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The Production Structure and the Demand  
for Labor in Postwar Japanese Agriculture,

1952-82

by

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## 1. Introduction

The rapid growth of the Japanese economy during the postwar years has accompanied a sizable transfer of labor from agriculture to the non-agricultural sectors. The total number of agricultural gainful workers declined from 15.6 million in 1952 to 5.7 million in 1982. The average rate of decrease was 3.3 percent. In terms of labor hours per unit of land, this rate was 4.0 percent for the average farm for the same period.

What were then the factors which can explain this drastic decline of agricultural labor? Two factors have traditionally been considered as the determinants of labor migration from agriculture to non-agricultural sectors; "push" and "pull". "Push" refers to the pressures generated within agriculture which tend to reduce agricultural employment such as the rise of farm wages relative to the prices of output and inputs and labor-saving technological progress. In short, "push" may be said to refer to the factors which affect the demand for labor in agricultural production. On the other hand, "pull" refers to the forces which cause a reduction in the supply of labor to agricultural production such as the decline of farm wages relative to non-farm wages and increase in alternative employment opportunities in non-agricultural sectors. The interaction of these two forces generates the migration from agriculture to non-agricultural sectors (Cowling, Metcalf, and Rayner).

This study, however, focuses on the analysis of only the push factors. That is, the production structure of agriculture is to be analyzed by shedding a special light on the demand for labor. For this objective, a translog cost function model will be estimated for the period 1952-82

by making use of farm level data. In the process of estimation, the hypothesis of cost minimization by the farm will be explicitly tested together with the hypotheses on the functional form such as homotheticity, constant returns to scale, Cobb-Douglas production function, and Hicks neutral technical change.

Based on the estimates of the final specification of the translog cost function with the imposition of parameter restrictions if necessary, the Allen partial elasticities of substitution between pairs of factor inputs, own- and cross-price elasticities of demand for factor inputs, and biased impacts of technical change and nonhomotheticity will be estimated. In addition, the changes in relative factor uses for the period 1952-82 will be decomposed into the scale effect, the total substitution effects, and the biased technical change effect. The empirical findings of this study are expected to be useful for policy makers who seek for policies for labor adjustment in agriculture.

## 2. Methodology

It is assumed that the farm has the production function specified as

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

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 annual index of time. If the production function has convex isoquants, and if the farm employs 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).

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

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

For econometric estimation one needs to use a specific functional form for  $G$ . The present study employs the translog form which can be written as:

$$(3) \quad \begin{aligned} \ln C^* = & \alpha_0 + \alpha_Q \ln Q + \sum_{i=1}^5 \alpha_i \ln P_i + \epsilon_t \ln t \\ & + \frac{1}{2} \gamma_{QQ} (\ln Q)^2 + \frac{1}{2} \sum_{i=1}^5 \sum_{j=1}^5 \gamma_{ij} \ln P_i \ln P_j \\ & + \sum_{i=1}^5 \delta_{Qi} \ln Q \ln P_i + \rho_{tQ} \ln t \ln Q \\ & + \sum_{i=1}^5 \mu_{ti} \ln t \ln P_i + \frac{1}{2} \epsilon_{tt} (\ln t)^2 \end{aligned}$$

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

This translog cost function can be regarded as a quadratic approximation to the unspecified true cost function. It is assumed that the translog cost function (3) is twice differentiable, so that the Hessian of this function with respect to the input prices is symmetric. This implies the symmetry restrictions,<sup>1)</sup>  $\gamma_{ij} = \gamma_{ji}$  for  $i \neq j$  ( $i, j = L, M, I, T, O$ ).

Assuming that the farm takes input prices as given and by making use of the Shephard duality theorem, the cost share functions can be derived as:

$$(4) \quad S_i = \frac{\partial C^*}{\partial P_i} \frac{P_i}{C^*} = \frac{\partial \ln C^*}{\partial \ln P_i}$$

$$= \alpha_i + \sum_{j=1}^5 \gamma_{ij} \ln P_j + \delta_{Qi} \ln Q + u_{ti} \ln t$$

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

Any sensible cost function must be homogeneous of degree one in input prices. That is, a proportional change in input prices entails a change in total cost in the same proportion. This requires in the translog function (3) that  $\sum_{i=1}^5 \alpha_i = 1$ ,  $\sum_{j=1}^5 \gamma_{ij} = 0$ ,  $\sum_{i=1}^5 \delta_{Qi} = 0$ , and  $\sum_{i=1}^5 \mu_{ti} = 0$  ( $i, j = L, M, I, T, O$ ). Essentially, the same set of restrictions on parameters follows from the adding-up requirement of the cost shares.

#### Tests of Hypotheses

Observe that there are parameters which appear in more than one of the five cost share functions and that all of the parameters of the five cost share functions appear in the translog cost function. The equality of these parameters is a necessary and sufficient condition for the system of equations to be consistent with cost minimizing behavior of the farm. The equality of the parameters can be explicitly tested. If this test is rejected, equation (3) is not valid and hence the imposition of the equality restrictions may cause biases in the estimated parameters of the system of equations. To avoid this, one has to specify a different cost function such as a variable cost function (Brown and Christensen).

Several hypotheses concerning the structure of technology are also

tested. The first hypothesis to be tested is separability of the cost function in output and input prices. Such functional separability indicates homotheticity of the technology. If the cost function (2) is multiplicatively separable, it can be written as  $C^* = F(Q) \cdot H(P, t)$ . Taking logarithms of both sides yields  $\ln C^* = \ln F(Q) + \ln H(P, t)$ . This implies the following set of restrictions on the translog cost function (3);  $\delta_{Qi} = 0$  ( $i = L, M, I, T, O$ ) and  $\rho_{tQ} = 0$ . This empirically implies that changes in output level or scale do not affect the cost shares.

Second, if the production function (1) exhibits constant returns to scale, then the cost function (2) can be written as  $C^*(Q, P, t) = Q \cdot H(P, t)$ . This implies the following set of parameter restrictions on the translog cost function;  $\alpha_Q = 1$ ,  $\delta_{Qi} = 0$  ( $i = L, M, I, T, O$ ), and  $\rho_{Qt} = 0$ .

Third, the production function (1) is Cobb-Douglas if its dual cost function has the form  $C^* = A(t) Q^{a_Q} \prod_i P_i^{a_i}$ . In terms of the translog cost function, this implies that  $\gamma_{QQ} = 0$ ,  $\gamma_{ij} = 0$  for all  $i$  and  $j$ ,  $\delta_{Qi} = 0$  for all  $i$ ,  $\rho_{tQ} = 0$ ,  $\mu_{ti} = 0$  for all  $i$ , and  $\epsilon_{tt} = 0$  ( $i, j = L, M, I, T, O$ ).

Finally, if the production function (1) is characterized by Hicks neutral technical change, the corresponding dual cost function (2) can be written as  $C^*(Q, P, t) = A(t) \cdot f(Q, P)$ . This implies the following set of parameter restrictions on the translog cost function:  $\rho_{tQ} = 0$  and  $u_{ti} = 0$  for all  $i$  ( $= L, M, I, T, O$ ).

The test of these four hypotheses concerning the production technology will be carried out conditionally on the validity of the equality

test, since the equality hypothesis is the maintained hypothesis of the cost function approach used in the present study.

Allen Partial elasticities of Substitution

Uzawa has derived the Allen partial elasticities of substitution (AES) between inputs  $i$  and  $j$  as

$$\sigma_{ij} = \frac{C^* C_{ij}^*}{C_i^* C_j^*}$$

where

$$C_i^* = \frac{\partial C^*}{\partial P_i}, \quad C_{ij}^* = \frac{\partial^2 C^*}{\partial P_i \partial P_j}$$

and by definition,  $\sigma_{ij} = \sigma_{ji}$ . With the translog cost function the AES can be given as (Binswanger)

$$(5) \quad \sigma_{ii} = \frac{\gamma_{ii} + S_i - S_i^2}{S_i^2}, \quad i = L, M, I, T, O,$$

$$(6) \quad \sigma_{ij} = \frac{\gamma_{ij} + S_i S_j}{S_i S_j}, \quad i \neq j, i, j = L, M, I, T, O,$$

where  $S_i$ 's are the cost shares. These AES are not constrained to be constant but may vary with the values of the cost shares.

The price elasticity of demand for factor inputs,  $\eta_{ij}$ , is defined as,

$$\eta_{ij} = \frac{\partial \ln X_i}{\partial \ln P_j}$$

where output quantity and all other input prices are fixed. Allen has shown that the AES are analytically related to the price elasticities of demand for factor inputs as,

$$(7) \quad \eta_{ij} = S_j \sigma_{ij} \quad , \quad i, j = L, M, I, T, O.$$

Hence, even though  $\sigma_{ij} = \sigma_{ji}$ , in general  $\eta_{ij} \neq \eta_{ji}$ .

Biased Impacts of Technical Change

If the test of hypothesis of Hicks neutral technical change could not be rejected, then the technical change is neutral. If it is rejected, then there exist biased impacts of technical change on the use of factor inputs. It is of great interest to evaluate such impacts numerically. Binswanger has shown a procedure of estimating biases of technical change in the translog cost function framework. However, his method is to measure the effect of technical change on absolute use of an individual input. It is more interesting and faithful to Hicks definition to evaluate the effect of technical change on relative uses of factor inputs in the framework of a multi-input production technology (Weaver).

Modifying Weaver's definition for the case of the translog cost function, we define that technical change is Hicks'

$$\left. \begin{array}{l} \text{saving} \\ X_i \text{ neutral} \\ \text{using} \end{array} \right\} \text{ relative to } X_j \quad \text{if}$$

$$(8) \quad B_{ij} = \frac{\partial \ln S_i}{\partial \ln t} - \frac{\partial \ln S_j}{\partial \ln t} \gtrless 0 .$$

In terms of the parameters of the translog cost function of this study,  $B_{ij}$  can be expressed as,

$$(9) \quad B_{ij} = \frac{\mu_{ti}}{S_i} - \frac{\mu_{tj}}{S_j} .$$

Nonhomotheticity

The bias due to a scale change or nonhomotheticity of the production function is conceptually analogous to the bias due to technical change. That is, nonhomotheticity implies that as the scale of operations of the firm increases, given all other technical properties of the production process, unit requirements of one factor input will decline (or increase) compared to those of another factor input (Nadiri).

A scale change is defined as a change in output caused by a proportional change in all input prices. Therefore, the effects of scale change on factor cost shares can be used to measure the nonhomotheticity of the production technology. Antle proposed a measure of nonhomotheticity in a multi-input translog profit function framework. His measure can be translated into a measure of nonhomotheticity in the framework of the multi-input translog cost function as,  $N_i = \partial \ln S_i / \partial \ln Q$ .

However, this measures the effect of nonhomotheticity only on absolute use of an individual input. Instead, as in the case of the measurement of biases of technical change, it may be more economically meaningful to measure the effect of nonhomotheticity on relative uses of factor inputs in the framework of a multi-input production technology. Thus, extending Antle's definition, we propose a measure of nonhomotheticity in the multi-input translog cost function framework as follows.

$X_i$  is nonhomothetically 

saving	}	relative to $X_j$ if
neutral		
using		

$$(10) \quad N_{ij} = \frac{\partial \ln S_i}{\partial \ln Q} - \frac{\partial \ln S_j}{\partial \ln Q} \gtrless 0.$$

In terms of the parameters of the cost share functions,

$$(11) \quad N_{ij} = \frac{\delta_{Qi}}{S_i} - \frac{\delta_{Qj}}{S_j}.$$

### Decomposition Analysis of Changes in Factor Combination Ratios

The measures of biases,  $B_{ij}$  and  $N_{ij}$ , will indicate the directions and magnitudes of the effects of non-neutral technical change and non-homotheticity, respectively, on relative uses of factors of production. However, both measures may not give a clear answer to the question of what factor has contributed how much to the explanation of the actual changes in relative factor uses. In order to measure the degree of such a contribution, it may be useful to apply a decomposition analysis which can be developed as follows.

To begin, write the cost-minimizing input demand as,

$$(12) \quad X_i^* = X_i^*(Q, P_L, P_M, P_I, P_T, P_O, t).$$

By differentiating (10) totally with respect to time, dividing both sides by  $X_i^*$ , and expressing the growth rate by  $G(\cdot)$ , we obtain,

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

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

A change in relative factor use is given by the change in the factor combination ratio as

$G(X_i^*/X_j^*) = G(X_i^*) - G(X_j^*)$ , which reduces to:

$$(13) \quad G(X_i^*) - G(X_j^*) = \left[ \frac{\partial \ln X_i^*}{\partial \ln Q} G(Q) - \frac{\partial \ln X_j^*}{\partial \ln Q} G(Q) \right] \\ + \left[ \sum_{k=1}^5 \frac{\partial \ln X_i^*}{\partial \ln P_k} G(P_k) - \sum_{k=1}^5 \frac{\partial \ln X_j^*}{\partial \ln P_k} G(P_k) \right] \\ + \left[ \frac{\partial \ln X_i^*}{\partial t} - \frac{\partial \ln X_j^*}{\partial t} \right], \\ i \neq j, \quad i, j, k = L, M, I, T, O.$$

With the framework of the translog cost function in the present study,

(13) can be written as,

$$(14) \quad G(X_i^*) - G(X_j^*) = \left[ \frac{\delta_{Q_i}}{S_i} G(Q) - \frac{\delta_{Q_j}}{S_j} G(Q) \right] \\ + \left[ \sum_{k=1}^5 S_k \sigma_{ik} G(P_k) - \sum_{k=1}^5 S_k \sigma_{jk} G(P_k) \right] \\ + \left[ \frac{\partial \ln X_i^*}{\partial t} - \frac{\partial \ln X_j^*}{\partial t} \right], \\ i \neq j, \quad i, j, k = L, M, I, T, O.$$

The first term measures the effect of a scale change on the relative factor use (the scale effect hereafter). Note that if the technology is homothetic, this term vanishes since  $\delta_{Q_i} = 0$  for all  $i$  ( $= L, M, I, T, O$ ). The second term measures the effect of factor substitutions due to factor price changes (the total substitution effect hereafter). The last term measures the effect of technical change. Note however that if the technical change were Hicks neutral, then its

effects on the proportional changes in requirements for the two factor inputs would have to be identical. Therefore, the last term catches the effect of non-neutral technical change (the biased technical change effect hereafter).

### 3. The Data

The data required for the estimation of the model are the total cost, the quantity of output, and the prices and cost shares of the five factors of production; 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 hereafter) and the Survey Report on Prices and Wages in Rural Villages (PWRV hereafter) published annually by the Ministry of Agriculture, Forestry, and Fisheries. The data processing was carried out for the national average farm for the period 1952-82. Thus the number of observations is 31.

Indeed, it is possible to increase the sample size by taking the average farm in each different size class in each year for all Japan excluding Hokkaido district because of the different size classification. A similar procedure has been used by Kako who studied the rice production structure of Kinki district for the period 1953-70. However, because of changes in the size classification, it is almost impossible by this procedure to obtain the necessary data for the average farm in the smallest size class with 0.5 hectares and less. Since the share of the number of farms in this stratum in the total number of farms in

Japan has been as large as around 40 percent, exclusion of farms in this size class in the estimation may cause a significant bias in the estimated parameters. This is why we did not follow this procedure in the present study. Although the sample size (and hence the degrees of freedom) is small, our procedure is expected to avoid such 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. 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 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. Finally, the quantity and price of labor were divided by the respective 1952 values and hence are expressed in index terms.

The quantity ( $X_M$ ) and price ( $P_M$ ) of machinery were constructed as the Törnqvist quantity and price indexes. In this computation, the

cost of machinery ( $P_M X_M$ ) was defined as the sum of the costs for machinery, energy, and rentals, and the price indexes corresponding to these items were obtained from the PWRV. The base year for these indexes is 1952.

The quantity ( $X_I$ ) and price ( $P_I$ ) of intermediate inputs were also defined as the Törnqvist quantity and price indexes with the base year being set at 1952. The cost of intermediate inputs ( $P_I X_I$ ) was defined as the sum of the expenditures on fertilizer, feed, agri-chemicals, materials, clothes, and others. Again, the price indexes for these items were taken from the PWRV for the computation of the Törnqvist indexes.

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  $X_T$ . The quantity and price indexes were constructed by dividing  $X_T$  and  $P_T$  by the respective 1952 values.

The Törnqvist indexes were also constructed for the quantity ( $X_O$ ) and price ( $P_O$ ) of other inputs where base year was set at 1952. For this computation, the cost of other inputs ( $P_O X_O$ ) was defined as the sum of the expenditures on animals, plants, and farm buildings and structures. The price indexes for these items were taken from the PWRV.

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).

#### 4. Statistical Method

Two methods have been proposed in the literature for the estimation of translog cost function models. One is to assume that the translog cost function provides an exact representation of the technology in the relevant range. With this assumption only  $n-1$  cost share equations are jointly estimated by assuming errors in optimizing behavior. Advantages of this method are: (1) the sample size could be small; (2) test procedures of statistical hypotheses are simpler; and (3) parameter restrictions, if any, may be much less and hence the computational difficulty and time can be drastically reduced. Because of these advantages, this method has been widely adopted (e.g., Binswanger, Berndt and Wood, Denny and May, Denny and Fuss, Kako, and Antle and Aitah).

The other method is to interpret the translog functional form as a second-order local approximation to an arbitrary functional form. This suggests that one examines the implications of the assumption that the translog cost function is only an approximation to the true underlying cost function. This means that the translog cost function ought to be included with the system of  $n-1$  cost share equations for efficient estimation (Diewert). Besides, an advantage of this method is that one can directly test hypotheses on the technology structure such as homotheticity, homogeneity, neutral technical change, and Cobb-Douglas functional form by making use of the coefficients of the translog cost function. This method has also been employed widely in the literature (e.g., Christensen and Green, Brown and Christensen, and Moroney and Trapani).

We will employ the latter method in this study, since part of our interest is to test explicitly the technology structure of agricultural production during the postwar years.

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 (4). The covariance 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 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 linear homogeneity restrictions on the translog cost function (3) and the adding-up (which is equivalent to the linear homogeneity) restrictions 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 adding-up restrictions after the system is estimated.

The set of final estimating equations are as follows.

$$(15) \quad \ln C^*/P_0 = \alpha_0 + \alpha_Q \ln Q + \sum_{i=1}^4 \alpha_i \ln P_i/P_0 + \epsilon_t \ln t \\ + \frac{1}{2} \gamma_{QQ} (\ln Q)^2 + \frac{1}{2} \sum_{i=1}^4 \sum_{j=1}^4 \gamma_{ij} \ln P_i/P_0 \ln P_j/P_0$$

$$\begin{aligned}
 & + \sum_{i=1}^4 \delta_{Qi} \ln Q \ln P_i/P_0 + \rho_{tQ} \ln Q \ln t \\
 & + \sum_{i=1}^4 \mu_{ti} \ln t \ln P_i/P_0 + \frac{1}{2} \epsilon_{tt} (\ln t)^2 ,
 \end{aligned}$$

$$(16) \quad S_i = \alpha_i + \delta_{Qi} \ln Q + \sum_{j=1}^4 \gamma_{ij} \ln P_j/P_0 + \mu_{ti} \ln t ,$$

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

These five equations are to be estimated jointly by Zellner's efficient method. In the process of estimation, the statistical hypotheses described in section two will be tested and, based on the results of the tests, constraints will be imposed on the coefficients in the equations if necessary.

Note however that the tests of the equality hypothesis and the hypotheses on the technology structure can now be expressed in simpler forms because of the a priori imposition of the linear homogeneity restrictions.

## 5. Empirical Results

### Tests of Hypotheses and Final Specification

The translog cost function (15) and the four cost share equations (16) were estimated first by ordinary least squares method in order to see the goodness of fit. The  $R^2$ 's were 0.999, 0.984, 0.924, 0.820, and 0.888 respectively for the translog cost function, the labor cost share, the machinery cost share, the intermediate inputs cost share, and the

land cost share equations, indicating a fairly good fit of the model.

Next, the five statistical hypotheses described in section two were tested. They are (1) equality, (2) homotheticity, (3) constant returns to scale, (4) Cobb-Douglas production function, and (5) Hicks neutral technical change. We employed test statistics based on F ratios. To control the overall level of significance of the series of tests, the overall level of significance was set at 0.05. This implies that the probability of rejecting a true hypothesis in our series of tests is 0.05. We first assigned a level of significance of 0.01 to the test of the equality restrictions implied by cost minimization. We then assigned a level of significance of 0.04 to the rest four tests of restrictions on the technology structure. These four sets of tests are nested; under the null hypothesis, the sum of levels of significance provides a close approximation to the level of significance for the four sets of tests simultaneously.

Test statistics are presented in Table 1. At a level of significance of 0.01 we cannot reject the equality hypothesis, indicating that the restrictions implied by cost minimization is valid. Proceeding conditionally on the validity of the hypothesis of cost minimization, the four hypotheses concerning the technology structure were tested.

First, we reject the null hypothesis of homotheticity. This implies that changes in output level or scale affect the cost shares. Second, we reject the null hypothesis of constant returns to scale, indicating that there exist economies (or diseconomies) of scale in agricultural production. Third, we reject decisively the null hypothesis that the

Table 1. Statistical Hypotheses Tested

Hypothesis		Computed F	Critical F <sub>0.01</sub>
1. Equality	(28, 99)	1.21	2.03
2. Homotheticity conditional on equality	(5, 127)	11.4	3.17
3. Constant returns to scale conditional on equality	(7, 127)	29.1	2.79
4. Cobb-Douglas production function conditional on equality	(21, 127)	110.6	2.03
5. Hicks neutral technical change conditional on equality	(5, 127)	10.7	2.96

Note: Figures in parentheses are the degrees of freedom.

production technology is represented by Cobb-Douglas function. This means that there are pairs of factor inputs whose AES are not unity. Finally, we reject the null hypothesis of Hicks neutral technical change, implying that there exist biased impacts of technical change on relative uses of factor inputs.

Based on the results of the tests of hypotheses, the system of the translog cost function and the four cost share equations were jointly estimated by imposing the restrictions which are tested but not rejected. In the present case, only the equality restrictions were imposed. The implied estimates of the parameters of the system of equations can immediately be obtained by making use of the parameter relationships of the linear homogeneity restrictions. The estimates of the translog cost function is presented in Table 2<sup>2)</sup>. This set of estimates is referred to as our final specification and will be used for further analyses.

Before proceeding further to empirical analyses, however, it is necessary to check whether or not the estimates of the translog cost function presented in Table 2 are consistent with monotonicity and concavity in the input prices. An implication of non-monotonicity is that demands for inputs may be negative. An implication of non-concavity is that the demand elasticities may have incorrect signs or magnitudes. Thus, in order for the empirical results to be economically meaningful, monotonicity and concavity must be satisfied.

However, the translog cost function is not in general globally monotonic increasing and concave in input prices. It is however possible for the translog cost function to be locally monotonically increasing

Table 2. Estimates of the Translog Cost Function for 1952-82

Parameter	Coefficient	t-value	Parameter	Coefficient	t-value
$\alpha_0$	5.121	14.86	$\gamma_{MI}$	-0.0397	-4.200
$\alpha_Q$	-1.377	-1.385	$\gamma_{MT}$	0.006	0.465
$\alpha_L$	0.6986	33.17	$\gamma_{MO}$	-0.003	
$\alpha_M$	0.0256	1.566	$\gamma_{IT}$	-0.0348	-2.861
$\alpha_I$	0.1331	7.166	$\gamma_{IO}$	0.0320	
$\alpha_T$	0.0498	1.987	$\gamma_{TO}$	-0.0151	
$\alpha_0$	0.0929		$\delta_{QL}$	-0.1276	-3.506
$\epsilon_t$	0.5903	1.447	$\delta_{QM}$	-0.0050	-0.201
$\gamma_{QQ}$	-2.552	-1.979	$\delta_{QI}$	0.0871	2.876
$\gamma_{LL}$	-0.0657	-2.548	$\delta_{QT}$	0.0191	0.511
$\gamma_{MM}$	0.0673	6.218	$\delta_{QO}$	0.0405	
$\gamma_{II}$	0.0425	3.128	$\rho_{tQ}$	-0.4149	-1.756
$\gamma_{TT}$	-0.0000	-0.001	$\mu_{tL}$	-0.0460	-3.319
$\gamma_{OO}$	-0.0553		$\mu_{tM}$	0.0277	2.686
$\gamma_{LM}$	-0.0251	-2.111	$\mu_{tI}$	0.0330	2.782
$\gamma_{LI}$	0.0136	0.866	$\mu_{tT}$	-0.0128	-0.805
$\gamma_{LT}$	0.0499	3.132	$\mu_{tO}$	-0.0147	
$\gamma_{LO}$	0.0409		$\epsilon_{tt}$	1.130	2.051

Note: The coefficients without the t-values were computed by making use of the linear homogeneity restrictions. In this computation, however, the statistically insignificant coefficients were assumed to be zero.

and concave. The fitted cost function is thus checked for monotonicity and concavity 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 2 is well-behaved within the region of the sample observation.

Allen Partial Elasticities of Substitution and Price Elasticities of Demand

In order to measure factor substitution possibilities we computed the AES ( $\sigma_{ij}$ ) and price elasticities of demand ( $\eta_{ij}$ ) as formulated in (5), (6), and (7). The results are presented in Tables 3 and 4. Several important findings emerge from these tables.

First, the own-price elasticity of labor demand shows an increasing trend over time, from -0.45 in 1952 to -0.75 in 1982. This indicates that the farm became more and more responsive over time to changes in farm wages in the demand for labor.

Second, the demand elasticities for machinery, intermediate inputs, land, and other inputs with respect to the price of labor are all positive, indicating that they were substitutes of labor. The AES between labor and machinery ( $\sigma_{LM}$ ) is less than unity which is smaller than Kako's estimate, 0.93. However,  $\sigma_{LM}$  shows an increasing trend over time, from 0.31 in 1952 to 0.62 in 1982. This implies that the substitutability between labor and machinery increased over time.

Table 3. Allen Partial Elasticities of Substitution,  
1952-82 (Selected Years)

AES	1952	1960	1970	1982
$\sigma_{LM}$	0.31	0.54	0.59	0.62
$\sigma_{LI}$	1.00	1.00	1.00	1.00
$\sigma_{LT}$	2.55	2.09	1.74	1.74
$\sigma_{LO}$	1.82	2.35	2.60	2.70
$\sigma_{MI}$	-3.18	-1.22	-0.60	-0.20
$\sigma_{MT}$	1.00	1.00	1.00	1.00
$\sigma_{MO}$	0.42	0.48	0.63	0.73
$\sigma_{IT}$	-3.13	-1.33	-0.26	-0.05
$\sigma_{IO}$	3.46	4.22	4.08	3.68
$\sigma_{TO}$	-2.94	-2.69	-1.03	-0.59

Table 4. Price Elasticities of Factor Demand,  
1952-82 (Selected Years)

Price Elasticity	1952	1960	1970	1982
$\eta_{LL}$	-0.45	-0.53	-0.65	-0.75
$\eta_{LM}$	0.02	0.05	0.07	0.10
$\eta_{LI}$	0.17	0.19	0.20	0.20
$\eta_{LT}$	0.13	0.16	0.24	0.28
$\eta_{LO}$	0.14	0.12	0.14	0.16
$\eta_{ML}$	0.20	0.32	0.29	0.26
$\eta_{MM}$	-0.03	-0.19	-0.34	-0.42
$\eta_{MI}$	-0.54	-0.23	-0.12	-0.04
$\eta_{MT}$	0.05	0.08	0.14	0.16
$\eta_{MO}$	0.03	0.03	0.33	0.43
$\eta_{IL}$	0.65	0.59	0.48	0.41
$\eta_{IM}$	-0.18	-0.11	-0.08	-0.03
$\eta_{II}$	-0.58	-0.59	-0.59	-0.59
$\eta_{IT}$	-0.16	-0.10	-0.04	-0.01
$\eta_{IO}$	0.27	0.22	0.22	0.21
$\eta_{TL}$	1.65	1.22	0.84	0.72
$\eta_{TM}$	0.06	0.09	0.13	0.16
$\eta_{TI}$	-0.53	-0.25	-0.06	-0.01
$\eta_{TT}$	-0.95	-0.92	-0.86	-0.84
$\eta_{TO}$	-0.23	-0.14	-0.05	-0.03
$\eta_{OL}$	1.18	1.37	1.26	1.12
$\eta_{OM}$	0.02	0.05	0.08	0.12
$\eta_{OI}$	0.59	0.81	0.80	0.75
$\eta_{OT}$	-0.15	-0.21	-0.14	-0.10
$\eta_{OO}$	-1.64	-2.01	-1.99	-1.89

On the other hand, the substitutability between labor and land ( $\sigma_{LT}$ ) and that between labor and other inputs ( $\sigma_{LO}$ ) were very high —  $\sigma_{LT}$  ranges from 2.6 in 1952 to 1.7 in 1982 and  $\sigma_{LO}$  from 1.8 in 1952 to 2.7 in 1982. Furthermore, the demand for land and other inputs were fairly elastic — the own-price elasticities range from -0.84 to -0.95 and from -1.64 to -2.01, respectively.

Third, the AES between labor and intermediate inputs ( $\sigma_{LI}$ ) was unity for the whole period 1952-82, indicating that intermediate inputs were a fairly good substitute of labor. On the other hand, intermediate inputs were a strong complement of both machinery and land during the early 1950's through the mid-1960's. However, the complementarity decreased drastically after 1970. This may have been caused by the increased share of purchased feed in the expenditure on intermediate inputs especially after around the mid-1960's. Feed appears not to have such a strong complementarity with either machinery or land as fertilizers and agri-chemicals. Nevertheless, this complementarity of intermediate inputs with machinery and land implies that mechanical technological progress represented by the increased use of mechanical power has been promoted in parallel with bio-chemical technological progress represented by the increased use of fertilizers and agri-chemicals in postwar Japanese agriculture.

In sum, the substitutability of labor with machinery, intermediate inputs, land, and other inputs and the complementarity of intermediate inputs with machinery and land may indicate that the simultaneous promotion of mechanical and bio-chemical technologies in postwar

Japanese agriculture has played an important role in reducing labor input in production.

Biased Impacts of Technical Change and Nonhomotheticity

Estimates of biases caused by technical change ( $B_{ij}$ ) and by non-homotheticity ( $N_{ij}$ ) as measured respectively by (9) and (11) are presented in Tables 5 and 6, respectively. Some findings particularly with regard to labor input are noteworthy.

First,  $B_{LM}$ ,  $B_{LI}$ ,  $B_{LT}$ , and  $B_{LO}$  are all negative according to Table 5. This indicates that technical change was labor-saving relative to machinery, intermediate inputs, land, and other inputs. In particular, it was highly labor-saving relative to machinery during the 1950's through the 1960's and then the degree of the bias declined and became almost constant. This is consistent with the fact that the rapid migration of labor out of agriculture accompanied the drastic mechanization during the 1950's through the early 1970's, whereas after that the pace of both labor migration and mechanization has considerably slowed down largely due to the slow-down of the growth of the non-agricultural sectors.

Next,  $N_{LM}$ ,  $N_{LI}$ ,  $N_{LT}$ , and  $N_{LO}$  are also all negative as shown in Table 6. This implies that output expansion results in decreases in labor use in agricultural production relative to machinery, intermediate inputs, land, and other inputs. In other words, output expansion was found to have caused nonhomothetically labor-saving biases relative to all the other factors of production.

We may say from these findings that biases caused by technical

Table 5. Annual Measures of Technical Change Biases,  
1952-82 (Selected Years)

	$B_{LM}$	$B_{LI}$	$B_{LT}$	$B_{LO}$	$B_{MI}$
1952	-0.566	-0.265	-0.071	-0.120	0.300
1960	-0.375	-0.252	-0.079	-0.204	0.123
1970	-0.314	-0.263	-0.095	-0.183	0.051
1982	-0.283	-0.272	-0.111	-0.141	0.011
	$B_{MT}$	$B_{MO}$	$B_{IT}$	$B_{IO}$	$B_{TO}$
1952	0.494	0.686	0.195	0.386	0.191
1960	0.296	0.579	0.173	0.456	0.283
1970	0.219	0.497	0.168	0.446	0.278
1982	0.172	0.425	0.161	0.413	0.253

Table 6. Annual Measures of Nonhomotheticity,  
1952-82 (Selected Years)

	$N_{LM}$	$N_{LI}$	$N_{LT}$	$N_{LO}$	$N_{MI}$
1952	-0.197	-0.711	-0.197	-0.725	-0.514
1960	-0.218	-0.675	-0.218	-0.997	-0.457
1970	-0.264	-0.707	-0.264	-1.029	-0.444
1982	-0.309	-0.734	-0.309	-1.005	-0.425

  

	$N_{MT}$	$N_{MO}$	$N_{IT}$	$N_{IO}$	$N_{TO}$
1952	0	-0.528	0.514	-0.013	-0.528
1960	0	-0.779	0.457	-0.322	-0.779
1970	0	-0.765	0.444	-0.322	-0.765
1982	0	-0.696	0.425	-0.271	-0.696

change and nonhomotheticity had significant impacts on the drastic decline in labor input in postwar Japanese agriculture.

#### Decomposition Analysis of Changes in Relative Factor Uses

In order to simulate the changes in relative factor uses in the postwar agricultural production at the micro level, they were decomposed into the scale effect, the total substitution effect, and the biased technical change effect for the sample period 1952-82. The decomposition was carried out for all the factor combination ratios by making use of (14) for three periods, 1952-60, 1960-70, and 1970-82, together with the whole period, 1952-82. However, since our interest in this study is centered around labor demand in agriculture, the estimates for only four factor combination ratios related to labor are presented in Table 7. They are labor/machinery (L/M), labor/intermediate inputs (L/I), labor/land (L/T), and labor/other inputs (L/O).

As clearly seen in column 3 in Table 7, labor input declined drastically relative to all the other four factor inputs; the annual rates of decrease over the 1952-82 period were 12.0, 12.5, 4.0, and 5.5 percent relative to machinery, intermediate inputs, land, and other inputs, respectively. Observe also that these rates were consistently at the maxima for the period 1960-70 during which the Japanese economy experienced the most rapid growth in its history.

The factors responsible for these drastic decline of labor input relative to the other factor inputs are now investigated by relying on Table 7.

Table 7. Decomposition Analysis of Annual Changes  
in Factor Combination Ratios with Respect  
to Labor, 1952-82

(unit: %)

Factor combination ratio	Period	Change in factor combination	Scale effect	Total substitution effect	Biased technical change effect
L/M	1952-60	-8.96 (100.0)	-0.32 ( 3.6)	-4.66 (52.1)	-3.97 (44.3)
	1960-70	-16.95 (100.0)	-1.35 ( 8.0)	-7.80 (46.0)	-7.80 (46.0)
	1970-82	-8.02 (100.0)	-0.48 ( 6.0)	-1.09 (13.6)	-6.45 (80.4)
	1952-82	-11.95 (100.0)	-0.87 ( 7.3)	-5.42 (45.4)	-5.66 (47.4)
L/I	1952-60	-9.94 (100.0)	-1.09 (10.9)	-5.36 (53.9)	-3.49 (35.1)
	1960-70	-16.92 (100.0)	-3.82 (22.5)	-11.04 (65.3)	-2.06 (12.2)
	1970-82	-5.85 (100.0)	-1.20 (20.4)	-3.17 (54.2)	-1.48 (25.4)
	1952-82	-12.48 (100.0)	-2.43 (19.5)	-7.82 (62.6)	-2.23 (17.9)
L/T	1952-60	-1.25 (100.0)	-0.32 (25.8)	-0.39 (31.3)	-0.54 (42.9)
	1960-70	-4.04 (100.0)	-1.35 (33.5)	-2.31 (57.3)	-0.37 ( 9.2)
	1970-82	-3.66 (100.0)	-0.48 (13.1)	-2.61 (71.4)	-0.57 (15.5)
	1952-82	-3.97 (100.0)	-0.87 (21.9)	-3.44 (86.6)	0.34 (-8.5)
L/O	1952-60	-3.41 (100.0)	-1.32 (38.8)	-2.12 (62.0)	0.03 (-0.8)
	1960-70	-8.51 (100.0)	-5.68 (66.7)	-2.76 (32.5)	-0.07 ( 0.8)
	1970-82	-4.01 (100.0)	-1.82 (45.4)	-3.79 (94.5)	1.60 (-39.8)
	1952-82	-5.49 (100.0)	-3.47 (63.1)	-2.28 (41.5)	0.26 (-4.7)

First, the decline of labor relative to machinery is explained largely by the total substitution effect and the biased technical change effect; 45 and 47 percent are explained by these two effects, respectively, for the period 1952-82. However, the contribution of the total substitution effect drastically declined to only 14 percent for the 1970-82 period, while that of the biased technical change effect increased to 80 percent for the same period. The contribution of the scale effect was only 7 percent on the average.

Our result for the periods 1952-60 and 1960-70 do not support Kako's where the biased technical change explained as much as 70 percent of the decline of labor relative to machinery and the rest 30 percent was due to the total substitution effect for the period 1953-70. This over-estimation of the biased technical change effect by Kako may have come not only from his assumption of homotheticity so that he failed to distinguish the scale effect, but also from the omission of farms in the smallest size class in the estimation of the model.

Second, the decline of labor relative to intermediate inputs is explained largely by the total substitution effect; the contribution of this effect was about 63 percent on the average for the 1952-82 period. The contributions of the biased technical change effect and the scale effect were on the average 18 and 20 percent, respectively.

Third, the most important factor responsible for the decline of labor relative to land was found to be the total substitution effect. Although the biased technical change effect was an important factor during the 1950's (43 percent of contribution), it became smaller after

that period (9 and 16 percent of contribution for the periods 1960-70 and 1970-82, respectively). On the other hand, the scale effect was fairly large during the 1950's and the 1960's (26-34 percent), although it declined in the period 1970-82 (13 percent).

Finally, the decline of labor relative to other inputs is explained mainly by the scale effect and the total substitution effect. In particular, the significant contribution of the scale effect is noteworthy; it was as large as 63 percent on the average during the whole period 1952-82. On the other hand, the biased technical change effect was negligible; it was even negative.

#### 6. Concluding Remarks

In this paper we have estimated the translog cost function for the period 1952-82 in order to investigate mainly the demand for labor in agricultural production on the farm level.

In the process of estimation, we have explicitly tested the hypothesis of cost minimizing behavior of the farm and found that it cannot be rejected. We have further explored the functional structure of agricultural production by testing the hypotheses of homotheticity, constant returns to scale, Cobb-Douglas production function, and Hicks neutral technical change, and found that these null hypotheses are all rejected. We then estimated the translog cost function and the cost share equations jointly by imposing the equality restrictions and arrived at an economically meaningful final specification of the model. This

set of the estimated coefficients was used to compute the Allen partial elasticities of factor substitution, the price elasticities of demand for factors of production, and the biased impacts of technical change and nonhomotheticity on the relative input uses. In addition, the annual changes in the factor combination ratios with regard to labor input was analyzed for the sample period 1952-82 by decomposing them into the scale effect, the total substitution effect, and the biased technical change effect. The results can be summarized as follows.

(1) Although the demand for labor was found to be inelastic, farmers became more and more responsive over time to changes in the farm wage rates. Moreover, the demand elasticities particularly of land and other inputs with respect to the price of labor were positive and fairly large, indicating farmers' elastic demand for these factor inputs in relation to labor input.

(2) The substitutability between labor and machinery was rather low, though the AES increased over time. However, intermediate inputs, land, and other inputs were found to be good substitutes of labor.

(3) Technical change was found to be biased toward labor-saving relative to machinery, intermediate inputs, land, and other inputs. Since the price of labor relative to those of the other four factor inputs increased during the postwar years, we may say that this result is consistent with the induced innovation hypothesis by Hayami and Ruttan.

(4) The bias caused by a scale change was found to be nonhomothetically labor-saving relative to all the other four factor inputs.

That is, output expansion resulted in biased impacts of reducing labor use relative to all the other factor inputs.

(5) According to the decomposition analysis, the total substitution (or price) effect was found to explain a large part of the decline of labor relative to all the other inputs. The technical change effect biased toward labor-saving was found to play as important a role in reducing labor relative to machinery as the total substitution effect. However, it explains only a small part of the decline of labor relative to intermediate inputs, land, and other inputs. The scale effect was found to explain a fairly large part of the decline of labor relative to intermediate inputs, land, and in particular other inputs.

We may conclude from these findings that farmers have been rather responsive to the economic variables in varying the relative factor uses in postwar Japanese agriculture. And this may explain the drastic decrease in labor input on farms during the postwar years.

Footnotes

1) Christensen, Jorgenson, and Lau (1973, p.35) give a clear distinction between the "symmetry" restrictions and the "equality" restrictions. The former is related to the symmetric Hessian of a twice-differentiable function, while the latter refers to the equality of parameters appearing in more than two equations in the system of, say, the translog cost function and the cost share functions.

2) The estimates of the cost share equations can be omitted, since they are all included in the estimates of the translog cost function.

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