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Biased Technological Change and Factor Demand in Postwar Japanese Agriculture, 1958–84

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(Accepted 18 November 1987)

Abstract

Kuroda, Y., 1988. Biased technological change and factor demand in postwar Japanese agriculture, 1958–84. *Agric. Econ.*, 2: 101–122.

The objective of this study is to gain a better understanding of factor substitutions in postwar Japanese agriculture by shedding special light on biased technological change. Such biased technological change is first measured, then associated with the movements of factor prices, and then tested for the Hicksian induced-innovation hypothesis. In addition, a decomposition analysis is carried out in order to quantitatively examine the importance of the biased effects for determining changes in factor-cost shares and factor proportions during the 1958–84 period.

A slightly modified Stevenson–Greene 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 such that all coefficients of the ordinary translog cost function may change over time. This is more realistic than the ordinary translog cost function which assumes that all coefficients are constant over the period of estimation. Another attractive feature is that it enables us to test the induced-innovation hypothesis directly. The model is applied to the 1958–84 period by making use of farm-level data.

The results show that technological change was biased towards saving labor and other inputs and using machinery, intermediate inputs, and land. This biased technological change is found to be, in principle, consistent with the induced-innovation hypothesis. Furthermore, it is shown through decomposition analyses that the biased technological change had significant impacts on changes in factor-cost shares and factor proportions during these years.

The empirical results of this study imply that technological change in Japanese agriculture has, in general, proceeded in a manner consistent with factor endowments conditions since the late 1950s. An implication of this study for agriculture in less-developed countries is that agricultural policies seeking development through technological progress should be carried out so as to take advantage of peculiar factor endowments conditions in the individual countries.

1. Introduction

One of the most remarkable changes in Japanese agriculture since the late 1950s has been a drastic decline in labor, with dramatic increases in machinery and intermediate inputs, as seen in Fig. 1. These changes in relative factor uses in agriculture have played important roles in the process of economic growth, not only in agriculture but also in the non-agricultural sectors. In agriculture, the decline in labor has increased the level of labor productivity at a considerably high rate of about 6% per year since 1958. At the same time, migratory inflow has also contributed significantly to the growth of the non-agricultural sectors.

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

Therefore, one may be wrong to assert, for example, that by looking at the opposing movement in the levels of factor inputs and relative factor prices from Figs. 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 would be correct only if the production process for this period is characterized both by Hicks (1963) neutral technological change and by homotheticity. According to Fig. 3, the labor cost share shrank considerably 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 non-homotheticity in agricultural production during the period in question.

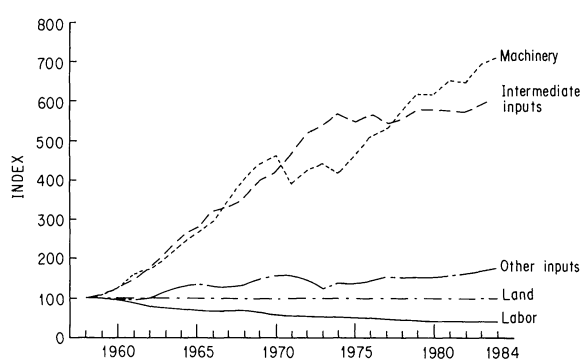


Fig. 1. Indices of factor inputs. Each factor input is a weighted average index where the weights are the shares of the numbers of farm households of the four size classes, 0.5–1.0, 1.0–1.5, 1.5–2.0, and 2.0 or over, in the total number of farm households of these size classes. For the details of computation of the indices of factor inputs, refer to Section 4.

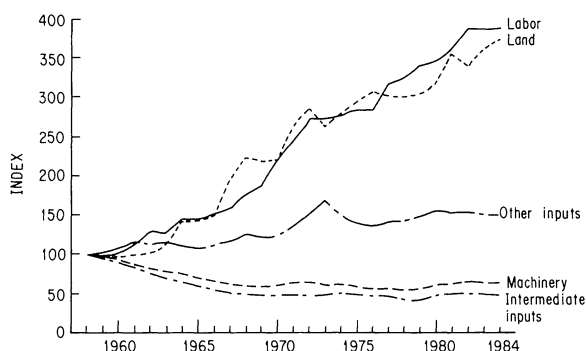


Fig. 2. Indices of relative factor prices. Each factor price is a weighted average index. The weights are the same as in Fig. 1. It is then deflated by output price index. For the details of computation of price indices, refer to Section 4.

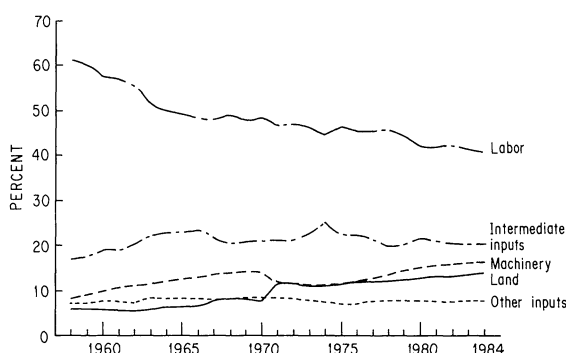


Fig. 3. Changes in factor cost shares. Each factor cost share is a weighted average share. The weights are the same as in Fig. 1. For the details of computation of factor cost shares, refer to Section 4.

The objective of this study, to gain a better understanding of factor substitutions in postwar Japanese agriculture, is to shed special light on biased technological change in agricultural production. This objective is to be achieved first by measuring biases of technological change and then testing for the Hicksian (1963) induced-innovation hypothesis. In addition, a decomposition analysis is carried out in order to quantitatively understand the importance of such biased effects of technological change 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 such that all coefficients of ordinary translog cost function may change over time. This is more realistic than in the case of the ordinary

translog cost function, where it is assumed that all coefficients are constant over the period of estimation. Another attractive feature is that it enables us to test the induced-innovation hypothesis directly. The model is estimated for the period 1958–84 by making use of aggregate farm 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), Kako (1979), Le Thanh Nghiep (1979), Lee (1983), Kawagoe et al. (1986) and Kuroda (1987). Shintani and Hayami (1975) applied a two-level multi-factor CES production function model with factor-augmenting technological change (developed by Sato, 1967) to pre- and postwar Japanese agriculture. A recent work by Kawagoe et al. (1986), who tested for the Hicksian induced-innovation hypothesis for U.S. and Japanese agriculture for the period 1880–1980, is essentially along the same lines as Shintani and Hayami (1975) in the sense that they employed a two-level CES production function with factor-augmenting technological change. As is well known, the introduction of the two-level multi-factor CES production function implies 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 held constant over time or across firms. If such assumptions are not warranted in the real world, the estimated results will be biased.

On the other hand, Kako (1979), Le Thanh Nghiep (1979) and Kuroda (1987) employ the framework of the translog cost function, 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 et al. (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) estimated the translog production function instead of the translog cost function, following essentially the same procedure as above.

Though attractive, the framework of using 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 both time and factor-cost shares. The second disadvantage, as is clear in the two-step procedure proposed by Binswanger (1974a), is that there is no allowance for testing the induced-innovation hypothesis directly within the model. Such a possibility may make the model more attractive. Jorgenson and Fraumeni (1981) developed a framework where the rate of technological change is treated endogenously, i.e., as a function of relative factor prices and time. However, technological change biases in their model are fixed. In this sense, therefore, we cannot evaluate the validity of the induced-innovation hypothesis, i.e. whether 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 Stevenson's with some rearrangement. 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 through incorporating the 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 changes in factor prices 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, though with a slight modification in the manner of introducing the time variable. 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:

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

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 input 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):

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

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), with a slight modification

for econometric estimation, the following translog form of the cost function may be specified:

$$\begin{aligned} \ln C^* = & \alpha^t + \alpha_Q^t \ln Q + \sum_{i=1}^5 \alpha_i^t \ln P_i + \frac{1}{2} \gamma_{QQ}^t (\ln Q)^2 + \frac{1}{2} \sum_{i=1}^5 \sum_{j=1}^5 \gamma_{ij}^t \ln P_i \ln P_j \\ & + \sum_{i=1}^5 \delta_{Qi}^t \ln Q \ln P_i \quad i=j=L, M, I, T, O \end{aligned} \quad (3)$$

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

$$\begin{aligned} \alpha^t &= \alpha + \alpha' \ln t \\ \alpha_Q^t &= \alpha_Q + \alpha'_Q \ln t \\ \alpha_i^t &= \alpha_i + \alpha'_i \ln t \\ \gamma_{QQ}^t &= \gamma_{QQ} + \gamma'_{QQ} \ln t \\ \gamma_{ij}^t &= \gamma_{ij} + \gamma'_{ij} \ln t \\ \delta_{Qi}^t &= \delta_{Qi} + \delta'_{Qi} \ln t \end{aligned} \quad i=L, M, I, T, O \quad (4)$$

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:

$$\gamma_{ij} = \gamma_{ji} \quad \text{and} \quad \gamma'_{ij} = \gamma'_{ji} \quad \text{for } i \neq j, \quad i, j = L, M, I, T, O$$

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

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

$$\text{where } S_i = \frac{\partial C^* P_i}{\partial P_i C^*} = \frac{\partial \ln C^*}{\partial \ln P_i} \quad i=j=L, M, I, T, O$$

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):

$$\begin{aligned}
 \sum_{i=1}^5 \alpha_i &= 1 & \sum_{i=1}^5 \alpha'_i &= 0 \\
 \sum_{i=1}^5 \gamma_{ij} &= \sum_{j=1}^5 \gamma_{ij} = 0 & \sum_{i=1}^5 \gamma'_{ij} &= \sum_{j=1}^5 \gamma'_{ij} = 0 & i=j=L, M, I, T, O \\
 \sum_{i=1}^5 \delta_{Qi} &= 0 & \sum_{i=1}^5 \delta'_{Qi} &= 0
 \end{aligned} \tag{6}$$

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:

$$\frac{\partial S_i}{\partial \ln t} = \alpha'_i + \sum_{j=1}^5 \gamma'_{ij} \ln P_j + \delta'_{Qi} \ln Q \quad i=j=L, M, I, T, O \tag{7}$$

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 (Stevenson, 1980, p. 166), i.e.

$$\frac{\partial^2 S_i}{\partial \ln t \partial \ln P_j} = \gamma'_{ij} \tag{8}$$

where we expect $\gamma'_{ij} > 0$ for $i \neq j$ and $\gamma'_{ij} < 0$ for $i = j$ ($i, j = L, M, I, T, O$). However, γ'_{ij} could be interpreted as examining the effects of simultaneous changes in technology and factor prices on factor-cost shares. If one follows faithfully the Hicksian induced-innovation hypothesis in that technological change biases are associated with factor price changes with certain time lags, this method may not be sufficiently appropriate for testing the hypothesis. Thus, we employ also the two-step procedure proposed by Binswanger (1974a) as follows.

One can immediately compute through equation (7) factor-price- and scale-induced technological change bias for each observation, so that one can easily calculate the cumulated technological change biases:

$$B_{it}^* = S_{i0} + \sum_t dS_{it}^* \quad i=L, M, I, T, O \tag{9}$$

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). These series of cumulated biases in technological change will be related to the historical movements of the corresponding factor prices.

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 (Greene, 1983, pp. 125–126), as:

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

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

$$\begin{aligned} \frac{dS_i}{dt} = & \frac{\partial \epsilon_{CQ}}{\partial \ln P_i} G(Q) + S_i \left[\sum_{j=1}^5 e_{ij} G(P_j) + \left\{ G(P_i) - \sum_{j=1}^5 S_j G(P_j) \right\} \right] \\ & + dS_{it}^* \quad i, j = L, M, I, T, O \end{aligned} \quad (11)$$

where $G(\cdot)$ expresses the growth rate and ϵ_{CQ} is the cost-output elasticity defined as:

$$\epsilon_{CQ} = \frac{\partial \ln C^*}{\partial \ln Q} = \alpha_Q^t + \gamma_{QQ}^t \ln Q + \sum_{i=1}^5 \delta_{Qi}^t \ln P_i \quad i = L, M, I, T, O \quad (12)$$

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

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

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

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

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

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:

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

Totally differentiating (16) with respect to time and dividing both sides by X_i^* , we obtain:

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

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

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

which can be rewritten in the translog cost function framework:

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

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, in terms of the translog cost function employed by this study, can be written as:

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

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) reflects solely

¹We are implicitly assuming that each factor price is not affected by the levels of either output or technology whose proxy is time (t). Specifically, a word needs to be mentioned about changes in t . The i th factor price P_i changes as time passes. That is, the total derivative of P_i with respect to time is not zero. However, this only means that P_i appears to have changed as time passes, but in fact that P_i has changed due to changes to demand and supply conditions of factor inputs. In this study, P_i is exogenous and t is treated as a proxy for technology levels. Thus, it is assumed that, under the assumption that variables other than t are held constant, changes in t do not affect P_i . That is, the partial derivative of P_i with respect to t is zero.

the effect of biased technological change. Further, the first term of the right hand side of equation (20) measures the effect of nonhomotheticity. This term will vanish if the production process is characterized by homotheticity, since in such a case the cost function can be written as $\ln C^* = \ln h(Q) + \ln g(P, t)$ and hence $\delta_{Q_i}^t = 0$ for all i ($=L, M, I, T, O$).

3. Statistical method

Before describing the statistical specification, one has to note the following point: that any cost function approach may face simultaneous equations bias due to possible endogeneity of output level in the system. In order to avoid such a bias, introduction of instrumental variables may be useful (Antle and Crissman, 1988). Noting that input decisions should depend not on actual, realized output levels but on expected or planned levels of output, we estimate a supply function of the form:

$$Q = F(P_A, P_L, P_M, P_I, P_T, P_O, t)$$

specifying the translog form where P_A is the price of output. The fitted values of the instrumental variables, $\ln \hat{Q}$ and $(\ln \hat{Q})^2$, will be used for the estimation of the model. Since these measures of the instrumental variables are exogenous, the estimates of the translog cost function will be free of simultaneous equations bias.

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 covariance of the errors of any two equations is permitted to be non-zero for the same farm. However, the covariance of the errors of any two equations corresponding to different farms are assumed to be identically zero. Given this specification of errors, Iterative Three-Stage Least Squares (I3SLS) estimation method was chosen. Moreover, the efficiency of estimation can be increased by imposing known restrictions on the coefficients in the equations.

We impose a priori the equality restrictions² 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 be 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:

²The imposition of the equality restrictions implies that the assumption of cost minimization is maintained. It is possible to explicitly test this maintained hypothesis of cost-minimizing behavior as a statistical hypothesis (Christensen et al., 1973).

$$\begin{aligned}
\ln C^*/P_O = & \alpha_0^t + \alpha_Q^t \ln \hat{Q} + \sum_{i=1}^4 \alpha_i^t \ln(P_i/P_O) + \frac{1}{2} \gamma_{QQ}^t (\ln \hat{Q})^2 \\
& + \frac{1}{2} \sum_{i=1}^4 \sum_{j=1}^4 \gamma_{ij}^t \ln(P_i/P_O) \ln(P_j/P_O) \\
& + \sum_{i=1}^4 \delta_{Qi}^t \ln \hat{Q} \ln(P_i/P_O) + u_C
\end{aligned} \tag{21}$$

$$S_i = \alpha_i^t + \delta_{Qi}^t \ln \hat{Q} + \sum_{j=1}^4 \gamma_{ij}^t \ln(P_j/P_O) + u_i \quad i=j=L, M, I, T \tag{22}$$

where u_C and i_i ($i=L, M, I, T$) are random disturbance terms with zero means. These five equations will be estimated jointly by the I3SLS method.

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, intermediate inputs, land, and other inputs. 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 ha or over, from all Japan excluding the Hokkaido district because of the different size classification. Thus, the sample size is $27 \times 4 = 108$. Unfortunately, we could not directly obtain the data for the average farm in the smallest size class, 0.5 ha or less, because of changes in the size classification during the sample period. 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 (1936) approximation method of the Divisia index³. For this computation eleven different categories of crop and livestock products were distinguished. The base of all indexes is set at 1958 values taken from Class I.

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 ($P_M X_M$) was

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

defined as the sum of the costs for machinery, energy, and rentals; the cost of intermediate inputs ($P_I X_I$) as the sum of the expenditures on fertilizer, feed, agri-chemicals, materials, clothes, and others; and the cost of other inputs ($P_O X_O$) 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.

We note at this point that Kislev and Peterson (1982) strongly recommend machinery price index to be adjusted for quality changes. However, the basic assumption one has to make in order to obtain quality-adjusted machinery price index is that the quality improvement in farm machinery can be represented by the quality improvement in, say, wheel tractors. However, there are substantially many kinds of farm machinery other than tractors. Since it is very complicated and cumbersome to construct the quality indexes for all such machinery, we decided to use the machinery price index from the PWRV in order to compute the Törnqvist (1936) index of P_M . Of course, we have to note that P_M used in this study may have an upward bias, since it seems that the quality of farm machinery in general has been improved.

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 annually 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 ($P_L X_L$) 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 planted area. 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.

$$C = \sum_{i=1}^5 P_i X_i \quad (i=L, M, I, T, O)$$

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 check the goodness of fit. For the translog cost function, and the labor, machinery, intermediate

inputs, and land cost share equations, the R^2 's adjusted for degrees of freedom were 0.997, 0.952, 0.869, 0.584 and 0.923, respectively, indicating a fairly good fit for the model.

Next, in the process of the estimation by the I3SLS 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 ($H_0: \alpha'_i = \gamma'_{ij} = \delta'_{Qi} = 0, \forall_{i,j}$), (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 ($H_0: \delta'_{Qi} = 0, \forall_i$)⁴. An F -test procedure was applied to all these tests. As a result, all the null hypotheses were strongly rejected at either the 1% or 5% level of statistical significance. Results indicate that changes in scale affect factor cost shares, that technological change is not neutral in the Hicksian sense, and that biased technological change is induced by changes in relative factor prices and output level.

Thus, no restrictions other than the equality and linear homogeneity were imposed in estimating the system of the five equations. 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 \hat{S}_i 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, with the Hessian being 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 factor inputs and the Allen partial elasticities of substitution among them 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 2.⁵

Several points are noteworthy. First, the absolute values of the own-price elasticities for all the factor inputs were found to be smaller than unity, indi-

⁴Refer to Stevenson (1980) for details.

⁵All of the variables necessary to compute the indicators in this (and the following tables and figures) are weighted averages, with the weights being the shares of farm households in each size class (mentioned in Section 4) in the total number of farm households in the four size classes.

TABLE 1

Parameter estimates of the translog cost function

α	5.692*	γ_{MO}	0.032°	γ'_{II}	0.148*
α_Q	1.026*	γ_{IT}	-0.013	γ'_{TT}	0.033*
α_L	0.647*	γ_{IO}	-0.117°	γ'_{OO}	-0.038°
α_M	0.061*	γ_{TO}	0.002°	γ'_{LM}	0.034*
α_I	0.165*	δ_{QL}	-0.063*	γ'_{LI}	-0.020**
α_T	0.049*	δ_{QM}	0.071*	γ'_{LT}	-0.008
α_O	0.079°	δ_{QI}	-0.023*	γ'_{LO}	0.019°
γ_{QQ}	-0.555*	δ_{QT}	0.029*	γ'_{MI}	-0.170*
γ_{LL}	0.129*	δ_{QO}	-0.014°	γ'_{MT}	-0.017*
γ_{MM}	-0.365*	α'	-0.067*	γ'_{MO}	-0.021°
γ_{II}	-0.335*	α'_Q	-0.026	γ'_{IT}	-0.004
γ_{TT}	-0.008	α'_L	-0.065*	γ'_{IO}	0.046°
γ_{OO}	0.107°	α'_M	0.046*	γ'_{TO}	-0.005°
γ_{LM}	-0.128*	α'_I	0.031*	δ'_{QL}	0.003
γ_{LI}	0.049**	α'_T	-0.002	δ'_{QM}	-0.024*
γ_{LT}	-0.026	α'_O	-0.010°	δ'_{QI}	0.014*
γ_{LO}	-0.024°	γ'_{QQ}	0.158*	δ'_{QT}	-0.000
γ_{MI}	0.417*	γ'_{LL}	-0.025**	δ'_{QO}	0.007°
γ_{MT}	0.045*	γ'_{MM}	0.173*		

Notes: (1) * and ** indicate that the coefficients are statistically significant at the 5% and 10% levels, respectively. (2) Coefficients with ° were obtained by making use of linear homogeneity parameter restrictions.

cating that demand for these factor inputs is inelastic. This finding is consistent with those of Kako (1978) and Kuroda (1987). Second, the AES between labor and machinery was found to be smaller than unity, indicating that labor and machinery have not been good substitutes. However, the increasing trend in value of the AES from about 0.4–0.5 in the 1960s through 1970s to 0.7–0.8 in the 1980s may suggest a change in production technology. 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 hypersurface may not have been dominant in determining shifts in factor demands during the period in question.

Biases of technological changes

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 was then transformed into the index through dividing 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 Figs. 4a through 4e. These indexes are an appropriate measure of the

TABLE 2

Own-price elasticities and Allen partial elasticities of substitution, 1958–84 (selected years)

	Own-price elasticities			
	1960	1970	1980	1984
e_{LL}	-0.37	-0.38	-0.38	-0.38
e_{MM}	-0.61	-0.48	-0.36	-0.25
e_{II}	-0.76	-0.69	-0.63	-0.57
e_{TT}	-0.19	-0.20	-0.17	-0.11
e_{OO}	-0.68	-0.73	-0.77	-0.81
	Allen partial elasticities of substitution			
	1960	1970	1980	1984
σ_{LM}	0.38	0.54	0.73	0.79
σ_{LI}	0.88	0.86	0.82	0.81
σ_{LT}	0.23	0.38	0.47	0.52
σ_{LO}	1.05	1.17	1.34	1.39
σ_{MI}	-0.17	-0.25	-0.36	-0.47
σ_{MT}	0.22	0.24	0.20	0.25
σ_{MO}	-0.26	-0.32	-0.39	-0.49
σ_{IT}	0.17	0.10	0.12	0.18
σ_{IO}	0.84	0.79	0.75	0.75
σ_{TO}	0.03	0.08	0.07	0.12

Note: Equations (12), (13), and (14) were used for the computations.

extent to which a factor input increased over time due to biased technological change relative to the other factor inputs. This, however, 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 such a purpose it is more appropriate to employ the absolute change between the cumulative series of technological change 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 et al., 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 Figs. 4a through 4e that technological change during the 1958–84 was biased towards saving labor and other inputs and using machinery and intermediate inputs. Furthermore, land was biased towards saving until the mid-1960s, changing to be biased towards using after that. These directions of biased technological change basically agree with those found by Kako (1979) and Kawagoe et al. (1986).

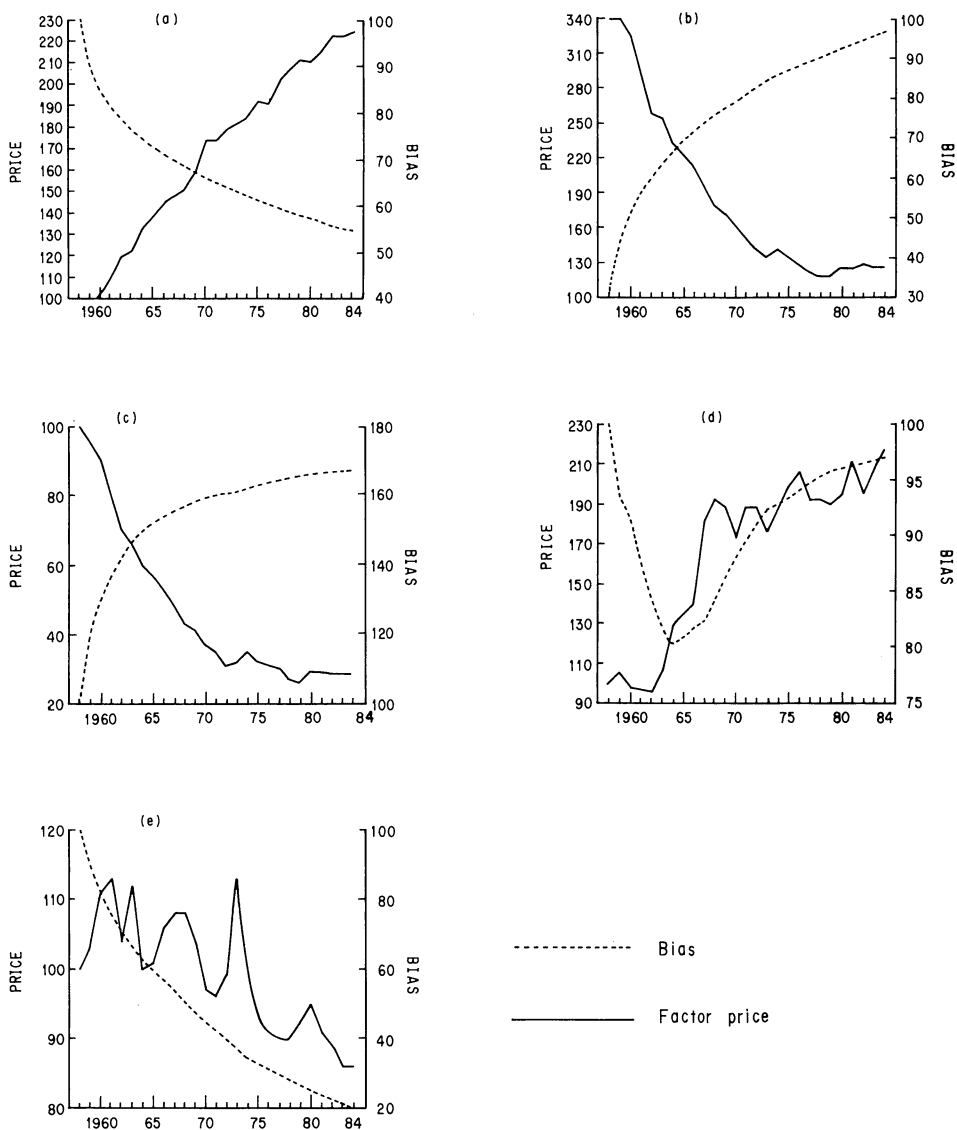


Fig. 4. Indices of measured bias of technological change and factor price indices relative to the divisia aggregated total input price index: (a) labor; (b) machinery; (c) intermediate inputs; (d) land; (e) other inputs.

The cumulative changes in the factor cost shares due to these technological change biases shown in Fig. 5 indicate that the absolute decrease in the cost share of labor and the increase in that of machinery were substantial, 28% and 20%, respectively, while the changes in the absolute shares of land and other inputs were small during the 1958–84 period. In the case of intermediate in-

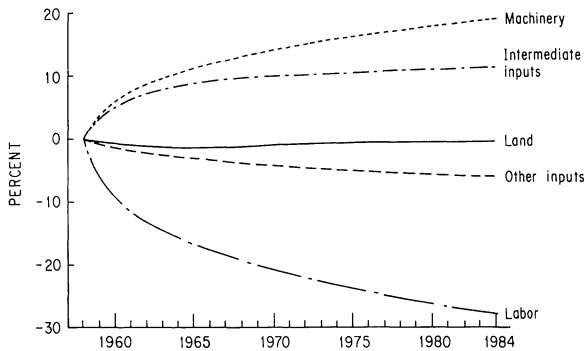


Fig. 5. Cumulated changes in factor cost shares due to biased technological change.

puts, the absolute increase in the cost share was considerably large until around 1970, but since then the speed of increase slackened.

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 of 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, measured biases are related to the relative factor movements, and thus the correlation of factor-saving biases to rising factor prices and vice 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 negative for labor and other inputs but positive for the other three inputs. Moreover, many of the γ'_{ij} are negative. These results suggest that the induced-innovation hypothesis may not be valid.

There are two reasons, however, that even with such a result the validity of the induced-innovation hypothesis may be defended. First, as mentioned in section two, this method may not be perfectly appropriate for testing the original Hicksian induced-innovation hypothesis. Since γ'_{ij} may be interpreted as investigating only the instantaneous correlation, and not the lagged correlation, between individual estimates of the annual series of technological change bias for the specific factor input and price. It may thus 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 (1974a), 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

TABLE 3

Estimates of factor-share bias equations (1958–84)

	constant	$\ln P_L$	$\ln P_M$	$\ln P_I$	$\ln P_T$	$\ln P_O$	$\ln^{\wedge} Q$
$\partial S_L / \partial t$	-0.065*	-0.025**	0.034*	-0.020**	-0.008	0.019°	0.003
$\partial S_M / \partial t$	0.046*	0.034*	0.173*	-0.170*	-0.016**	-0.021°	-0.024*
$\partial S_I / \partial t$	0.031*	-0.020**	-0.170*	0.148*	-0.004	0.046°	0.014*
$\partial S_T / \partial t$	-0.002	-0.008	-0.016**	-0.004	0.033*	-0.005°	-0.000
$\partial S_O / \partial t$	-0.010°	0.019°	-0.021°	0.046°	-0.005°	-0.038°	0.007°

Source: Table 1.

possibility is neutral. However, the innovation possibility curve, which is the envelope of all unit isoquants, may shift in a nonneutral manner (Kennedy, 1964; Ahmad, 1966). 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 Figs. 4a through 4e. These figures show the indexes of factor prices relative to the Törnqvist (1936)-approximated Divisia price index of total factor inputs. From these figures we can carry out 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 other hand, the machinery- and intermediate-inputs-using bias are associated with the declining trends in relative factor prices of machinery and intermediate inputs. Thus, one may conclude in these cases that the Hicksian induced-innovation hypothesis is valid.

Next, it was found in Fig. 4d that the land-saving technological change bias appears to be associated with the slightly decreasing trend of land price until the mid-1960s, while after the mid-1960s, technological change bias turned to be land-using and seems to be associated with the increasing trend in land price⁶. Furthermore, as seen in Fig. 4e, the other-inputs-saving bias appears to be related with the decreasing trend of the price of other inputs for the overall 1958–84 period. These findings seem to violate the Hicksian induced-innovation theory. Nevertheless, two arguments are possible which would make these findings consistent with the induced-innovation hypothesis. First, we may argue that innovation possibilities must have been biased towards land-using (after the mid-1960s) and other-inputs-saving (for the whole period)

⁶Lee (1983) has obtained a similar result.

regardless of the role of factor prices in determining biases. In particular, the innovation possibility curve might have shifted in particular in the land-using direction considering the fact that farm mechanization in general requires largerscale land area for efficient machinery utilization. Another argument is that the parallel movement of the land price and the land-using bias implies that the land price (defined as the rent per unit of land) might have been largely endogenous, suggesting that technological change bias seems to have been an important factor which affected the movement of land price during the period in question.

Decomposition analyses of changes in factor cost shares and factor proportions

Thus far we have investigated the directions of biases in 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 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). These calculations were 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 Tables 4 and 5. But, the results based on the estimates for the subperiods were found to be in general very similar to those for the whole period.

According to the estimates in Table 4, the most important determinant of changes in annual average cost shares of labor, machinery, and intermediate inputs was the effects due to biased technological change. These effects overwhelmed the negative total substitution effects stemming from changes in relative factor prices. In the case of land, the most important contributor to the annual average cost share change was the total substitution effect. Still, biased technological change had a significant impact on the increase in the land cost share. For other inputs, the negative effects due to biased technological change was substantial. We may thus conclude that biased technological change effects were a dominant factor in explaining changes in the factor cost shares.

Next, changes in the labor-related factor proportions will be investigated in Table 5. In the case of the change in the labor–machinery ratio, 82% of the average annual rate of change in this ratio (-10.5%) was found to be explained by the effect of labor-saving and machinery-using technological change, and 37% of this ratio was found to be due to the total price-induced substitution effect along an isoquant hypersphere. The most dominant contributor to the change in the labor–intermediate–inputs ratio was the total substitution effect (69%). Still, the labor-saving and intermediate-inputs-using technological change was also important in explaining the drastic change in this factor pro-

TABLE 4

Decomposition analysis of annual average changes in estimated factor cost shares (1958-84) (unit: %)

Factor input	Annual change in factor share	Scale effect	Total substitution effect	Biased technological change effect	Residual
Labor	-0.84 (100.0)	-0.14 (16.9)	0.24 (-28.5)	-1.04 (123.8)	-0.10 (-12.2)
Machinery	0.32 (100.0)	0.03 (10.2)	-0.41 (-128.6)	0.73 (228.1)	-0.03 (-9.7)
Intermediate inputs	0.26 (100.0)	0.03 (11.1)	-0.20 (-75.8)	0.42 (161.5)	0.01 (3.2)
Land	0.32 (100.0)	0.07 (23.1)	0.14 (45.1)	-0.01 (-3.1)	0.11 (34.9)
Other inputs	0.01 (100.0)	0.007 (65.5)	0.15 (1541.7)	-0.22 (-2200.0)	0.07 (692.8)

TABLE 5

Decomposition analysis of annual rates of changes in factor proportions with respect to labor (1958-84) (Unit: %)

Factor proportion	Annual rate of changes in factor proportion	Scale effect	Total substitution effect	Biased technological change effect	Residual
Labor/Machinery	-10.47 (100.0)	-0.62 (5.9)	-3.85 (36.8)	-8.55 (81.7)	-2.55 (-24.4)
Labor/Intermediate inputs	-10.16 (100.0)	-0.42 (4.1)	-7.05 (69.4)	-4.28 (42.1)	1.59 (-15.7)
Labor/Land	-3.51 (100.0)	-1.13 (32.3)	-1.07 (30.5)	-1.57 (44.7)	0.26 (-7.5)
Labor/Other inputs	-5.50 (100.0)	-0.38 (6.9)	-5.56 (101.1)	0.78 (-14.2)	-0.34 (6.2)

portion (42%). In the case of the labor-land ratio, the effect of biased technological change was found to be an important factor in determining the change in the ratio as indicated by a 45% contribution. However, it is noteworthy in this case that the contribution of the scale effect was found to be fairly large, i.e., 32%. As seen in equation (11), this effect is due to non-homotheticity of

the production process, and suggests that estimation of models which assume homotheticity would derive misleading conclusions in this sort of analysis.

We do not deeply address the case of the labor–other inputs ratio since other inputs in this study are a conglomerate of factor inputs with different characteristics, such as buildings and structures, animals, and plants. They were introduced into the analysis in order 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, however, is that the large contribution of the total substitution effect (101%) must have been due to its relatively large AES’s with labor and intermediate inputs as shown in Table 2.

6. Summary and conclusion

The findings of this study are summarized as follows.

Technological change in Japanese agriculture since the late 1950s has been strongly biased towards labor-saving, machinery- and intermediate-inputs-using, and slightly biased towards land-using after the mid-1960s. 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 land-using bias of technological change.

Changes in the cost structure through changes in factor cost shares were found to be largely due to biased technological change.

The drastic changes in labor-related factor proportions during the 1958–84 period were attributed largely to the biased effects of technological change. Price-induced substitution effects along an isoquant hypersphere have also contributed to a fairly large degree to the determination of 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 factor endowment conditions. An implication of this study for agriculture in less developed countries is that agricultural policies seeking development through technological progress should be carried out so as to take advantage of peculiar factor endowment conditions in the individual countries.

Acknowledgement

The author is most grateful to Y. Maruyama at the University of Tsukuba, Y. Yamamoto at Obihiro Veterinary University and the two anonymous reviewers for useful comments and advices. He also acknowledges Bruce Lambert at the Graduate School of Management Science and Public Policy Studies, University of Tsukuba, for his careful editing of the English. The responsibility for any errors, however, rests solely with the author.

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