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The Output Bias of Technological Change in Postwar Japanese Agriculture

by

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1. Introduction

Japanese agriculture experienced a drastic change in its output mix over the past three decades. This change in the output mix was caused mainly by a remarkable growth in livestock production as shown in Table 1. The value of livestock production in 1984 became five times as much as that in 1955; the annual growth rate was as high as 5.6 percent for this period. On the other hand, crop production was stagnant for the same period, especially during the 1965-84 period; the annual rate of growth for the 1955-84 period was only 0.2 percent. As a result, the share of livestock production in the total agricultural production increased substantially from 7.9 percent in 1955 to 27.5 percent in 1984. This drastic decline in crop production was mainly due to the relative decline in the status of rice production whose share in the total agricultural production reduced from 47.2 percent in 1955 to only 30.2 percent in 1984. Consequently, livestock production has turned out to be as equally important as rice production in Japanese agriculture in recent years.

No one will disagree with the statement that the basic factor that influenced such a high growth in livestock production has been a strong and persistent demand for livestock products due to the increased per capita income resulted from the rapid growth of the Japanese economy as a whole since the mid-1950s. However, even under such a favorable condition on the demand side, it may not have been possible for livestock production to grow with such a high pace if the supply side conditions had not been adjusted to the changes in the food consumption patterns. If technological and managerial improvements in livestock

Table 1. Values of Crop and Livestock Production, 1955-84 (Selected Years)

(Unit: 10 billion yen at 1980 prices)

Year	Crops		Livestock	Others	Total Production
	Total	Rice			
1955	8,006 (87.6)	4,313 (47.2)	726 (7.9)	403 (4.5)	9,135 (100.0)
1965	8,768 (80.3)	4,437 (40.6)	1,710 (15.7)	442 (4.0)	10,920 (100.0)
1975	8,751 (73.5)	4,390 (36.9)	2,563 (21.5)	594 (5.0)	11,908 (100.0)
1984	8,509 (66.6)	3,853 (30.2)	3,518 (27.5)	743 (5.8)	12,770 (100.0)

Source: Ministry of Agriculture, Forestry, and Fisheries, Japan, Social Accounts of Agriculture and Farm Households, various years.

Notes: 1. Others include cocoons and agricultural services.

2. Figures in parentheses are percentage shares in total production.

production, which were associated with the enlargement of business scale and abundant supply of cheap feed grains from abroad, had not been made, such a high growth in livestock production would not have been achieved.

The prime objective of this study is then to investgate the production structure of agriculture in order to explain why livestock production has been able to grow with such a high rate as compared with crop production during the last three decades. In particular, considering the following fact, it is hypothesized that technological change has been biased towards livestock-production-favoring. That is, livestock production during the last three decades was managed in general by higher-quality producers who were younger and specialized in livestock production and hence took up positive attitudes towards technological and managerial improvements by which it has been possible to raise a large number of livestock. On the other hand, a large part of crop, especially, rice production was carried out by in general lower-quality farmers who were often the older, part-timers, or non-specialists and hence were not that positive in improving their managements.

Furthermore, it must be noted that this drastic change in the output mix has proceeded simultaneously with drastic changes in relative factor uses as represented by a sizable transfer of agricultural labor to the nonagricultural sectors which has been accompanied by a rapid mechanization of agricultural production. Although the basic factors that influenced such changes in the levels of relative utilizations of factor inputs in agricultural production must have been changes in the relative factor prices and biases in technological change[1], one may not deny that the drastic change in the composition of agricultural outputs during the period under question must also have affected the relative uses of factor inputs. The second objective of this study is then to investigate the impacts of the change in the output mix on the allocation of factor inputs in agricultural production during the last three decades.

An important contribution of this study to the literature is in the empirical measurement of the output bias brought about by technological change in agriculture. Although a number of empirical studies with the models of multiproduct cost and profit or revenue functions have been published (Lopez, Ray, Shumway, and Weaver for the analysis of agriculture, and Burgess, Denny and Pinto, Brown, Caves, and Christensen, and Fuss and Waverman for the analysis of nonagriculture), there are only a few studies which treat explicitly output biases in technological change[2/] — there is almost none in the field of agricultural economics. Furthermore, although a number of studies with empirical estimations of factor biases in technological change have been documented (Binswanger, Kako 1979, Antle), they have failed to investigate the impacts of changes in the composition of outputs on the factor biases simply because their specifications of the models are single-output translog cost or profit functions. Since this study is to introduce a multiproduct framework, the impacts of changes in the output mix on factor biases can be quantitatively distinguished.

For the abovementioned objectives, the framework of a multiproduct translog (or translog joint) cost function is introduced as most relevant. The reasons for this are as follows. First of all, only when a multiproduct framework is employed, can one explicitly measure output biases in technological change.

Furthermore, although empirical models with the framework of the translog cost function have been extensively applied for the analysis of Japanese agriculture (e.g., Kako 1978, Abe, Nghiep, Chino, and Kuroda), all these studies have focused on a single output, assuming that input allocation decisions are separable and can be made independently of output allocation decisions[3/]. However, the framework of a translog joint cost function will place no such restrictions on the relationships among inputs and outputs. Since, in general, one would expect the cost-minimizing amount of each factor input to depend not only on factor prices but also on the composition of outputs, introduction of the framework of a translog joint cost function may be considered to be most relevant to tackle the problems set up in the present study. Indeed, separability between factor inputs and outputs is treated in this study as an important hypothesis concerning the functional form which will be explicitly tested statistically in the process of estimation together with other hypotheses such as Hicks neutral technological change in inputs, in outputs, and in both inputs and outputs.

The cost function approach has been chosed for the following three reasons. First, the government regulated output prices through price support programs at certain levels during the period under question. These continuous price support programs may have caused "slack" or "inert area" (Leibenstein) in farm management due mainly to lack of competition, so that farmers may have failed to maximize profits through marginal cost pricing even though they may have suceeded in achieving optimization in factor input allocations. Under such a situation, an approach such as a profit or revenue function may not be appropriate. Moreover, the government introduced in the late 1960s an allotment program particularly for rice production which has been the most important product in Japanese agriculture in order to balance the supply with the demand. At least, the level of crop products could then be treated as exogenous. Second, the cost function approach yields direct estimates of the various Allen partial elasticities of substitution. Third, the cost function approach allows us to exploit duality theory without imposing any restrictions on the returns to scale in the underlying technology.

The translog joint cost function will be estimated for the period 1958-84 by making use of farm-level aggregate data[4]. Based on the estimates, the marginal costs of outputs will be computed in order to test the hypothesis concerning with output biases in technological change. In addition, the Allen partial elasticities of substitution and demand elasticities of factor inputs with respect to own-prices and output quantities and factor biases in technological change will be measured in order to investigate the impacts of changes in the output mix on relative factor uses.

2. Methodology

This study defines the following multiproduct cost function.

$$C = G\,(Q_G, Q_A, P_L, P_M, P_F, P_C, P_T, t) \qquad (1)$$

where C is the minimized total cost; Q_G and Q_A are crop and livestock products, respectively; P_L, P_M, P_F, P_C, and P_T are the prices of labor (X_L), machinery (X_M), feed and livestock (X_F), fertilizers and agrichemicals (X_C), and structures and land (X_T), respectively; and t is time as an index of technological change.

For econometric estimation, the following input-output nonseparable and Hicks nonneutral translog form is employed for (1)[5/].

$$
\begin{aligned}
(2) \qquad \ell nC = {} & \alpha_0 + \sum_{i=1}^{2} \alpha_i \ell nQ_i + \sum_{j=1}^{5} \beta_j \ell nP_j + \epsilon_t \ell nt \\
& + \frac{1}{2} \sum_{i=1}^{2} \sum_{k=1}^{2} \gamma_{ik} \ell nQ_i \ell nQ_k + \frac{1}{2} \sum_{j=1}^{5} \sum_{\ell=1}^{5} \delta_{j\ell} \ell nP_j \ell nP_\ell \\
& + \sum_{i=1}^{2} \sum_{j=1}^{5} \rho_{ij} \ell nQ_i \ell nP_j + \sum_{i=1}^{2} \mu_{it} \ell nQ_i \ell nt \\
& + \sum_{j=1}^{5} \nu_{jt} \ell nP_j \ell nt + \frac{1}{2} \epsilon_{tt} (\ell nt)^2
\end{aligned}
$$

where $\gamma_{ik} = \gamma_{ki}$ and $\delta_{j\ell} = \delta_{\ell j}$; $i, k = G, A$; and $j, \ell = L, M, F, C, T$.

Assuming that farms take factor prices as given and using the Shephard's lemma, the cost share equations can be derived as:

$$
(3) \qquad S_i = \frac{\partial \ell nC}{\partial \ell nP_i} = \frac{\partial C}{\partial P_i} \frac{P_i}{C} = \beta_i + \sum_{j=1}^{5} \delta_{ij} \ell nP_j + \sum_{k=1}^{2} \rho_{ki} \ell nQ_k + \nu_{it} \ell nt
$$

where $i, j = L, M, F, C, T$; $k = G, A$; and $S_i = P_i X_i / C$.

At this point, it may be relevant to mention about statistical hypotheses to be tested in the process of estimation of the translog joint cost function. The following tests are of critical importance for the subsequent analysis concerning with both input and output biases in technological change and elasticities of demand for and substitution between factor inputs.

To begin with, if the technology is separable with respect to a partitioning between inputs and outputs, provided that the production frontier is linear homogeneous in the outputs, the translog cost function can be written as $C(Q, P, t) = H(Q, t) \cdot J(P, t)$ (Hall). This multiplicative separability implies the following set of parameter restrictions on the translog cost function: $\sum_{i=1}^{2} \alpha_i = 1$; $\sum_{i=1}^{2} \gamma_{ij} = 0, \ \forall_j$; $\sum_{i=1}^{2} \mu_{it} = 0$; and $\rho_{ik} = 0, \ \forall_{i,k}$ ($i, j = G, A$; $k = L, M, F, C, T$). Rejection of this hypothesis implies that the marginal rates of substitution between pairs of factor inputs are not independent of the composition of outputs, and marginal rates of transformation between pairs of outputs are not independent of the composition of factor inputs.

Next, Hicks neutrality of technological change can also be tested. In this case, depending on whether the dual cost function is multiplicatively nonseparable or separable in inputs and outputs, several cases may be distinguished. First, if the cost function is not separable and characterized by Hicks neutral technological change, it can be written as $C(Q, P, t) = A(t)H(Q, P)$. This implies the following set of parameter restrictions on the translog joint cost function: $\mu_{it} = 0, \ \forall_i$ and $\nu_{jt} = 0, \ \forall_j$ ($i = G, A$; $j = L, M, F, C, T$). Technological change in this case may be defined as extended Hicks-neutral technological change in a multiproduct version (Blackorby, Lovell, and Thursby). If this hypothesis could not be rejected, then there exists Hicks neutrality in both inputs and outputs. That is, technological change leaves expansion paths unchanged in both input and output spaces. Rejection of this hypothesis implies that there exists Hicks-nonneutral technological change. However, one may not a priori distinguish whether nonneutrality exists in inputs or outputs or both. In such a case, one has to examine the statistical significance of the estimates of the above coefficients.

Second, if the cost function is multiplicatively separable in inputs and outputs and technological change is Hicks neutral in outputs, then the cost function can be written as $C(Q, P, t) = A^1(t)H^1(Q)H^2(P, t)$. This implies the following parameter restrictions: $\sum_{i=1}^{2} \alpha_i = 1$; $\sum_{i=1}^{2} \gamma_{ij} = 0$, $\forall_j$; $\rho_{ik} = 0$, $\forall_{i,k}$; and $\mu_{it} = 0$, $\forall_i$ $(i, j = G, A;\ k = L, M, F, C, T)$.

Third, if the cost function is multiplicatively input-output separable and characterized by Hicks-neutral technological change in inputs, then it can be written as $C(Q, P, t) = B^1(t)J^1(P)J^2(Q, t)$. The implied parameter restrictions are: $\sum_{i=1}^{2} \alpha_i = 1$; $\sum_{i=1}^{2} \gamma_{ij} = 0$, $\forall_j$; $\sum_{i=1}^{2} \mu_{it} = 0$; $\nu_{kt} = 0$, $\forall_k$; and $\rho_{ik} = 0$, $\forall_{i,k}$ $(i, j = G, A;\ k = L, M, F, C, T)$.

Finally, if the cost function is multiplicatively separable and characterized by Hicks neutrality in both inputs and outputs, then it can be written as $C(Q, P, t) = B(t)G^1(Q)G^2(P)$, implying the following parameter restrictions: $\sum_{i=1}^{2} \alpha_i = 1$; $\sum_{i=1}^{2} \gamma_{ij} = 0$, $\forall_j$; $\rho_{ik} = 0$, $\forall_{i,k}$; $\mu_{it} = 0$, $\forall_i$; and $\nu_{kt} = 0$, $\forall_k$ $(i, j = G, A;\ k = L, M, F, C, T)$.

Note however that the last three hypotheses are valid only when the cost function is multiplicatively separable in inputs and outputs. Thus, if the hypothesis of separability is rejected, there would be no need to carry out these tests. Furthermore, all of the abovementioned hypotheses will be tested conditionally on the maintained hypothesis of cost minimization which requires the equality of parameters across all equations.

In order to achieve the first objective of this study, we introduce a measure of the bias of technological change in outputs following Antle and Capalbo. In the case of a two-product cost function as in this study, an output bias measure can be constructed to detect a movement of the expansion path in output space. It is thus defined as

$$(4) \qquad B_{ij}^{Q} \equiv \partial \ell n\left(\frac{\partial C}{\partial Q_i} / \frac{\partial C}{\partial Q_j}\right) / \partial t$$

$$= \frac{\partial \ell n MC_i}{\partial t} - \frac{\partial \ell n MC_j}{\partial t}$$

$$= \dot{MC}_i - \dot{MC}_j .$$

B_{ij}^{Q} measures the change in the slope of the isorevenue curve due to technological change, at a given point in output space. That is, B_{ij}^{Q} measures the rotation of the production possibility curves at this point due to technological change, as illustrated in Figure 1. The initial expansion path is $e(t_1)$ and the farm-firm is producing at point E_1. Technological change leads to a new expansion path $e(t_2)$. The production possibility curve T_2T_2 on the new expansion path passes through point E_1. B_{ij}^{Q} measures the change in the slope of the isorevenue line P_1 tangent to T_1T_1 to the slope of the isorevenue line P_2 tangent to T_2T_2. Thus, $B_{ij}^{Q} = 0$ if and only if technological change is Hicks neutral and the expansion path leaves unchanged by technological change. Otherwise technological change is biased.

Thus, the bias in technological change in output space may be defined as output j-favoring (or output i-disfavoring) if $B_{ij}^{Q} > 0$, neutral if $B_{ij}^{Q} = 0$, or output i-favoring (or output j-disfavoring) if $B_{ij}^{Q} < 0$. In words, output-biased technological change can be classified

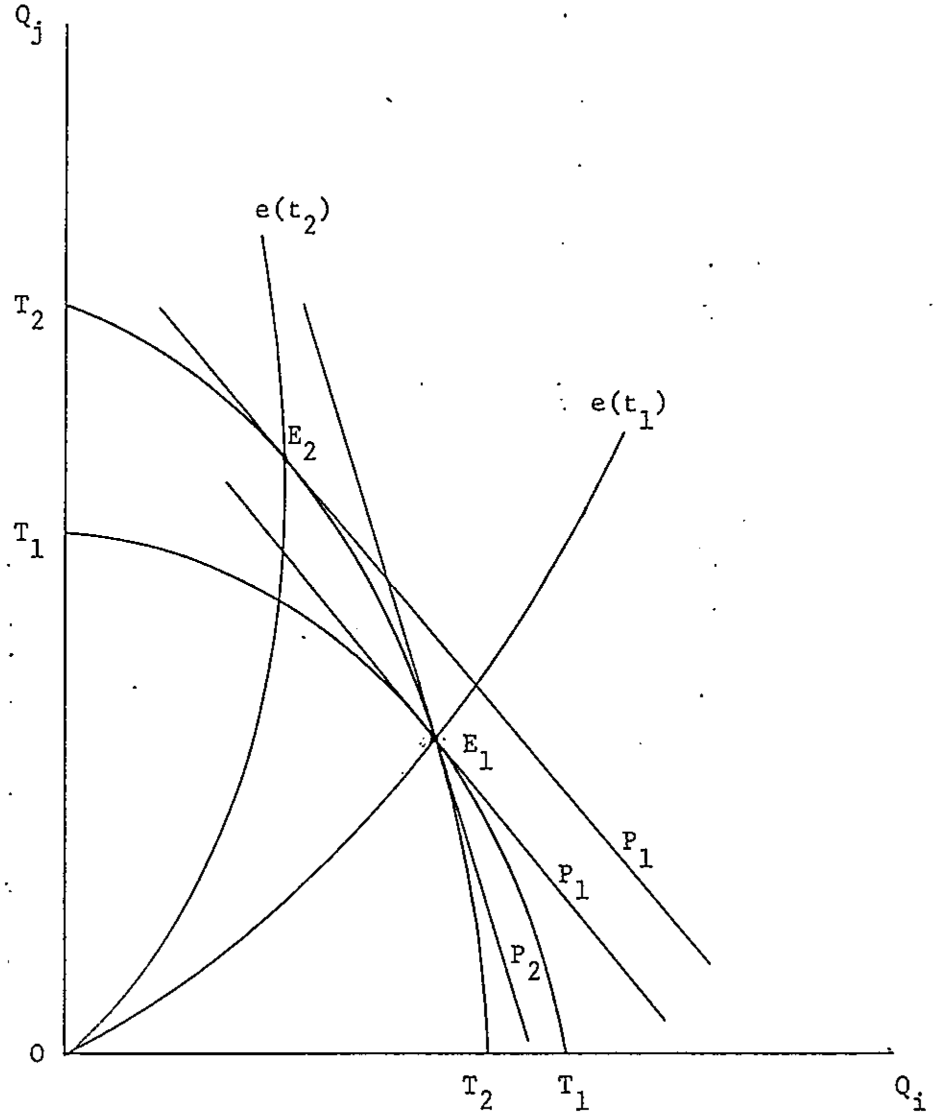

Figure 1. Biased Technological Change in Output Space in a Multiproduct Cost Function Framework

according as its initial effects are to increase, leave unchanged, or diminish the ratio of the marginal cost of output i to that of output j. The technological change may be called output j-favoring, neutral, or output i-favoring.

In terms of the multiproduct translog cost function in this study, the marginal cost of each output can be derived by differentiating the cost function with respect to that output as:

$$(5) \qquad \frac{\partial \ell nC}{\partial \ell nQ_i} = \alpha_i + \sum_{j=1}^{5} \rho_{ij} \ell nP_j + \sum_{k=1}^{2} \gamma_{ik} \ell nQ_k + \mu_{it} \ell nt,$$

where i, k = G, A and j = L, M, F, C, T. These equations can be transformed into marginal cost equations simply by multiplying both sides by C/Q_i. Since the marginal costs can be estimated for each observation for the estimation period (1958-84), the rates of growth of the marginal costs necessary to evaluate B_{ij}^{Q} in (4) can easily be obtained for any subperiods as well as for the overall period. We expect B_{GA}^{Q} $(= \dot{MC}_G - \dot{MC}_A)$ to be positive, i.e., livestock-favoring technological change, for the period under question in order for our hypothesis to be valid.

The second objective of this study is to investigate how the changes in the output mix affected the relative factor uses during the last three decades. In order to tackle this problem, we will compute the Allen partial elasticities of substitutions (AES) between pairs of factor inputs and the elasticities of demand for factor inputs with respect to factor prices and output quantities. In addition, the biased impacts of technological change on relative factor uses will be measured.

The AES and price elasticities for factor inputs can be computed by the following formulas (Berndt and Christensen):

$$(6)\qquad \sigma_{ij} = (\delta_{ij} + S_i S_j)/S_i S_j, \quad i \neq j,\ i = j = L, M, F, C, T,$$

$$(7)\qquad \sigma_{ii} = (\delta_{ii} + S_i^2 - S_i)/S_i^2, \quad i = L, M, F, C, T,$$

$$(8)\qquad e_{ij} = S_j \sigma_{ij}, \qquad i, j = L, M, F, C, T.$$

The factor demand elasticities with respect to output quantities, e_{ik}, can be computed by

$$e_{ik} = \frac{\partial \ell n X_i}{\partial \ell n Q_k} = \frac{\partial \ell n C}{\partial \ell n Q_k} + \frac{\partial \ell n}{\partial \ell n Q_k}\left(\frac{\partial \ell n C}{\partial \ell n P_i}\right)$$

by making use of the relation $S_i = P_i X_i / C = \partial \ell n C / \partial \ell n P_i$ (i = L, M, F, C, T; k = G, A). Making use of the parameters of the translog joint cost function, e_{ik} can be expressed as,

$$(9)\qquad e_{ik} = \alpha_k + \sum_{i=1}^{5} \rho_{ki} \ell n P_i + \sum_{k=1}^{2} \gamma_{k\ell} \ell n Q_\ell + \mu_{kt} \ell n t + \frac{\rho_{ki}}{S_i},$$

$$i = L, M, F, C, T; \quad k, \ell = G, A.$$

Antle and Capalbo has proposed an overall bias measure of technological change in input space in both the single-product and multiproduct cases by extending Binswanger's definition of the bias measure to the case of nonhomothetic (in the single-product case) and input-output nonseparable (in the multiproduct case) production technologies. According to their definition, the change in optimal cost shares due to technological change can be decomposed into a scale effect which is caught by a movement along the expansion path and a bias effect due to the shifting of the expansion path. In the multiproduct case, the overall bias measure is defined in a formal manner as,

$$(10) \qquad B_i^e = B_i + \left[\sum_{j=1}^{m} \frac{\partial \ell n S_i(Q,P,t)}{\partial \ell n Q_j} \cdot \left(\frac{\partial \ell n C}{\partial \ell n Q_j}\right)^{-1} \right] \left(- \frac{\partial \ell n C}{\partial t}\right),$$

where $B_i \equiv \partial \ell n S_i(Q, P, t)/\partial t$. Since input-output separability implies $\partial \ell n S_i/\partial \ell n Q_j = 0$ for all i and j, the scale effect, i.e., the second term of (10), is eliminated and thus the overall bias measure is composed only of the effect of a shift in the expansion path.

In terms of the translog joint cost function in this study, the cost-output elasticities ($\epsilon_{CQ_j} = \partial \ell n C/\partial \ell n Q_j$) can be computed by equation (5) and the negative of the rate of cost diminution ($\lambda = -\partial \ell n C/\partial t$) can be obtained by:

$$(11) \qquad \lambda = - \frac{\partial \ell n C}{\partial t} = (\epsilon_t + \sum_{i=1}^{2} \mu_{it} \ell n Q_i + \sum_{j=1}^{5} \nu_{jt} \ell n P_j + \epsilon_{tt} \ell n t)/t,$$

where i = G, A and j = L, M, F, C, T. Thus, the overall bias can be measured by,

$$(12) \qquad B_i^e = B_i + \frac{\lambda}{S_i} \cdot \frac{\rho_{Gi}}{\epsilon_{CQ_G}} + \frac{\lambda}{S_i} \cdot \frac{\rho_{Ai}}{\epsilon_{CQ_A}} \quad .$$

The first term of the right hand side measures the bias in response to a shift in the expansion path, the second term measures the scale effect due to crop production, and the last term measures the scale effect due to livestock production.

3. The Data

The data required for the estimation of the model is the total

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cost, the quantities of the two outputs, crop and livestock products, and the prices and cost shares of the five factor inputs; labor, machinery, feed and livestock, fertilizers and agrichemicals, and structures and land. The major sources of data used to process these variables are the Survey Report on Farm Household Economy (FHE) and the Survey Report on Prices and Wages in Rural Villages (PWRV) published annually by the Ministry of Agriculture, Forestry, and Fisheries. In each year of the 1958-84 period one average farm was taken from each of the four size classes, 0.5-1.0, 1.0-1.5, 1.5-2.0, and 2.0 hectares or over, from all Japan excluding the Hokkaido district because of the different size classification. Thus, the sample size is 27 × 4 = 108[6].

At this point, it may be necessary to say a word about the nature of data for the "average farm" reported in the FHE. The data of the FHE is basically compiled by sampling method each year. The "average" data is obtained by simply averaging data of sample farms. However, such average data does not always imply that every sample farm produces every kind of output with every kind of factor input.

In reality, it has been common, since already around 1960, for most farms to be monoculture or quasi-monoculture producers whose sale of the major product shares more than 80 percent or 60-80 percent in the total sale[7]. Therefore, the drastic increase in the share of livestock production in the total agricultural production mentioned in section one, for example, may not imply that each farm increased livestock production relatively much more than crop production. Instead, it should be interpreted in such a manner that livestock producers increased their output relatively more than crop producers.

In this sense, therefore, the "average" data in the FHE which is obtained by averaging data of sample farms from such a population may be regarded as representing an aggregate level rather than the farm level.

The quantity and price indexes of crop products (Q_G and P_G) were computed by the Törnqvist approximation method of the Divisia index. For this computation, ten different categories of crop products were distinguished and the price indexes for these categories were taken from the PWRV. The quantity index of livestock products (Q_A) was obtained by dividing the market sales of livestock products, by the price index of livestock products (P_A) taken from the PWRV. The base year of these and the following indexes is set at 1958.

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 1958 values and hence are expressed in index terms.

The quantity and price indexes of machinery (X_M and P_M), feed and livestock (X_F and P_F), and fertilizers and agrichemicals (X_C and P_C) were constructed as the Törnqvist quantity and price indexes. In these computations, the cost of machinery ($P_M X_M$) was defined as the sum of the expenditures on machinery, energy, and rentals; the cost of feed and livestock ($P_F X_M$) as the sum of expenditures on feed and livestock; and the cost of fertilizers and agrichemicals ($P_C X_C$) as the sum of the expenditures on fertilizers, insecticides and herbicides, seeds, materials, and clothes. All of the price indexes necessary in these computations were obtained from PWRV.

The Törqvist quantity and price indexes (X_T and P_T) were also estimated for structures and land. For this computation, the price of land was estimated by dividing the cost for rented land by the rented land area. The cost of land was estimated by multiplying the arable land area (including rented land area) by the price of land. Then, the cost of structures and land ($P_T X_T$) was obtained as the sum of the expenditures on plants and farm buildings and structures and the cost of land. The price indexes corresponding to the first two items were obtained from the PWRV.

Finally, the total cost (C) was defined as the sum of the expenditures on the five categories of factor inputs, i.e., $C = \sum_{i=1}^{5} P_i X_i$ (i = L, M, F, C, T). 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

Before describing the statistical specification, the following two points are worth mentioning. First, any cost function approach may face simultaneous equations bias due to the possible endogeneity of output levels in the system[8]. In order to avoid such a bias, introduction of instrumental variables may be useful (Antle and Crissman). Noting that input decisions should depend not on actual, realized output levels but on expected or planned levels of outputs, we will estimate a supply function of the form

$$Q_{it} = F_i(P_G, P_A, P_L, P_M, P_F, P_C, P_T, t), \quad i = G, A,$$

specifying them with the translog form and using the same set of data described in the previous section. The fitted values will then be used as estimates of expected output levels in the translog joint cost function. These measures of expected output levels ($\hat{Q}_G$ and $\hat{Q}_A$) are exogenous and therefore the estimates of the translog joint cost function will be free of simultaneous equations bias.

Second, any cost function must satisfy linear homogeneity in factor prices as a regularity condition. This requires in the translog joint cost function that $\sum_{i=1}^{5} \beta_i = 1$, $\sum_{j=1}^{5} \delta_{ij} = 0$, $\sum_{j=1}^{5} \rho_{kj} = 0$, and $\sum_{j=1}^{5} \nu_{jt} = 0$ (i, j = L, M, F, C, T; k = G, A). This implies that any one of the prices can be used as a numerair. Using the price index of structures and land (P_T) as a numerair and imposing these parameter restrictions, the translog cost and factor cost share functions (2) and (3) can be rewritten as:

$$(13) \qquad \ell nC/P_T = \alpha_0 + \sum_{i=1}^{2} \alpha_i \ell nQ_i + \sum_{j=1}^{4} \beta_j \ell nP_j/P_T + \epsilon_t \ell nt$$
$$+ \frac{1}{2} \sum_{i=1}^{2} \sum_{k=1}^{2} \gamma_{ik} \ell nQ_i \ell nQ_k + \frac{1}{2} \sum_{j=1}^{4} \sum_{\ell=1}^{4} \delta_{j\ell} \ell nP_j/P_T \ell nP_\ell/P_T$$

$$+ \sum_{i=1}^{2} \sum_{j=1}^{4} \rho_{ij} \ln Q_i \ln P_j/P_T + \sum_{i=1}^{2} \mu_{it} \ln Q_i \ln t$$

$$+ \sum_{j=1}^{4} \nu_{jt} \ln P_j/P_T \ln t + \frac{1}{2} \epsilon_{tt} (\ln t)^2$$

$$(14) \qquad S_j = \beta_j + \sum_{j=1}^{4} \delta_{j\ell} \ln P_j/P_T + \sum_{i=1}^{2} \rho_{ij} \ln Q_i + \nu_{jt} \ln t$$

$$i, k = G, A, \quad j, \ell = L, M, F, C.$$

The estimates of the coefficients of the cost share equation of structures and land (S_T) can immediately be obtained by making use of the parameter relationships of the linear homogeneity after the system is estimated. The system of the five equations in (13) and (14) will be jointly estimated for the 1958-84 period.

For statistical specification we assume an additive error with zero expectations and finite variance for each of the five equations of the model given in (13) and (14). 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, iterated 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. As described earlier, the statistical hypotheses will be tested in the process of estimation and, based on the results of the tests, constraints will be imposed on the coefficients in the equations if necessary in order to increase the efficiency of estimation[9].

5. Empirical Results

5.1 Tests of Statistical Hypotheses and Final Specification[10]

The statistical hypotheses described in section two were first tested. The first test carried out is input-output separability conditional on the maintained hypothesis of cost minimization (i.e., across-equations equality)[11]. The computed F with the degrees of freedom (12,504) was 191.4. Since the critical F's with these degrees of freedom are respectively 1.75 and 2.18 at the 5 and 1 percent significance levels, this hypothesis is strongly rejected. This implies that input decisions and output decisions are not independent of each other. That is, changes in the composition of outputs give impacts on the elasticities of demand for and substitution between factor inputs as well as technological change biases if technological change is not Hicks neutral. Conversely, changes in the factor proportions affect the marginal rate of transformation between the two outputs.

Second, extended Hicks neutrality in both inputs and outputs was tested again conditionally on the across-equations equality. The computed F was 14.3 with the degrees of freedom (6,504) and decisively rejected since the critical F's are respectively 2.10 and 2.80 at the 5 and 1 percent significance levels. This implies that biases in technological change exist in either input space or output space or both. The question of which space is biased may roughly be examined by looking at the estimated coefficients of $\hat{\mu}_{it}$ (i = G, A) and $\hat{\nu}_{jt}$ (j = L, M, F, C, T) when the final specification of estimates of the translog cost function is provided.

Since the input-output separability test was strongly rejected, the remaining tests concerning with Hicks neutrality on the condition of the input-output separability were not carried out.

Based on the results of the tests of hypotheses, the system of equations were jointly estimated this time imposing the restrictions which were tested but not rejected. In the present case, only the across-equations equality restrictions of the maintained hypothesis of cost minimization 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 joint cost function are presented in Table 2. This set of estimates is referred to as our final specification and will be used for empirical analyses[12].

5.2 The Output Bias of Technological Change

The primal objective of this study was to investigate the factor for the rapid growth of livestock production on the supply side during the last three decades. For this objective, it was hypothesized that technological change has been relatively livestock-production-favoring (or crop-production-disfavoring), that is, $B^Q_{GA} = \dot{MC}_G - \dot{MC}_A > 0$.

In order to test this hypothesis, the marginal cost of crop and livestock production (MC_G and MC_A) were computed using equation (5) for the 1958-84 period[13]. In addition, using the marginal costs and the price indexes of these products (P_G and P_A), the marginal cost-price ratios and the marginal rate of transformation together with the price ratio were computed for the same period. However, since all the variables in the model are expressed in index terms, the estimated MC_s and

Table 2. Estimates of the Translog Joint Cost Function for 1958-84

Parameter	Coefficient	Parameter	Coefficient	Parameter	Coefficient
α_0	-0.0072	δ_{CC}	0.0456*	ρ_{GC}	-0.0734*
α_G	0.7330*	δ_{TT}	0.0187°	ρ_{GT}	0.0456°
α_A	0.0420	δ_{LM}	-0.0407*	ρ_{AL}	-0.0502*
β_L	0.5972*	δ_{LF}	-0.0038	ρ_{AM}	-0.0228*
β_M	0.0763	δ_{LC}	-0.0073**	ρ_{AF}	0.0558*
β_F	0.0897*	δ_{LT}	0.0359°	ρ_{AC}	0.0224*
β_C	0.1659*	δ_{MF}	-0.0087*	ρ_{AT}	-0.0052°
β_T	0.0709°	δ_{MC}	-0.0034	μ_{Gt}	-0.0603**
ϵ_t	0.0914*	δ_{MT}	-0.0184°	μ_{At}	0.1958*
γ_{GG}	-0.1344*	δ_{FC}	-0.0206*	ν_{Lt}	-0.0465*
γ_{AA}	-0.0819	δ_{FT}	-0.0220°	ν_{Mt}	0.0304*
γ_{GA}	0.0091	δ_{CT}	-0.0143°	ν_{Ft}	0.0049**
δ_{LL}	0.0159	ρ_{GL}	-0.0171*	ν_{Ct}	0.0132*
δ_{MM}	0.0710*	ρ_{GM}	0.0363*	ν_{Tt}	-0.0020°
δ_{FF}	0.0551*	ρ_{GF}	-0.0574*	e_{tt}	-0.1748*

Note: * and ** indicate that the coefficients are statistically significant at the 5 and 10 percent levels, respectively. Coefficients with ° were computed by making use of the linear homogeneity restrictions.

the related statistics are also expressed in index terms by setting the 1958 values to 1.0. These estimates are provided in Table 3.

It is clearly seen in this table that the marginal cost of crop production grew faster than that of livestock production for any subperiods during the 1958-84 period: for example, the compound annual rates of growth ($\dot{MC}_G$ and $\dot{MC}_A$) for the overall period were 5.9 and 4.4 percent, respectively. This implies that $B^Q_{GA} > 0$, indicating that technological change during the 1958-84 period was characterized by livestock-production-favoring and crop-production-disfavoring.

This process of the output bias of technological change can more clearly be captured by a diagramatical interpretation. All we have to do is change the notations of the horizontal and vertical axes in Figure 1 from Q_i to Q_G and from Q_j to Q_A. Then, the shift of the production possibility frontiers from, say, T_1T_1 to T_2T_2 corresponds to relatively livestock-production-favoring technological change in the two-product cost function framework as in this study. This implies a shift (an increase) in the marginal rate of transformation from P_1 to P_2. The estimated MRT in Table 3 is consistent with this shift.

Observe further in Table 3 that the marginal cost of crop production (MC_G) increased with almost the same rate as the price (P_G), suggesting that farms almost achieved revenue maximization in the planned level of the crop production. On the other hand, MC_A increased as fast as the price of livestock production (P_A) until around the mid-1960s, whereas after that period the rate of increase in MC_A slowed down relative to that in P_A. This indicates that farms did not achieve revenue maximization in livestock production after the late 1960s and

Table 3. Indexes of Output Prices, Marginal Costs, Marginal Cost-Price Ratio, Marginal Rate of Transformation, and Output Price Ratio, 1958-84 (Selected Years)

Year	Price index		Marginal cost		MC-price ratio		MRT	Price ratio
	P_G	P_A	MC_G	MC_A	$\frac{MC_G}{P_G}$	$\frac{MC_A}{P_A}$	$\frac{MC_G}{MC_A}$	$\frac{P_G}{P_A}$
1958	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1965	1.58	1.42	1.59	1.41	1.00	0.99	1.12	1.11
1975	3.44	3.21	3.47	3.09	1.01	0.97	1.12	1.07
1984	4.39	3.37	4.42	3.09	1.01	0.92	1.43	1.30

Note: 1. Subscripts G and A refer to crop and livestock production, respectively.

2. For the computation of output price indexes, refer to section three.

3. Marginal costs were computed based on equations (5).

4. All of the indexes were obtained based on the weighted averages of the necessary variables for their computations. The weights used are the shares of the numbers of farm households of the four size classes (described in section three) in the total number of farm households of these four size classes.

thus there was a room for the farms to expand the planned level of livestock production in order to maximize the total revenue. This relatively slow increase in MC_A compared with MC_G accounts for the faster increase in the MRT, especially after the mid-1960s, compared with the price ratio. This in turn indicates that technological and/or managerial improvements in livestock production were achieved more favorably than in crop production during the period under question.

The output bias of technological change may also be investigated by examining directly parameter estimates of the translog joint cost function provided in Table 2. As suggested earlier, the parameter estimates of μ_{it} (i = G, A) may be used as an indicator of the output bias of technological change in the following manner. Under the assumption of marginal cost pricing, equations (5) can be regarded as the "revenue" share (in total cost) equations. One may then define the output bias measure of technological change analogously to the input bias measure proposed by Binswanger. We define here technological change as output i-favoring, neutral, or output i-disfavoring according as $\partial R_i/\partial \ell nt$ is positive, equal to zero, or negative, where $R_i = \partial \ell n\hat{C}/\partial \ell nQ_i$ $(= P_iQ_i/C)$.

According to Table 2, $\hat{\mu}_{Gt}$ and $\hat{\mu}_{At}$ are respectively -0.063 and 0.1958 and are statistically significant at the 10 and 5 percent levels, respectively, using the asymptotically estimated t-values. This result indicates again that agricultural production during the 1958-84 period was characterized by livestock-production-favoring technological change.

5.3 Elasticities of Substitution between and Demand for Factor Inputs and Factor Biases in Technological Change

In order to investigate how the changes in the output mix affected the relative factor uses during the last three decades, the AES and the elasticities of demand for factor inputs with respect to own prices and output quantities were computed using equations (6) through (9). In addition, the biased impacts of Hicks nonneutral technological change on the relative factor uses were measured based on equation (12). It is clearly seen in these equations that these elasticities and technological change biases are affected by the composition of outputs, since the factor cost shares (S_i) are a function of the quantities of outputs due to the nonseparable property of the model in this study (i.e., ρ_{ij} and μ_{it} are not all zeros where $i = G, A$ and $j = L, M, I, T, O$). The computed results of own-price demand elasticities and AES, output-quantity demand elasticities, and factor bias measures are provided in Tables 4, 5, and 6, respectively.

To begin with, it was found in Table 4 that the own-price elasticities of demand for factors are all less than unity in absolute terms, indicating that the demand for these factor inputs were inelastic during the 1958-84 period.

Let us compare our estimates with those in previous studies. However, the comparison will be limited to the own-price elasticities of only labor and machinery obtained through estimating translog cost functions, since the definitions of the other variables are widely different among the studies referred. Kako (1978) and Chino have estimated the translog cost function for rice production for the 1953-70 and

1958-78 periods, respectively, and obtained the own-price demand elasticities of labor, 0.40 $\sim$0.47 and 0.56 in absolute terms for the respective periods. Kuroda estimated the translog cost function based on aggregate farm level data for the 1952-82 period and obtained the elasticity of 0.61 in absolute term. These values of elasticities may be said to be consistent with the one in this study.

The elasticities of demand for machinery obtained by Kako and Chino were 0.54 (1953) $\sim$ 0.59 (1970) and 0.42, in absolute terms, respectively, while Kuroda obtained 0.25. It seems that Kako and Chino's estimates are slightly greater than the one obtained in this study, 0.27.

Next, it was found in Table 4 that feed and livestock, fertilizers and agrichemicals, and structures and land are fairly good substitutes for labor. Machinery was found to be also a substitute of labor. However, the value of the AES, σ_{LM}, was as small as 0.20. This value is, though seemingly smaller, roughly consistent with that by Kuroda, 0.55, on the average for the 1952-82 period. However, it is much smaller than those obtained by Kako and Chino, 0.93 and 1.17, respectively. It should be noted here that they obtained these estimates based on the parameter estimates of homothetic translog cost functions. According to a sensitivity analysis made in Appendix B, the labor-machinery elasticity of substitution seems to have a tendency to turn out to be larger if the restictions due to the assumption of input-output separability (homotheticity in a single-output model) are imposed. Thus, Kako and Chino's estimates of σ_{LM} are likely to have been overestimated.

The AES and price elasticities of demand as such may not offer direct information to investigate the impacts of changes in the output mix on the relative factor uses, unless they are estimated separately based on the parameter estimates of the translog cost function specified separately for crop and livestock production. However, an investigation of the demand elasticities of factor demand with respect to the (planned) quantity of each output may throw some light on this problem. Let us then examine the output-quantity demand elasticities reported in Table 5. Several important findings emerge from this table.

First, the demand elasticity of labor with respect to the quantity of crop output($\hat{Q}_G$) was found to be 0.57 which is almost double as large as that with respect to the quantity of livestock output ($\hat{Q}_A$), 0.32. This implies that a unit expansion of livestock production requires less amount of labor than a unit expansion of crop production. We may thus infer that the rapid growth of livestock production during the period under question had a relatively stronger impact on the rapid migration of labor from the agricultural to nonagricultural sectors than increase in crop production.

Second, the demand for machinery with respect to $\hat{Q}_G$ was found to be fairly elastic, while that with respect to $\hat{Q}_A$ was found to be much less elastic; the values of elasticities are 0.92 and 0.25, respectively. This may imply that a unit expansion of crop production requires larger amount of machinery input than that of livestock production.

Third, as expected a priori the demand elasticity of feed and livestock with respect to $\hat{Q}_G$ was found to be very small, while that with respect to $\hat{Q}_A$ was found to be fairly large (0.93). Furthermore,

Table 4. Own-Price Demand Elasticities and Allen Partial Elasticities of Substitution (Averages for 1958-84)

	Labor	Machinery	Feed and livestock	Fertilizers and agrichemicals	Structures and land
Own-price elasticities	-0.53 (0.05)	-0.27 (0.06)	-0.40 (0.07)	-0.57 (0.00)	-0.72 (0.01)

Allen partial elasticities of substitution

	Machinery	Feed and livestock	Fertilizers and agrichemicals	Structures and land
Labor	0.20 (0.06)	0.92 (0.01)	0.91 (0.01)	1.62 (0.07)
Machinery		0.35 (0.18)	0.85 (0.03)	-0.21 (0.42)
Feed and livestock			0.05 (0.21)	-0.50 (0.62)
Fertilizers and agrichemicals				0.43 (0.16)

Note: Standard errors in parentheses are computed as follows:

$$SE(e_{ii}) = SE(\delta_{ii})/S_i \; ; \; SE(\sigma_{ij}) = SE(\delta_{ij})/S_i S_j .$$

For the estimates concerning with other inputs, standard errors cannot be computed, since the δ_{iT} (i = L, M, F, C, T) were obtained as implied estimates through the linear homogeneity restrictions.

Table 5. Demand Elasticities with Respect to Output Quantities (Averages for 1958-84)

	Labor	Machinery	Feed and livestock	Fertilizers and agrichemicals	Structures and land
With respect to $\hat{Q}_G$	0.57 (0.04)	0.92 (0.07)	0.11 (0.05)	0.58 (0.03)	0.96 (0.11)
With respect to $\hat{Q}_A$	0.32 (0.11)	0.25 (0.15)	0.93 (0.08)	0.56 (0.12)	0.40 (0.14)

Note: 1. Figures in parentheses are conventionally computed standard deviations of means.

2. $\hat{Q}_G$ and $\hat{Q}_A$ are estimated planned levels of crop and livestock production. The details of the estimation procedure are given in section four.

the demand elasticities of fertilizers and agrichemicals with respect to $\hat{Q}_G$ and $\hat{Q}_A$ were found to be almost equal.

Finally, the demand elasticity of structures and land with respect to $\hat{Q}_G$ was found to be much greater than that with respect to $\hat{Q}_A$ (0.96 and 0.40, respectively). This may reflect the fact that livestock production in Japan has been practiced by raising livestock mainly with purchased grain feed, which does not require large area of farm land for pasture production.

The effects of technological change on factor cost shares were computed by making use of equation (12). The results are presented in Table 6. Several findings are noteworthy. First, the overall bias measures (B_i^e) show that technological change during the 1958-84 period was strongly biased towards labor-saving and machinery-using. Furthermore, these overall bias measures indicate that technological change was biased towards feed and livestock, fertilizers and agrichemicals, and structures and land. Note that a major part of all of these overall biases is explained by the bias changes due to shifts in the expansion path (B_i).

This finding supports the results obtained by Kako (1979) and Chino who found labor-saving and machinery-using technological change in rice production for the 1953-70 and 1958-78 periods, respectively. Since the price of labor relative to those of machinery, feed and livestock, fertilizers and agrichemicals, and structures and land increased during the last three decades, it may be said that our result as well as those by Kako and Chino is consistent with the induced innovation hypothesis by Hayami and Ruttan. Furthermore, as seen clearly in Table 6, the degrees of the biases towards labor and against machinery are much larger than those of the biases with respect to the other factor inputs. We may thus infer that these biased effects of labor-saving and machinery-using technological change contributed to a substantial extent to the labor-machinery substitution during the sample period, whereas the degree of substitution with respect to changes in the relative prices was found to be fairy small as indicated by the Allen partial elasticity of substitution (0.20 in Table 4).

Second, investigations of the scale effects (B^S_{iG} and B^S_{iA}) shed light on the effects of changes in the output mix on the directions and magnitudes in the relative factor uses. The scale effect due to crop production was in the directions in strongly saving feed and livestock (as was easily expected), slightly saving labor and fertilizers and agrichemicals, and using machinery. On the other hand, the scale effect due to livestock production was found to be strongly against labor and machinery, strongly towards feed and livestock and fertilizers and agrichemicals, and slightly against structures and land.

Above all, we note here that although both crop and livestock production had labor-saving scale effects, the extent of labor-saving effect due to livestock production was found to be greater than that due to crop production. This finding may indicate that an expansion of livestock production requires a relatively less amount of labor than in the case of expansion of crop production. Combining this finding with the finding that technological change was livestock-output-favoring, and with the finding that the demand elasticity of labor with respect to the quantity of livestock production was smaller than that with

Table 6. Factor Biases in Technological Change

(Averages for 1958-84)

(Unit: %)

	B_i	B^S_{iG}	B^S_{iA}	B^e_i
Labor	-1.12 (67)	-0.10 (6)	-0.44 (27)	-1.66 (100)
Machinery	2.98 (100)	0.76 (26)	-0.77 (-26)	2.97 (100)
Feed and livestock	0.52 (41)	-1.21 (-95)	1.96 (154)	1.27 (100)
Fertilizers and agrichemicals	0.78 (68)	-0.09 (-8)	0.46 (40)	1.15 (100)
Structures and land	0.78 (53)	0.85 (58)	-0.17 (-11)	1.46 (100)

Notes: 1. B_i is the total cost-share change due to technological change, B^S_{iG} and B^S_{iA} are the scale effects, and $B^e_i = B_i + B^S_{iG} + B^S_{iA}$ is the pure bias effect due to a shift in the expansion path.

2. Percentage contributions are in parentheses.

respect to the quantity of crop production, we may infer that the rapid expansion of livestock production during the sample period made a positive contribution to the rapid transfer of labor from agriculture to the nonagricultural sectors.

6. Concluding Remarks

This study was motivated to investigate (1) the factors responsible for the drastic growth of livestock production and (2) the impacts of the changes in the output mix due to this rapid increase in livestock production on the relative uses of factor inputs in Japanese agriculture during the last three decades. For this objective, a multi-output multi-input translog cost function was specified where two outputs, crops and livestock, are distinguished, and estimated for the period 1958-84 by making use of farm-level aggregate data for all Japan excluding the Hokkaido region. The major findings based on the empirical analysis are as follows.

First of all, we found that technological change was biased towards livestock production. This output-biased technological change may be considered to be largely responsible for the rapid growth in livestock production on the supply side during the last three decades.

Furthermore, we found that the changes in the composition of crop and livestock outputs had significant impacts on the relative uses of factor inputs. Above all, the most important finding is that an expansion of livestock production requires relatively less labor input than in the case of an expansion of crop production. The empirical implication of this finding is that the drastic increase in livestock production had a positive effect on the rapid transfer of labor from agriculture to the nonagricultural sectors during the last three decades.

Let us finally say a word about the limitations of this study. Within the framework of a translog joint cost function as used in this study, it is difficult to distinguish the impacts of a change in output mix on the estimates of Allen partial elasticities of factor substitution and price elasticities of factor demand. For the study of investigating such impacts in detail, it may be recommended to estimate a single output translog cost function specified separately for each output, although it is impossible in that case to investigate in particular such a phenomenon as output-favoring technological change. Moreover, the estimation of the translog joint cost function in this study was carried out excluding the smallest size-calss farms and the Hokkaido district whose share of livestock production in the total production has been very high. Our estimates therefore should not be regarded as representative for whole Japanese agriculture.

Appendix Table A. Numbers of Farm Households in Different Size Classes, 1958-84 (Selected Years)

(Unit: 1,000 households)

Year	- 0.5	0.5 - 1.0	1.0 - 1.5	1.5 - 2.0	2.0 -	Total
1958	2,275	1,907	1,002	404	235	5,823
	(39)	(33)	(17)	(7)	(4)	(100)
1965	2,096	1,762	945	407	256	5,466
	(38)	(32)	(18)	(8)	(5)	(100)
1975	1,995	1,436	727	349	312	4,819
	(41)	(30)	(15)	(7)	(7)	(100)
1984	1,792	1,251	629	324	364	4,360
	(41)	(29)	(14)	(7)	(8)	(100)

Source: Ministry of Agriculture, Forestry and Fisheries, Japan. Statistical Yearbook of Ministry of Agriculture, Forestry, and Fisheries, various issues.

Notes: 1. The unit of size is expressed in hectares.

2. Numbers in parentheses are the shares in the total number of farm households.

Appendix B Sensitivity Analysis for the Diamond-McFadden-Rodoriguez Impossibility Problem

Woodward clearly states the "impossibility" problem as: "If technical change is not Hicks neutral, estimating elasticities on the assumption of Hicks neutrality will bias the parameter estimates. Thus, one cannot use substitution elasticities generated from a Hicks-neutral framework to correctly calculate the series of biased technical change. One can estimate the elasticities if the rates of biased technical change are assumed to be constant or one can estimate the variable rates of technical change if the values of the elasticities are known, but one cannot estimate both simultaneously."

Although Diamond, McFadden, and Rodoriguez suggested to use pooled cross-sectional time series data to avoid this problem, it could be only a compromise. A convinsingly satisfactory procedure to avoid this identification problem has not been offered in the literature. As such, it is very likely that estimates in this study are biased due to this "impossibility" problem.

Thus, in order to check the magnitudes and directions of such a possible bias, we have carried out a sensitivity analysis for the estimates of the AES and own-price demand elasticities of factor demand. For this objective, four specifications of the translog joint cost function were estimated: Model 1, input-output nonseparable and Hicks nonneutral in both inputs and outputs; Model 2, input-output nonseparable and Hicks neutral in both inputs and outputs; Model 3, input-output separable and Hicks nonneutral in both inputs and outputs; and Model 4, input-output separable and Hicks neutral in both inputs and outputs. The results are presented in Appendix Table B. The major attention will be given to the results of the first two models, since the statistical hypothesis of separability was strongly rejected. All we need to do is note that evaluations of estimates based on the a priori assumption of input-output separability without testing the validity are very likely to be misleading.

Through a rough comparison of the results between Models 1 and 2, we may find that both series of the own-price elasticities and AES look in general very similar. There are however several elasticities of substitution whose values are different between the two specifications; σ_{LM}, σ_{MF}, σ_{MC}, and σ_{MT}. The differences in the values of these elasticities between the two models may be regarded as the lower and upper limits. The true elasticities may be considered to lie somewhere between these ranges. Since these ranges may not be considered to be that substantial, we may conclude that the bias due to the "impossibility" problem, if any, is negligible.

Appendix Table B. Own-Price Demand Elasticities and Allen Partial Elasticities of Substitution for Various Models (Averages for 1958-84)

		Model 1	Model 2	Model 3	Model 4
Own-price demand elasticities	e_{LL}	-0.53	-0.69	-0.68	-2.08
	e_{MM}	-0.27	-0.31	-0.46	-3.75
	e_{FF}	-0.40	-0.40	-0.13	-3.44
	e_{CC}	-0.57	-0.60	-0.44	-4.86
	e_{TT}	-0.72	-0.80	-0.62	-1.07
Allen partial elasticities of substitution	σ_{LM}	0.20	0.76	1.05	1.39
	σ_{LF}	0.92	1.16	0.78	-0.10
	σ_{LC}	0.91	1.20	0.95	1.64
	σ_{LT}	1.62	1.69	1.72	1.23
	σ_{MF}	0.35	-0.48	1.46	-0.27
	σ_{MC}	0.85	0.10	-0.19	-1.38
	σ_{MT}	-0.21	0.03	-0.82	-0.06
	σ_{FC}	0.05	-0.09	-0.99	1.92
	σ_{FT}	-0.50	-0.37	-1.52	2.53
	σ_{CT}	0.43	0.49	0.86	1.14

Note: Model 1: Nonseparable and Hicks nonneutral in both inputs and outputs.
Model 2: Nonseparable and Hicks neutral in both inputs and outputs.
Model 3: Separable and Hicks nonneutral in both inputs and outputs.
Model 4: Separable and Hicks neutral in both inputs and outputs.

Footnotes

1/ Kako (1978) and Kuroda have found through a decomposition analysis that the substitution effects due to changes in relative factor prices and the effects of biased technical change were the most important factors for the changes in the factor combinations in postwar Japanese agriculture.

2/ Denny, Fuss, and Waverman introduced a multi-product translog cost function with "output-augmenting" form for the analysis of Canadian telecommunications.

3/ Kako and Chino, however, estimated a single output translog cost function for monoculture farms of rice production, so that they did not face such a problem under question.

4/ An introduction of a cost function derived from duality theory requires the assumption of rational behavior of the firm. According to Minami, Japanese economy passed its turning point around the end of the 1950's through the early 1960's, implying that farmers after this period may be considered to be in the neoclassical world by following the marginal principles. The estimating period 1958-84 in this study may thus satisfy this assumption. Indeed, the validity of the assumption of cost-minimizing behavior which is treated as a maintained hypothesis in this study will be statistically tested in the process of estimation. Refer to footnote 11.

5/ In this specification, the difficulty in distinguishing the effects of technological change from economies of scale can be avoided, since the underlying transformation function is nonholothetic in the sense that the technological change specification used does not shift the isoquants the same way that scale economies will (Sato, and Sato and Calem). In addition, the Diamond-McFadden-Rodriguez impossibility problem may partly be avoided since this study is to use pooled cross-section and time series data. However, in order to see how sensible the magnitudes of elasticities of substitution between and demand for factor inputs are to different specifications of the model, a sensitivity analysis will be carried out in Appendix B.

6/ The distribution of farms in these size classes together with the size class with 0.5 hectares or less is provided in Appendix Table A. It should be noted here that since technologies practiced by farms in producing either crops or livestock or joint production of them seem to be very similar across all size classes all over Japan, the simple pooling of these four cross-sectional units is expected not to cause significant bias in the estimates of the translog cost function. However, the data for the average farm in the smallest size class with 0.5 hectares or less was excluded because it is extremely cumbersom to construct the data consistent with the other size classes due to changes in the size classifications during the sample period. Since the share of the number of farms in this stratum in the total number of farms has been as large as around 40 percent as shown in Appendix Table A, it should be noted that exclusion of farms in this size class may cause some bias in the estimated parameters.

7/ The share of the number of monoculture or quasi-monoculture farms in the total number of farms selling products has been more than 90 percent excluding the Hokkaido district. The share of the number of farms selling products in the total number of farms has been around 80 percent.

8/ Indeed, the Törnqvist quantity indexes of the two outputs (Q_G and Q_A) explained in the previous section could not be obtained without assuming profit maximizing behavior of farm-firms. Thus, the observed output levels are implicitly treated as being endogenous to input decisions and total cost.

9/ Note that the tests of the statistical hypotheses concerning the technology structure can now be substantially simplified due to the imposition of the linear homogeneity restrictions.

10/ The translog cost function (13) and the four cost share equations in (14) were estimated first by ordinary least squares method in order to check the goodness of fit. The $\overline{R^2}$'s were 0.9971 for the translog cost function and 0.9367, 0.7615, 0.9110, and 0.5724 for the labor, machinery, feed-livestock, fertilizers-agrichemicals, and structures-land cost share equations, respectively, indicating a fairly good fit for the model.

11/ The across-equations equality was also explicitly tested in order to check the validity of the assumption of cost minimization. The computed F was 1.63 with the degrees of freedom (32,472). The critical F's are 1.46 and 1.70 at the 5 and 1 percent levels of statistical significance, respectively. This result implies that although the hypothesis is rejected at the 5 percent level, it could not be rejected at the 1 percent level, though barely. Thus, it may be said that the assumption of cost-minimizing behavior is valid.

12/ Before proceeding further, however, it is necessary to check whether or not the estimated translog cost function presented in Table 2 is consistent with the theoretical properties of monotonicity and concavity in the factor prices. In general, the translog cost function is not globally monotonic increasing and concave in factor prices. It is however possible for the translog cost function to be locally monotonically increasing and concave. The fitted cost function is thus checked for monotonicity and concavity at each observation. Monotonicity is satisfied if the estimated cost shares are positive. Concavity is satisfied if the Hessian of the translog cost function is negative semi-definite. All of the five cost shares estimated ($\hat{S}_i$) were positive and the Hessian was negative semi-definite at each observation. This indicates that the translog joint cost function represented by the estimated parameters in Table 2 is well-behaved within the region of the sample observation.

13/ All of the variables necessary to compute the MC_s and the following parameters are the weighted averages with the weights being the shares of the numbers of farm households of the four size classes (0.5-1.0, 1.0-1.5, 1.5-2.0, and 2.0 hectares or over) in the total number of farm households of these four size classes presented in Appendix Table A.

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