986

1. Introduction

One of the most remarkable changes in Japanese agriculture since the late 1950s has been a drastic decline in labor and dramatic increases in machinery and intermediate inputs as seen in Figure 1. These changes in relative factor uses in agriculture have played important roles in the process of economic growth in not only agriculture but also nonagricultural sectors. For example, the decline in agricultural labor has increased the level of labor productivity in agriculture with a considerably high rate like about 6 percent per year since 1958. On the other hand, it has contributed to a significant degree through migration to the growth of the nonagricultural sectors.

Needless to say, the basic factor for changes in factor proportions is substitutions among factor inputs. However, several factors affect the substitution possibilities among factor inputs. They are (1) price-induced substitution along an isoquant, (2) biased technological change, (3) nonhomotheticity, and (4) changes in output mix.

Therefore, one may be wrong if he asserts, for example, by looking at the movements in the opposite directions of the levels of factor inputs and relative factor prices in Figures 1 and 2, respectively, that the changes in factor proportions during the 1958-84 period were caused only by price-induced substitutions among factor inputs. Such an assertion could be correct only if the production process of this period was characterized not only by Hicks neutral technological change but also by homotheticity. According to Figure 3, the labor cost share considerably reduced over the period 1958-84, while the cost shares of machinery, intermediate inputs, and land showed an increasing trend for the same period. This may indicate the existence of biased effects of technological change and/or nonhomotheticity in agricultural production during the period under question.

The objective of this study is then to gain a better understanding in the factor substitutions in postwar Japanese agriculture by shedding a special light on biased technological change in agricultural production. This objective is to be achieved first by measuring biases of technological change. Then, those biases are to be tested for the Hicksian(1963) induced-innovation hypothesis. In addition, a decomposition analysis will be carried out in order to quantitatively understand how important the biased effects of technological change was in determining changes in actual factor proportions and factor cost shares during the period 1958-84.

For this objective a slightly modified Stevenson(1980)-Greene(1983) model of the translog cost function is employed. This model has at least two important advantages over ordinary translog cost functions. First, it incorporates time into the model so that all coefficients of ordinary translog cost function would change over time, which is more realistic than in the case of ordinary translog cost function where it is assumed that all coefficients are constant for the period of estimation. Another attractive feature is that it enables us to test directly the induced-innovation hypothesis. This model will be estimated for the period 1958-84 by making use of farm level aggregate data.

2. Methodology

Empirical studies of biased technological change in agriculture have been accumulating in the literature in recent years. In particular, due mainly to the pioneering work by Hayami and Ruttan(1971) who have proposed an induced-innovation development model, empirical study in this area of research has been popular among Japanese agricultural economists: for example, Shintani and Hayami (1975), Le Thank Nghiep (1979), Kako (1979), Lee (1983), Kuroda (1985), and Kawagoe, Otsuka, and Hayami (1986) to name only a few. Shintani and Hayami (1975) applied a two-level multi-factor CES production function model with factor-augmentating technological change developed by K. Sato (1967) to pre- and post-war Japanese agriculture. A most recent work by Kawagoe, Otsuka, and Hayami (1986) who tested for the Hicksion induced innovation hypothesis for U.S. and Japanese agriculture for the period 1880-1980, is essentially on the same line as Shintani and Hayami (1975) in the sense that they employed a two-level CES production function with factor-augmenting technological change. The introduction of the two-level multi-factor CES production function implies, as is well-known, restrictive assumptions on the partial elasticities of substitution and the a priori arbitrary separability of factors of production. Take for example the partial elasticity of substitution of a pair of factor inputs. It must be equal to that of any other pair of factor inputs and these elasticities of substitution are constant over time or across firms. If these assumptions are not warranted in the real world, the estimated results will be biased.

On the other hand, Le Thanh Nghiep (1979), Kako (1979), and Kuroda (1985) employed the framework of the translog cost fucntion which is much more flexible than that of the CES production function in the sense that no restrictive assumptions are imposed a priori on the elasticities of substitutions among factor inputs. These studies are basically an application of the pioneering work by Binswanger (1974a) who developed a framework of multi-factor biased technological change based on the translog cost function model originally developed by Christensen, Jorgenson, and Lau (1973). The essential feature of this framework is that technological change biases are first estimated based on the parameter estimates of the translog cost function and, then, the induced-innovation hypothesis is tested by associating the estimated biases with changes in factor prices. Lee (1983), though estimated the translog production function instead of the translog cost function, followed essentially the same procedure as above.

Though attractive, the framework of the ordinary translog cost function for measuring technological change biases and testing for the induced-innovation hypothesis carries at least two disadvantages. First, it is assumed that all coefficients of the translog cost function are constant over time. This implies, for example, that the partial elasticities of substitution among factor inputs vary over time only with respect to the factor cost shares. It may be more realistic to relax this rather restrictive assumption so that the elasticities of substitution vary over time with respect to time as well as the factor cost shares. Second, as is clear in the two-step procedure proposed by Binswanger (1974a), it does not allow us to test for the induced-innovation hypothesis directly within the model. It may be more attractive to incorporate the induced-innovation hypothesis into the model . Jorgenson and Fraumeni (1981) developed a framework where the rate of technological change is treated endogenously, i.e., it is a function of relative factor prices and time. However, technological change biases are fixed in their model. In this sense, therefore, it cannot evaluate the validity of the induced-innovation hypothesis that technological change biases are functions of relative factor prices (Berndt and Wood, 1982).

Stevenson (1980) developed a truncated third-order translog cost function model by incorporating time into the model. Greene (1983) has proposed a substantially similar model to the Stevenson's by some rearrangements. Let us then designate this model as the Stevenson-Greene model. As will be clear in the following paragraphs, this Stevenson-Greene model overcomes the first shortcoming of the ordinary translog cost function approach by the incorporation of time variable. Furthermore, it allows us to specifically test for price-induced technological bias. Another feature of this model is that the estimated technological biases already reflect the biases induced by relative factor changes and/or scale change (if the production process is not homothetic). Because of these advantages, the Stevenson-Greene model is employed in the present study with a slight modification in the manner of introducing the time variable. Furthermore, the decomposition analyses of changes in actual factor cost shares and factor proportions can conveniently be formulated with this model.

Now, it is assumed that farms have the following production function which satisfies the usual regularity conditions,

$$(1)\quad Q = F(X_L, X_M, X_I, X_T, X_O, t)$$

where Q is output, X_L, X_M, X_I, X_T, and X_O refer to labor, machinery, intermediate inputs, land, and other inputs; and t is an index of time. Assuming that factor inputs prices (P_i) are determined exogenously and farms employ the cost-minimizing input mix (X_i^*) for any level of output, then there exists a cost function that is dual to the production function (Diewert, 1974).

$$(2)\quad C^* = G(Q, P_L, P_M, P_I, P_T, P_O, t)$$

where P_i's are the factor input prices and $C^* = \sum_{i=1}^{5} P_i X_i^*$ (i = L, M, I, T, O) is the minimized total cost.

Following Stevenson (1980) and Greene (1983), the following translog form of the cost function may be specified with a slight modification for econometric estimation.

$$(3)\quad \ell n\ C^* = \alpha^t + \alpha_Q^t\ \ell n\ Q + \sum_{i=1}^{5} \alpha_i^t\ \ell n\ P_i + \frac{1}{2}\gamma_{QQ}^t\ (\ell n\ Q)^2 + \frac{1}{2}\sum_{i=1}^{5}\sum_{j=1}^{5}\gamma_{ij}^t\ \ell n\ P_i\ \ell n\ P_j + \sum_{i=1}^{5}\delta_{Qi}^t\ \ell n\ Q\ \ell n\ P_i$$

$$i = j = L, M, I, T, O$$

where all the paramters are assumed to vary log-linearly with time according to

$$\alpha^t = \alpha + \alpha'\ \ell n\ t$$

$$\alpha_Q^t = \alpha_Q + \alpha_Q'\ \ell n\ t$$

$$(4)\quad \alpha_i^t = \alpha_i + \alpha_i'\ \ell n\ t$$

$$\gamma_{ij}^t = \gamma_{ij} + \gamma_{ij}'\ \ell n\ t$$

$$\gamma_{Qi}^t = \gamma_{Qi} + \gamma_{Qi}'\ \ell n\ t$$

$$i = L, M, T, I, O.$$

This specification allows a non-neutral effect of time on all of the coefficients of the translog cost function and hence all the characteristics of the production structure are assumed to vary with time. Stevenson and Greene originally assumed that the parameters vary linearly with time. This assumption may not be appropriate for fitting the model to a long time-series data, since, in such a case, the non-neutral time effect becomes unusually large in later periods of time. This is why the log-linear time effect is assumed in the present study.

The above-specified translog cost function is assumed to be twice-differentiable, so that the Hessian of this function with respect to the factor input prices is symmetric. This implies the symmetry restrictions: $\gamma_{ij} = \gamma_{ji}$ and $\gamma'_{ij} = \gamma'_{ji}$ for $i \neq j$ $(i, j = L, M, I, T, O)$.

By making use of the Shephard's (1953) duality theorem, the cost share equations can be derived as:

$$(5) \quad S_i = \alpha_i + \sum_{j=1}^{5} \gamma_{ij} \ln P_j + \delta_{Qi} \ln Q + \alpha'_i \ln t + \sum_{j=1}^{5} \gamma'_{ij} \ln t \ln P_j + \delta'_{Qi} \ln t \ln Q$$

where $$S_i = \frac{\partial C^*}{\partial P_i} \frac{P_i}{C^*} = \frac{\partial \ln C^*}{\partial \ln P_i},$$

$$i = j = L, M, I, T, O.$$

Any sensible cost function must be homogenous of degree one in factor input prices. This requires the following restrictions on parameters of the translog cost function (3).

$$(6) \quad \begin{array}{ll} \sum_{i=1}^{5} \alpha_i = 1 & \sum_{i=1}^{5} \alpha'_i = 0 \\ \sum_{i=1}^{5} \gamma_{ij} = \sum_{j=1}^{5} \gamma_{ij} = 0 & \sum_{i=1}^{5} \gamma'_{ij} = \sum_{j=1}^{5} \gamma'_{ij} = 0 \\ \sum_{i=1}^{5} \gamma_{Qi} = 0 & \sum_{i=1}^{5} \gamma'_{Qi} = 0 \end{array}$$

$$i = j = L, M, I, T, O.$$

Essentially, the same set of restrictions follows from the adding-up requirement of the factor cost shares.

Technological change biases in the Hicksian sense can conveniently be defined in terms of factor cost shares (Binswanger, 1974a). The technological change bias with respect to the i-th factor input can be expressed in the present framework as

$$(7)\quad \frac{\partial S_i}{\partial \ln t} = \alpha'_i + \sum_{j=1}^{5} \gamma'_{ij} \ln P_j + \delta'_{Qi} \ln Q.$$

$$i = j = L, M, I, T, O.$$

As is clear in this expression, technological change biases are a function of relative factor prices and output level. This allows one to test for the induced-innovation hypothesis by examining the extent to which the technological change bias is induced by relative factor price changes, i.e.,

$$(8)\quad \frac{\partial^2 S_i}{\partial \ln t\, \partial \ln P_j} = \gamma'_{ij}$$

where we expect $\gamma'_{ij} > 0$ for $i \neq j$ and $\gamma'_{ij} < 0$ for $i = j$ $(i, j = L, M, I, T, O)$.

Moreover, equation (7) allows one to compute factor-price- and scale-induced technological change bias for each observation, so that one can easily calculate the cumulated technological change biases.

$$(9)\quad B^*_{it} = S_{i0} + \sum_t dS^*_{it} \qquad i = L, M, I, T, O,$$

where B^*_{it} is the cumulative technological change bias of the i-th factor input in time t; S_{i0} is the cost share in the initial time period; $dS^*_{it} = \partial S_i/\partial t$ which is immediately obtained by equation (7).

Next, in order to measure the relative magnitude of the effects of biased technological change on changes in the cost structure and factor proportions, a decomposition analysis can conveniently be introduced. First, the change in the factor cost share of the i-th factor input over time can be decomposed as (Greene, 1983, pp.125-126),

$$(10)\quad \frac{dS_i}{dt} = \frac{\partial S_i}{\partial \ln Q}\frac{d \ln Q}{dt} + \sum_{j=1}^{5}\frac{\partial S_i}{\partial \ln P_j}\frac{d \ln P_j}{dt} + \frac{\partial S_i}{\partial t}$$

which can be rewritten in the translog cost function model of this study as,

$$(11)\quad \frac{dS_i}{dt} = \frac{\epsilon_{CQ}}{\partial \ell n\, P_i}\, G(Q) + S_i\left[\sum_{j=1}^{5} e_{ij} G(P_j) + \left\{G(P_i) - \sum_{j=1}^{5} S_j G(P_j)\right\}\right] + dS^*_{it}$$

$$i,\ j = L,\ M,\ I,\ T,\ O$$

where ϵ_{CQ} is the cost-output elasticity defined as

$$(12)\quad \epsilon_{CQ} = \frac{\partial\ \ell n\ C^*}{\partial\ \ell n\ Q} = \alpha^t_Q + \gamma^t_{QQ}\ \ell n\ Q + \sum_{i=1}^{5} \delta^t_{Qi}\ \ell n\ Q$$

$$i = L,\ M,\ I,\ T,\ O$$

which offers information on returns to scale. The e_{ij}'s are the own- and cross-price elasticities of demand for the i-th factor input which are defined by Allen (1938) as,

$$(13)\quad e_{ij} = S_j\, \sigma_{ij}\ , \qquad i,\ j = L,\ M,\ I,\ T,\ O$$

where the σ_{ij}'s are the Allen partial elasticities of substitution (AES) which can be given with the translog cost function of this study as (Binswanger, 1974b),

$$(14)\quad \sigma_{ii} = \frac{\gamma^t_{ii} + S_i - S_i^2}{S_i^2}\ , \qquad i = L,\ M,\ I,\ T,\ O$$

$$(15)\quad \sigma_{ij} = \frac{\gamma^t_{ij} + S_i S_j}{S_i S_j}\ , \qquad i \neq j,\ i,\ j = L,\ M,\ I,\ T,\ O.$$

Second, the decomposition analysis of changes in factor proportions can be carried out as follows. To begin with, write the cost-minimizing demand for the i-th factor input as,

$$(16)\quad X^*_i = X^*_i(Q,\ P_L,\ P_M,\ P_I,\ P_T,\ P_O,\ t).$$

By differentiating (16) totally with respect to time, dividing both sides by X^*_i, and expressing the growth rate by $G(\cdot)$, we obtain,

$$(17)\quad G(X_i^*) = \frac{\partial \ln X_i^*}{\partial \ln Q} G(Q) + \sum_{k=1}^{5} \frac{\partial \ln X_i^*}{\partial \ln P_k} G(P_k) + \frac{\partial \ln X_i^*}{\partial t}$$

or, noting that $S_i = P_i X_i^*/C$,

$$(18)\quad G(X_i^*) = \left[\frac{\partial \ln C^*}{\partial \ln Q} + \frac{\partial \ln S_i}{\partial \ln Q}\right] G(Q) + \sum_{k=1}^{5} \frac{\partial \ln X_i^*}{\partial \ln P_k} G(P_k) + \left[\frac{\partial \ln C^*}{\partial t} + \frac{\partial \ln S_i}{\partial t}\right]^{1/}$$

which can be rewritten in the translog cost function framework,

$$(19)\quad G(X_i^*) = \left[\epsilon_{CQ} + \frac{\delta_{Qi}^t}{S_i}\right] G(Q) + \sum_{k=1}^{5} e_{ik} G(P_k) + \left[\frac{\partial \ln C^*}{\partial t} + \frac{dS_{it}^*}{S_i}\right]$$

$$i = k = L,\ M,\ I,\ T,\ O.$$

Equation (19) says that the rate of growth of demand for the i-th factor input can be decomposed into three effects: the scale effect, the total substitution effect, and technological change effect given respectively by the first, second, and third terms of the right hand side.

A change in relative factor use is given by the change in the factor proportion as, $G(X_i^*/X_j^*) = G(X_i^*) - G(X_j^*)$, which reduces to, in terms of the translog cost function of this study,

$$(20)\quad G(X_i^*) - G(X_j^*) = \left[\frac{\delta_{Qi}^t}{S_i} G(Q) - \frac{\delta_{Qj}^t}{S_j} G(Q)\right] + \left[\sum_{k=1}^{5} e_{ik} G(P_k) - \sum_{k=1}^{5} e_{jk} G(P_k)\right] + \left[\frac{dS_{it}^*}{S_i} - \frac{dS_{jt}^*}{S_j}\right].$$

That is, a change in the factor proportion can be decomposed into the scale effect, total substitution effect, and technological change effect. Note, however, that the last term of the right hand side of equation (20) catches the effect only of biased technological change. Note further that the first term of the right hand side of equation (20) measures the effect of non-homotheticity. This term will vanish if the production process is characterized by homotheticity, since in such a case the cost function can be written as $\ell n\ C^* = \ell n\ h(Q) + \ell n\ g(P,t)$ and hence $\delta^t_{Qi} = 0$ for all i (= L, M, I, T, O).

3. Statistical Method

For statistical specification we assume an additive error with zero expectations and finite variance for each of the six equations of the model given in equations (3) and (5). The convariance of the errors of any two equations is permitted to be nonzero for the same farm. However, the covariances of the errors of any two equations corresponding to different farms are assumed to be identically zero. Given this specification of errors, Zellner's (1962) method provides an asymptotically efficient estimators. Moreover, the efficiency of estimation can be increased by imposing known restrictions on the coefficients in the equations.

We impose a priori the symmetry restrictions[2/] and the linear homogeneity (equivalently the adding-up) restrictions given in (6) on the translog cost function (3) and on the cost share equations. This allows us to exclude arbitrarily any one equation from the five cost share equations. The cost share equation of other inputs was then omitted. The estimates of the coefficients of this equation can easily obtained by making use of the parameter relationships of the linear homogeneity restrictions after the system is estimated.

The set of final estimating equations are as follows.

$$(21)\quad \ell n\ C^* = \alpha^t_0 + \alpha^t_Q\ \ell n\ Q + \sum_{i=1}^{4} \alpha^t_i\ \ell n\ P_i/P_0 + \frac{1}{2}\ \gamma^t_{QQ}(\ell n\ Q)^2$$

$$+\frac{1}{2}\sum_{i=1}^{4}\sum_{j=1}^{4}\gamma_{ij}^{t}\ \ln P_i/P_0\ \ln P_j/P_0+\sum_{i=1}^{4}\delta_{Qi}^{t}\ \ln Q\ \ln P_i/P_0+u_C$$

$$(22)\quad S_i=\alpha_i^t+\delta_{Qi}^{t}\ \ln Q+\sum_{i=1}^{4}\gamma_{ij}^{t}\ \ln P_i/P_0\ \ln P_j/P_0+u_i$$

$$i = j = L, M, I, T$$

where u_C and u_i (i = L, M, I, T) are random disturbance terms with zero means. These five equations will be estimated jointly by the Iterative Seemingly Unrelated Regression (ISUR) method. This method is an improved version of Zellner's (1962) efficient estimation procedure by which, unless the procedure is iterated, the estimates are sensitive to which share equation is excluded (Oberhofer and Kmenta, 1974).

4. Data

The data required for the estimation of the model is the total cost, the quantity of output, and the prices and cost shares of the five factor inputs; labor, machinery, feed and livestock, fertilizers and agrichemicals, and structures and land. The major sources of data used to process these variables are the Survey Report on Farm Household Economy (FHE) and the Survey Report on Prices and Wages in Rural Villages (PWRV) published annually by the Ministry of Agriculture, Forestry, and Fisheries. In each year of the 1958-84 period one average farm was taken from each of the four size classes, 0.5-1.0, 1.0-1.5, 1.5-2.0, and 2.0 hectares and over, from all Japan excluded Hokkaido district because of the different size classification. Thus, the sample size is $27 \times 4 = 108$. Unfortunately, we had to give up to obtain the data for the average farm in the smallest size class with 0.5 hectares and less because of changes in the size classification during the sample period. Since the share of the number of farm in this stratum in the total number of farms has been as large as around 40 percent, it should be noted that exclusion of farms in this size class may cause some bias in the estimated parameters.

Now, the quantity and price indexes of output (Q and P_A) were computed by following Törnqvist approximation method of the Divisia index[3]. For this computation eleven different categories of farm products were distinguished for crop and livestock products. The base year of these (and the following) indexes is 1952.

The quantity and price indexes of machinery (X_M and P_M), intermediate inputs (X_I and P_I), and other inputs (X_O and P_O) were also constructed by the Törnqvist method. In these computations, the cost of machinery (P_MX_M) was defined as the sum of the costs for machinery, energy, and rentals; the cost of intermediate inputs (P_IX_I) as the sum of the expenditures on fertilizer, feed, agri-chemicals, materials, clothes, and others; and the cost of other inputs (P_OX_O) as the sum of the expenditures on animals, plants, and farm buildings and structures. The necessary data were taken from the FHE. In addition, the price data necessary for computing the Törnqvist indexes were obtained from the PWRV.

The quantity of labor (X_L) was defined as the total number of male-equivalent labor hours of operators, family, and hired workers. The number of male-equivalent labor hours by female workers was estimated by multiplying the number of female labor hours by the ratio of female daily wage rate to male wage rate which can be obtained annualy from the PWRV. The price of labor (P_L) was obtained by dividing the wage bill for temporary hired labor by the number of male-equivalent labor hours of temporary hired labor. The labor cost (P_LX_L) was defined as the sum of the labor cost for operator and family workers imputed by P_L and the wage bill for hired labor.

The quantity of land (X_T) was defined as the total area of arable land. The price of land (P_T) was obtained by dividing the cost for rented land by the rented land area. The land cost ($P_T X_T$) was estimated by multiplying P_T by X_T.

Finally, the total cost (C) was defined as the sum of the expenditures on these five categories of factor inputs, i.e., $C = \sum_{i=1}^{5} P_i X_i$ (i = L, M, I, T, O). The cost share (S_i) was obtained by dividing the expenditure on each category of factor inputs ($P_i X_i$) by the total cost (C).

5. Empirical Results

The translog cost function (21) and the four cost share functions (22) were estimated first by ordinary least squares method in order to see the goodness of fit. The R^2's adjusted for degrees of freedom were 0.997, 0.952, 0.869, 0.584, and 0.923 respectively for the translog cost function, and the labor, machinery, intermediate inputs, and land cost share equations, indicating a fairly good fit of the model.

Next, in the process of the estimation by the ISUR method, a number of hypotheses concerning the production technology were statistically tested. They are (1) homotheticity (H_0: $\delta_{Qi} = \delta'_{Qi} = 0, \forall i$), (2) Cobb-Douglas Production functional form (H_0: $\gamma_{QQ} = \gamma'_{QQ} = \gamma_{ij} = \gamma'_{ij} = \delta_{Qi} = \delta'_{Qi} = 0, \forall i,j$), (3) Hicks neutrality (H_0: $\alpha'_Q = \alpha'_i = \gamma'_{QQ} = \gamma'_{ij} = \delta'_{Qi} = 0, \forall i,j$), (4) no price-induced factor cost share bias (H_0: $\gamma'_{ij} = 0, \forall i,j$), and (5) no scale-induced factor cost share bias (H_0: $\delta'_{Qi}, \forall i$)[4/]. A F-test procedure was applied to all the tests. As a result, all the null hypotheses were strongly rejected at either the one percent or five percent level of statistical significance. This result indicates that changes in scale affect factor cost shares and that technological change is not neutral in the Hicksian sense. Moreover, it indicates that biased technological change is induced by changes in relative factor prices and output level.

Thus, no restrictions other than the symmetry and linear homogeneity were imposed in estimating the system of the five equations. However, in this step of restricted estimation, a t-test was applied to each coefficient, and the variables with the coefficients not being significant at the ten percent level were omitted from the system of the five equations in the second step of restricted estimation. The result is presented in Table 1. This set of estimates is referred to as the final specification of the model and will be used for further analyses.

In order for the empirical results to be economically meaningful, monotonicity and concavity of the cost function must be satisfied. The fitted cost function is thus checked for these regularity conditions at each observation. Monotonicity in prices is satisfied if the estimated cost shares S_i's are positive. Concavity is satisfied if the Hessian of the translog cost function is negative semi-definite. All the five cost shares estimated were positive and the Hessian was negative semi-definite at each observation. This implies that the translog cost function represented by the estimated parameters in Table 1 is well-behaved within the region of the sample observation.

Demand Elasticities and Elasticities of Substitution

By making use of equations (13), (14), and (15), the price elasticities of demand for and the Allen partial elasticities of substitution among factor inputs were calculated for each observation based on the estimates of the translog cost function given in Table 1. Only own-price elasticities and the Allen partial elasticities of substitution for selected years are presented in Table 2. Several point are noteworthy.

First, the absolute values of the own-price elasticities for all the factor inputs except for other inputs were found to be much smaller than unity, indicating that the demand for these factor inputs are very inelastic. This finding is consistent with those by Kako (1978) and Kuroda (1985), although their estimates are slightly larger than ours in absolute values.

Second, the AES between labor and machinery was found to be much smaller than unity, indicating that labor and machinery have not been good substitutes. However, the decreasing trend of the value of the AES from about 0.5-0.6 in the early 1960s to 0.1-0.2 in the 1970s and 1980s suggests a change in production technology. Farm mechanization in the 1950s through the mid 1960s proceeded with a rapid increase in smaller scale machinery represented by hand-driven cultivators which were substituted for labor with a relative ease. However, mechanization since the late 1960s has been characterized by an increase in larger-scale machinery such as riding-type tractors and rice-transplanters whose substitutability with labor has been considerably limited.

Finally, the AES's were in general found to be smaller than unity during the sample period. This indicates that price-induced factor substitutions along an isoquant hyperplane may not have been dominant in determining shifts in factor demands during the period under question.

Biases of Technological Change

In order to examine the direction and speed of bias, the cumulative technological change bias was computed for each factor input for the 1958-84 period by making use of equation (9). This series of bias were then transformed into the index by dividing the series by the 1958 value of each factor cost share i.e., $B^*_{it}/S_{i,1958}$ (i = L, M, I, T, O). The computed indexes of technological change biases are shown in Figures 4a through e. These indexes are an appropriate measure of the extent to which a factor input increased over time relative to the other factor inputs due to biased technological change. However, it may not be an appropriate measure, if one wants to compare the absolute effects of biased technological change on the cost structure of agricultural production. For this purpose, it is more appropriate to employ the absolute change between the cumulative series of technological bias and the factor cost share in the initial time period, i.e., $B^*_{it}-S_{i,1958}$, rather than $B^*_{it}/S_{i,1958}$. This measure indicates the cumulative change in the factor cost share due to biased technological change from the base year up to year t (Kawagoe, Otsuka, and Hayami, 1986, p.540). Figure 5 presents this cumulative change in the factor cost share for each factor input for the period 1958-84.

It was found in Figures 4a through e that technological change during the 1958-84 was biased towards saving labor and other inputs and using machinery, intermediate inputs, and land. These directions of biased technological change basically agree with those found by Kako (1979) and Kawagoe, et al. (1986). However, there is a sharp difference in the machinery-using bias between the present study and the study by Kawagoe, et al. The machinery-using bias in this study was found to be very sharp from 1958 up to around 1970. However, after that period, technological change seems to have turned out to be machinery-neutral or even machinery-saving though slight. This finding is very similar to Binswanger's (1974a) for U.S. agriculture which shows machinery-neutral or saving bias after the mid-1950s. On the other hand, Kawagoe, et al. (1986) have shown that machinery-using bias after around 1970 was even sharper than the previous years. This sharp contrast between the two studies might have come from the difference in the models employed (CES production function by Kawagoe, et al. versus the translog cost function with time varying parameters in this study) and from the data, especially, the price data used. As for the latter point, a further discussion will be made in later paragraphs when the induced-innovation hypothesis is tested.

The cumulative changes in the factor cost shares due to these technological change biases shown in Figure 5 indicate that the absolute decrease in the cost share of labor and the increase in that of the intermediate inputs were substantial, more than 30 percent in both cases, while machinery and land increased their shares around 6 to 8 percent during the 1958-84 period. The substantial intermediate-inputs-using bias in both relative and absolute senses might have been caused by a drastic increase in livestock production which required an increased use of feed imported cheaply from abroad.

Test of Induced-Innovation Hypothesis

Let us now proceed to test for the induced-innovation hypothesis originally proposed by Hicks (1963). The basic idea of the induced-innovation hypothesis is that biases in technological change will depend on relative factor prices. As the relative factor prices change, technological change will be biased to save the factor that has become relatively more expensive.

To test this hypothesis, therefore, the measured biases are related to the relative factor movements, and thus the correlation of factor-saving biases to rising factor prices and vise versa is inspected. As mentioned in section two, the test for this hypothesis can immediately be carried out through equation (8). If $\gamma'_{ii} < 0$ and γ'_{ij} $(i \neq j) > 0$, it may be said that the induced-innovation hypothesis is valid. This can be checked by the estimates of the factor-share bias equations given in Table 3.

According to Table 3, γ'_{ii} are all positive except for other inputs. Moreover, many of the γ'_{ij}'s are negative. This result suggests that the induced-innovation hypothesis is not valid.

We argue however that this result may not deny the validity of the induced-innovation hypothesis for two reasons. First, the method used here is to investigate the correlations only between the individual estimates of the annual series of the technological change bias of the factor input and factor prices. It may be more appropriate to relate the cumulative bias ($B^*_{it} = S_{i0} + \sum_t dS^*_{it}$) to the movements of factor prices as employed by Binswanger (1974), Kako (1979), Lee (1983), and Kawagoe, et al. (1986). Second, the concept of the Hicksian induced-innovation hypothesis mentioned so far implicitly assumes that the historical innovation possibility is neutral. However, the innovation possibility curve, which is the envelope of all unit isoquants, may shift in a nonneutral manner (Ahmad, 1966 and Kennedy, 1964). If, for example, it is comparatively easier to develop technology that will save relatively more of a single factor, say labor, one could say that the innovation possibility function is biased in a labor-saving or capital-using direction. Thus, biasedness of technological change need not be intimately associated with factor price changes.

We now return to Figures 4a through e. In these figures, the indexes of factor prices relative to the Törnqvist(1936)-approximated Divisia index of total factor inputs are drawn. We can carry out in these figures a casual examination of the correlation between the cumulative factor share bias of technological change and the movement of the factor price for each factor input. First, in the case of labor input, the increasing trend of the relative price of labor is associated negatively with the labor-saving bias of technological change. On the contrary, the intermediate-inputs-using bias is associated with the declining trend of the relative factor price of intermediate inputs. Thus, one may conclude in these cases that the Hicksian induced-innovation hypothesis is valid.

Next, the machinery-using bias up to around 1970 appears to be correlated to the decreasing trend of the relative price of machinery input. The neutral- or even slightly saving-bias after around 1970 seems also to be associated with the rising trend of the relative machinery price. In this sense, one may say that the Hicksian induced-innovation hypothesis is valid, though a little weakly.

As mentioned earlier, the finding in this study that the bias in the machinery factor share was almost neutral or even slightly saving offers a sharp contrast with that by Kawagoe, et al. (1986) who found a strong machinery-using bias after (as well as before) 1970. This difference may have come from the differences both in the models used and in the definitions of the price of machinery input. Since the different characteristics of the models were already discussed in section two, only the difference in the definitions of the machinery price will be discussed here. The machinery price used by Kawagoe, et al. is defined as an average value of tractors per horsepower at a retail level adjusted for quality change in tractors. On the other hand, the machinery price employed in this study was defined as the Törnqvist-aggregated index of the index of the depreciation cost of machinery capital per machinery hour and the price indexes of energy and rentals. The latter reflects in a sense changes in the cost structure of the machinery inputs. Due to these differences in the definitions, the machinery price by Kawagoe, et al. shows a decreasing trend, while that in this study has an increasing trend after around 1971. We may thus infer, judging from this difference in tme movement of machinery price, that the former study found a strong machinery-using bias, while the latter found a machinery-neutral or saving bias after 1970. A further research need to be done on this point.

Finally, it is found in Figures 4d and e that land-using technological change bias appears to be related to the increasing land price[5], while the other-inputs-saving bias appears to be associated with the decreasing price of other inputs. These findings seem to violate the Hicksian induced-innovation theory. Nevertheless, two arguments are possible for these findings to be consistent with the induced-innovation hypothesis. First, we may argue that innovation possibilities must have been biased towards land-using and other-inputs-saving regardless of the role of factor prices in determining biases. Indeed, the innovation possibility curve might have shifted in particular in the land-using direction considering the fact that farm mechanization in general requires larger scale land area for the efficient utilization of machinery. Another argument is that the parallel movement of the land price and the land-using bias in particular may imply that the land price (defined as the rent per unit of land) has been largely endogenous, suggesting that technological change bias must have been an important factor which affected the movement of land price during the period under question.

Decomposition Analyses of Changes in Factor Cost Shares and Factor Proportions

Thus far we have investigated the directions of biases of technological change. We will now turn to the examination of the magnitudes of the effects of biased technological change on changes in the cost structure and on changes in factor proportions. For this purpose, changes in actual cost shares and factor proportions were respectively decomposed into the scale effect, the total factor substitution effect, and the biased technological change effect by making use of equations (11) and (20). In these computations, the biased technological change effect was calculated as a residual by subtracting the sum of the first two effects from the rate of change in each factor cost share or a factor proportion. This calculation was carried out for all the factor proportions (ten altogether) for a number of subperiods. However, in order to save space, only the results for the whole period 1958-84 and, in the case of the factor proportions, only those with respect to labor input are reported in Table 4 and 5. But, the findings based on the estimates for the subperiods are in general very similar to the one for the whole period.

According to the estimates in Table 4, more than 98 percent of the changes in the actual cost shares of all the factor inputs except for other inputs was found to be explained by the biased technological change. In the case of other inputs also, the contribution of the biased technological change to the change in their cost share was found to be fairly large, i.e., 77 percent. We may thus conclude that changes in the actual factor cost shares were almost completely caused by the biased technological change in Japanese agriculture during the period 1958-84.

We will next investigate changes in the labor-related factor proportions in Table 5. As was already excepted from the estimates of the AES among the factor inputs given in Table 3 many of which were found to be less than unity, the contribution of the total substitution effect was in general found to be fairly small in determining the changes in factor proportions with respect to labor. The major contributor was found to be biased technological change. In particular, in the case of the change in the labor-machinery ratio, 66 percent of the average annual rate of change in this ratio (-10.4 percent) was found to be explained by the effect of labor-saving and machinery-using technological change, and only 26 percent of this rate was found to be due to the total price-induced substitution effect along an isoquant. In the case of the labor-intermediate inputs ratio, the contribution of the total substitution effect was found to be fairly large, 47 percent which was almost as large as that of the biased technological change effect, i.e., 50 percent. In the case of the labor-land ratio, the effect of biased technological change in the labor-saving and land-using directions was found to be the dominant factor in determining the change in the ratio as indicated by the value as high as 71 percent. However, it is noteworthy in this case that the contribution of the scale effect was found to be fairly large, i.e., 31 percent. As seen in equation (11), this effect is due to nonhomotheticity of the production process. Thus, this suggests that estimation of models with homotheticity assumption would mislead the derived conclusion in this sort of analysis.

We do not have much to talk about the case of the labor-other inputs ratio since other inputs in this study are a conglomerate of all kinds of factor inputs with different characteristics such as buildings and structures, animals, and plants. They were introduced in the analysis to obtain a full coverage of costs. Systematic behavior of any individual component of "other" inputs is likely to be obscured in the conglomerate. One point clear here is that the large contribution of the total substitution effect (87 percent) must have been due to its very large AES's with labor and machinery as shown in Table 2.

6. Summary and Conclusion

The findings of this study may be summarized as follows.

(1) Technological change in postwar Japanese agriculture has been strongly biased towards labor-saving and machinery-, intermediate-inputs-, and land-using. This biased technological change was found to be in principle consistent with the induced innovation hypothesis. However, the parallel movements of land price and land-using bias may have partly been due to the endogeneity of land price. That is, the peculiar upswing of farm land price may be attributed partly to the significant land-using bias of technological change.

(2) Changes in the cost structure through changes in factor cost shares were found to be almost completely due to biased technological change.

(3) The drastic changes in labor-related factor proportions in postwar Japanese agriculture have been attributed largely to the biased effects of technological change. Price-induced substitution effects along an isoquant have contributed rather small part to the determination of the changes in labor-related factor proportions.

The results of our analysis imply that technological change in postwar Japanese agriculture has in general proceeded in a manner consistent with the factor endowments conditions. An implication of this study for agriculture in less developed countries will be that agricultural development policies through technological progress should be performed so as to take advantages of the factor endowments conditions in the individual countries.

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Footnotes

[1] We are implicitly assuming that each factor price is not a function of either the level of output or technological change at the farm level.

[2] The imposition of the symmetry restrictions implies that the assumption of cost minimization is maintained. Instead, one may explicitly test this maintained hypothesis of cost-minimizing behavior as a statistical hypothesis (Christensen, Jorgenson, and Lau, 1973).

[3] Refer to Binswanger (1974b) for details of the computation by the Törnqvist approximation method.

[4] Refer to Stevenson (1980) for details.

[5] Lee (1983) has obtained a similar result.

Table 1. Parameter Estimates of the Translog Cost Function

α	5.735*	γ_{MO}	-0.117	γ'_{II}	0
α_Q	0.950*	γ_{IT}	0.032 **	γ'_{TT}	0.029*
α_L	0.650*	γ_{IO}	-0.022	γ'_{OO}	-0.019
α_M	0.066*	γ_{TO}	-0.010	γ'_{LM}	-0.039*
α_I	0.150*	δ_{QL}	-0.056*	γ'_{LI}	0.044*
α_T	0.052*	δ_{QM}	0.065*	γ'_{LT}	0
α_O	0.082	δ_{QI}	0	γ'_{LO}	-0.028
γ_{QQ}	-0.351*	δ_{QT}	0.030*	γ'_{MI}	-0.029*
γ_{LL}	0.058**	δ_{QO}	-0.039	γ'_{MT}	-0.013*
γ_{MM}	0.082	α'	-0.102*	γ'_{MO}	0.045
γ_{II}	0.109*	α'_Q	0	γ'_{IT}	-0.017*
γ_{TT}	0	α'_L	-0.083*	γ'_{IO}	0.002
γ_{OO}	0.060	α'_M	0.024*	γ'_{TO}	0.0003
γ_{LM}	0.056*	α'_I	0.069*	δ'_{QL}	0
γ_{LI}	-0.154*	α'_T	0	δ'_{QM}	-0.016*
γ_{LT}	-0.049*	α'_O	-0.010	δ'_{QI}	0
γ_{LO}	0.089	γ'_{QQ}	0.091*	δ'_{QT}	0
γ_{MI}	0.035**	γ'_{LL}	0.023*	δ'_{QO}	0.016
γ_{MT}	0.027**	γ'_{MM}	0.036*		

Notes: 1) * and ** indicate that the coefficients are statistically significant at the 5 and 10 percent levels, respectively.

2) Parameters with zero coefficients are due to the result that they were not statistically significant at the 10 percent level in the first step of restricted estimation.

3) Coefficients with no asterisk were obtained by making use of parameter restrictions of the linear homogeneity.

Table 2. Own-Price Demand Elasticiteis and Allen Partial Elasticities of Substitution, 1958-84 (Selected Years)

	Own-Price Elasticities			
	1960	1970	1980	1984
e_{LL}	-0.291	-0.271	-0.264	-0.263
e_{MM}	-0.498	-0.160	-0.109	-0.128
e_{II}	-0.288	-0.334	-0.341	-0.341
e_{TT}	-0.373	-0.112	-0.122	-0.160
e_{OO}	-0.408	-0.766	-0.901	-0.937

	Allen Partial Elasticities of Substitution			
	1960	1970	1980	1984
σ_{LM}	0.619	0.199	0.108	0.114
σ_{LI}	0.147	0.702	0.884	0.932
σ_{LT}	-0.570	-0.073	0.059	0.103
σ_{LO}	2.363	1.439	1.042	0.901
σ_{MI}	1.145	-0.057	-0.130	-0.064
σ_{MT}	3.388	0.558	0.316	0.364
σ_{MO}	-8.061	0.706	2.925	3.222
σ_{IT}	2.111	0.594	0.471	0.494
σ_{IO}	-0.171	0.246	0.320	0.383
σ_{TO}	-1.271	-0.217	-0.004	0.151

Note: Equations (13), (14), and (15) were used for the computations.

Table 3. Estimates of Factor-Share Bias Equations

	constant	$\ell n\ P_L$	$\ell n\ P_M$	$\ell n\ P_I$	$\ell n\ P_T$	$\ell n\ P_O$	$\ell n\ Q$
$\partial S_L/\partial\ \ell n\ t$	-0.083	0.023	-0.039	0.044	0	-0.028	0
$\partial S_M/\partial\ \ell n\ t$	0.024	-0.039	0.036	-0.029	-0.013	0.045	-0.016
$\partial S_I/\partial\ \ell n\ t$	0.069	0.044	-0.029	0	-0.017	0.002	0
$\partial S_T/\partial\ \ell n\ t$	0	0	-0.013	-0.017	0.029	0.0003	0
$\partial S_O/\partial\ \ell n\ t$	-0.010	-0.028	0.045	0.002	0.0003	-0.019	0.016

Source: Table 1.

Table 4. Decomposition Analysis of Changes in Actual Factor Cost Shares, 1958-84

(Unit: %)

Factor input	Change in factor share	Scale effect	Total Substitution effect	Biased technological change effect
Labor	-20.47 (100.0)	-0.13 (0.6)	0.55 (-2.7)	-20.89 (102.0)
Machinery	8.12 (100.0)	0.06 (0.8)	0.10 (1.2)	7.96 (98.0)
Intermediate inputs	3.65 (100.0)	0 (0)	-0.53 (-14.4)	4.18 (114.4)
Land	8.09 (100.0)	0.07 (0.9)	0.09 (1.1)	7.93 (98.0)
Other inputs	0.61 (100.0)	0.00 (0.00)	0.14 (23.0)	0.47 (77.0)

Note: Equation (11) was used for the computation.

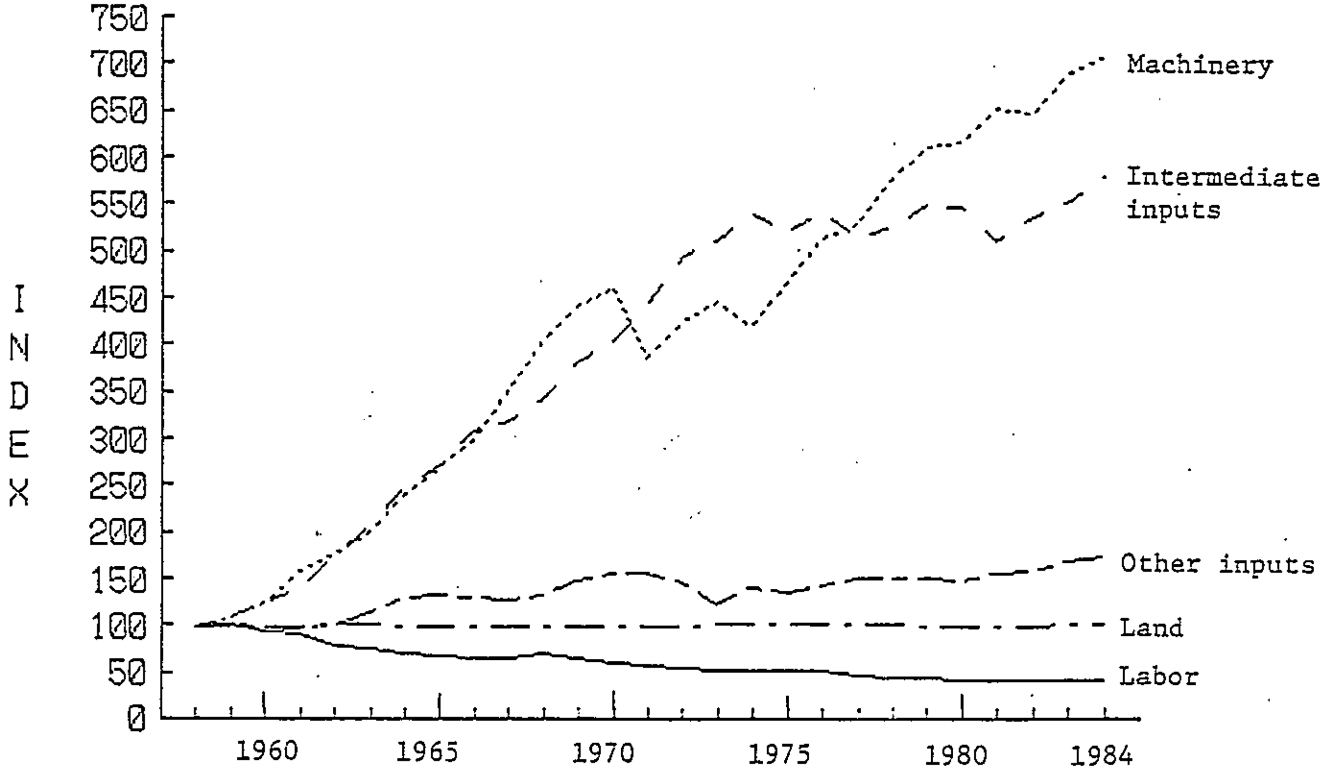
Table 5. Decomposition Analysis of Annual Rate of Changes in Factor Proportions with Respect to Labor, 1958-84

(Unit: %)

Factor proportion	Annual rate of change in factor proportion	Scale effect	Total substitution effect	Biased technological change effect
Labor/Machinery	-10.43 (100.0)	-0.81 (7.7)	-2.75 (26.4)	-6.88 (65.9)
Labor/Intermediate inputs	-9.93 (100.0)	-0.28 (2.8)	-4.70 (47.4)	-4.95 (49.9)
Labor/Land	-3.51 (100.0)	-1.08 (30.9)	0.07 (-2.1)	-2.50 (71.2)
Labor/Other inputs	-5.39 (100.0)	-0.28 (5.2)	-4.68 (86.9)	-0.43 (7.9)

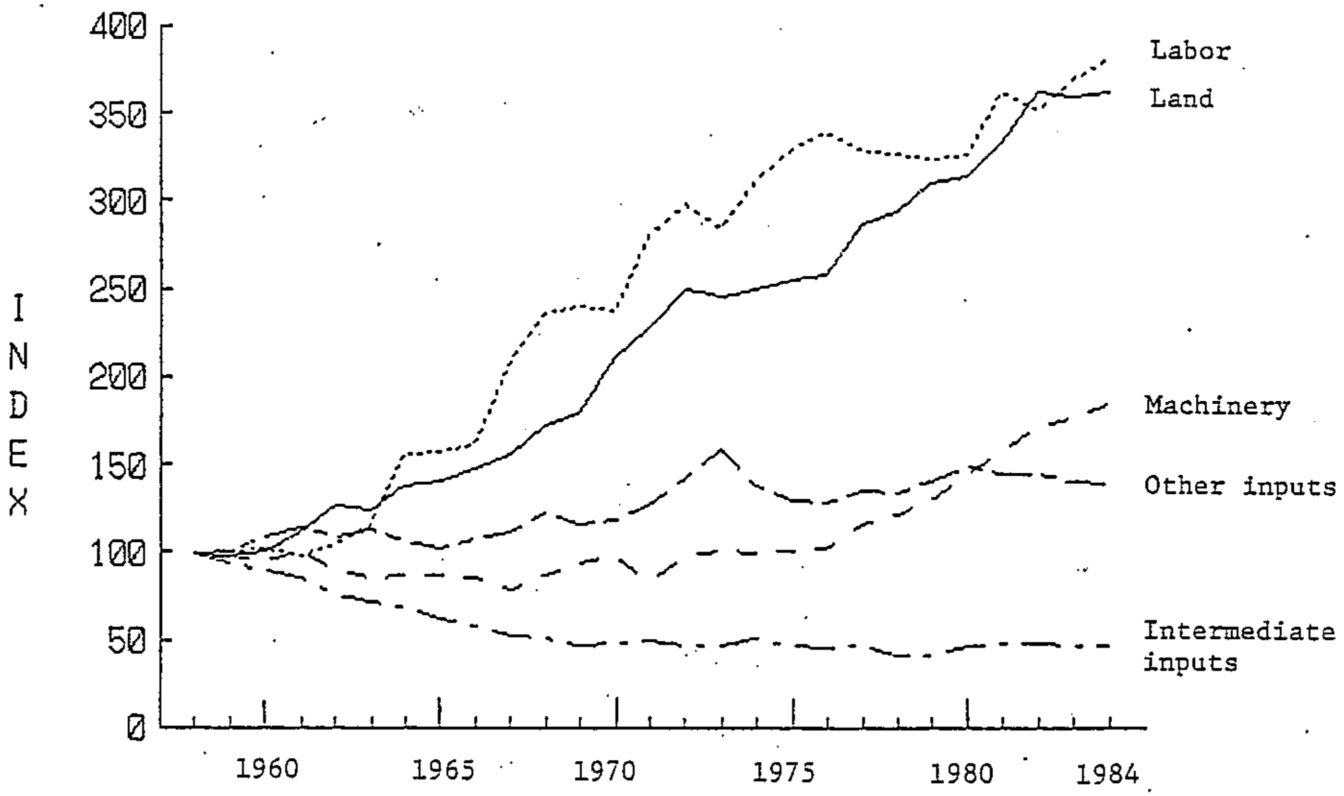
Note: Equation (20) was used for the computation.

Figure 1. Indexes of Factor Inputs



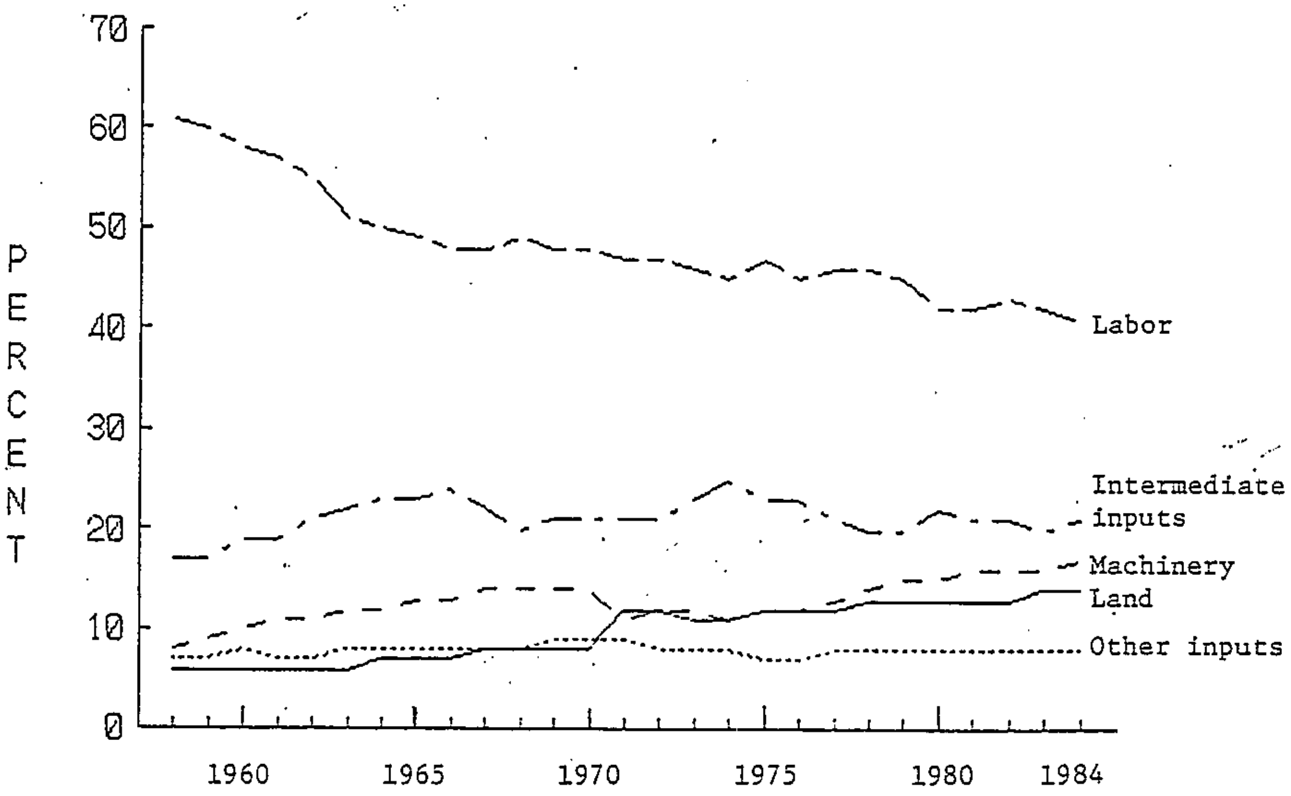
Note: Each factor input is a weighted average index where the weights are the shares of the numbers of farm households of the four size classes, 0.5-1.0, 1.0-1.5, 1.5-2.0, and 2.0 hectares and over, in the total number of farm households of these size classes. For details of computation of factor inputs, refer to section four.

Figure 2. Indexes of Relative Factor Prices



Note: Each factor price is a weighted average index where the weights are the shares of the numbers of farm households of the four size classes, 0.5–1.0, 1.0–1.5, 1.5–2.0, and 2.0 hectares and over, in the total number of farm households of these size classes. It is then deflated by output price index. For details of computation of prices, refer to section four.

Figure 3. Changes in Factor Cost Shares



Note: Each factor cost share is a weighted average share where the weights are the shares of the numbers of farm households of the four size classes, 0.5-1.0, 1.0-1.5, 1.5-2.0, and 2.0 hectares and over, in the total number of farm households of these size classes. For details of computation of factor shares, refer to section four.

Figure 4. Indexes of Measured Bias of Technological Change and Factor Price Indexes Relative to the Divisia Aggregated Input price Index

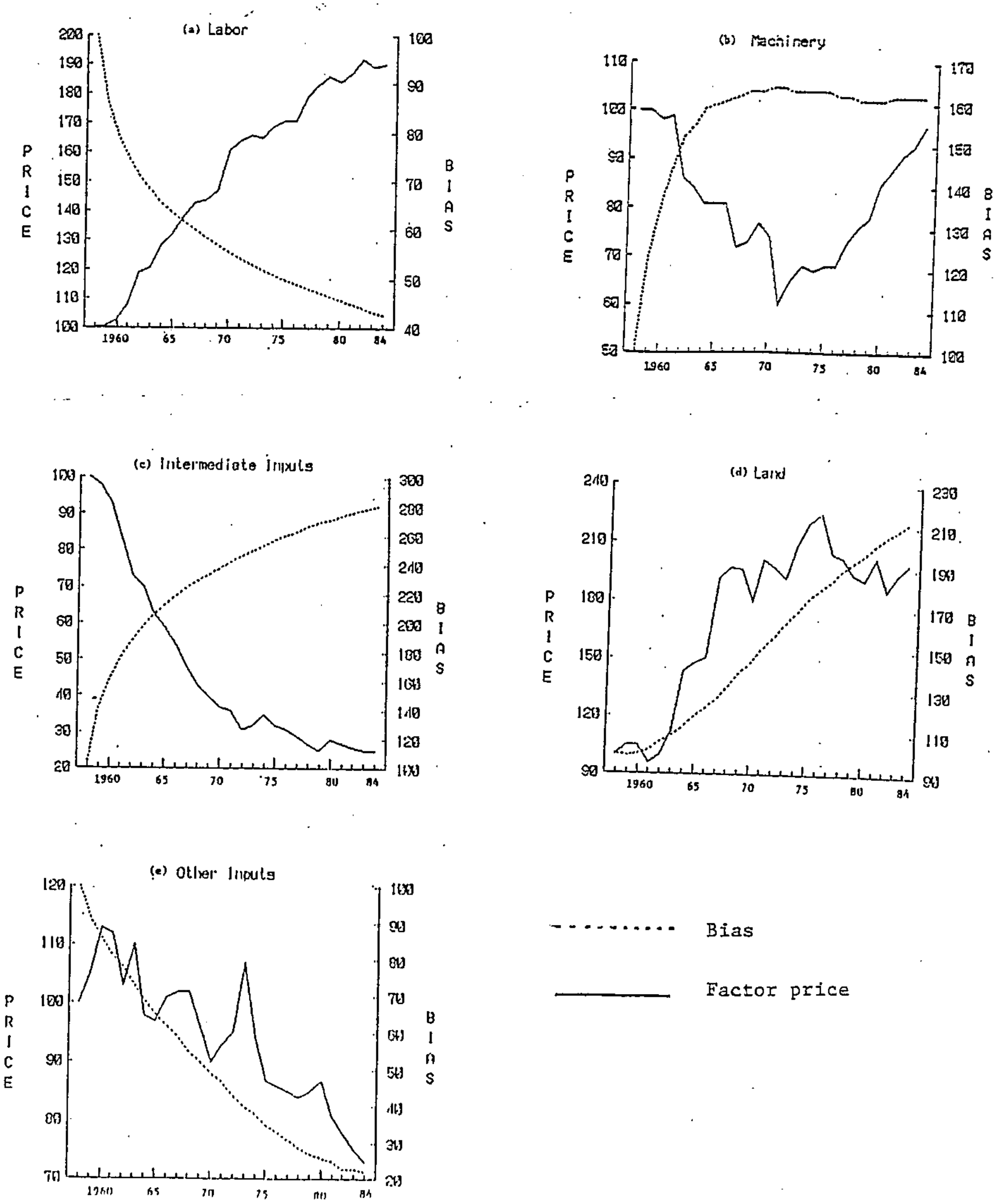


Figure 5. Cumulated Changes in Factor Cost Shares due to Biased Technological Change